COMMENTARY

Leveraging transboundary interactions for urban resilience and sustainability

Bolin Yu,[1] Zhimeng Jiang,[2,*] Rui Zhao,[3] Alexander Boxuan Wang,[4] Hongsheng Zhang,[1] and Zhenci Xu[1,*]

[1]Department of Geography, The University of Hong Kong, Hong Kong SAR 999077, China

[2]College of Urban and Environmental Sciences, Central China Normal University, Wuhan 430079, China

[3]State Key Laboratory of Pollution Control and Resources Reuse, College of Environmental Science and Engineering, Tongji University, Shanghai 200092, China

[4]High School, Shanghai American School Pudong Campus, Shanghai 201201, China

*Correspondence: xuzhenci@hku.hk (Z.X.); jzm@mails.ccnu.edu.cn (Z.J.)

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Modern cities, as dominant future human settlements, are essential for sustainable development and human well-being, but currently face significant risks and challenges. The United Nations projects that 68% of the world population will be urban dwellers by 2050. Rapid urbanization exposes cities to greater risks of extreme disasters,[1] which requires a new paradigm of governing urban resilience and underpinning urban sustainability. Fortifying urban resilience, as an approach for addressing urban risks and improving urban sustainability, focuses on enhancing the capacity of urban systems to withstand and recover from internal and external shocks, such as natural disasters (e.g. California wildfires and disastrous floods in Zhengzhou city), public health incidents (e.g. COVID-19), and economic crises, by restoring environmental, economic and social norms. In the era of globalization, urban communities have proliferating transboundary environmental-economic-social interactions with other regions[2] through various pathways, such as trade, city partnership and international aid. In this respect, urban resilience of one city is largely influenced by transboundary interactions from other places. However, cities are often treated as isolated entities in conventional urban resilience governance, rarely considering the role of transboundary interactions between adjacent regions and between distant regions in shaping urban resilience and sustainable development in the era of rapid urbanization and globalization.

Efforts to leverage transboundary interactions for improving urban resilience to stress, challenges, or uncertainties and sustainability are falling short, which are limited in scope and scale and hindered by institutional barriers, interest conflicts, partnerships, etc. A wider range of transboundary interactions between cities and other regions can enhance urban resilience and sustainability through the integration of environmental-economic-social flows, as illustrated in Figure 1. A timely appeal should be laid out for new management paradigms that integrate transboundary interactions between cities and other regions to strengthen urban resilience and sustainable development.

TRANSBOUNDARY INTERACTIONS SHAPE URBAN RESILIENCE AND SUSTAINABLE DEVELOPMENT

Resilient urban development encompasses multiple dimensions, including environmental, economic, and social resilience, all of which can be strengthened through the coordination of policies and optimal allocation of resources, such as capital, manpower, technology, information, service, materials, natural resources, and so on (Figure 1). Environmental resilience is a foundation for achieving economic and social resilience, while economic resilience serves as a crucial guarantee for achieving social resilience. Managing transboundary resource diversion could contribute to improving urban environmental resilience. For example, the South-to-North Water Diversion Project in China, which is the largest and longest one globally, has an annual water transfer volume of 45 billion m^3 and a planned investment of 77 billion US dollars, improving the water resource resilience to drought in northern China's water-scarce cities such as Beijing.[3] In addition, flood damages are not evenly distributed across cities in shared water bodies, especially for downstream cities. The upstream can timely share hydrological information, rainfall forecasts, and other data with downstream cities to provide sufficient time for them to take appropriate measures and reduce the impact of floods. However, transboundary environmental flows may engender adverse impacts as well. For instance, the wastewater generated by India upstream of the Ganges River has led to the aggravation of water pollution in Bangladesh's cities located downstream.

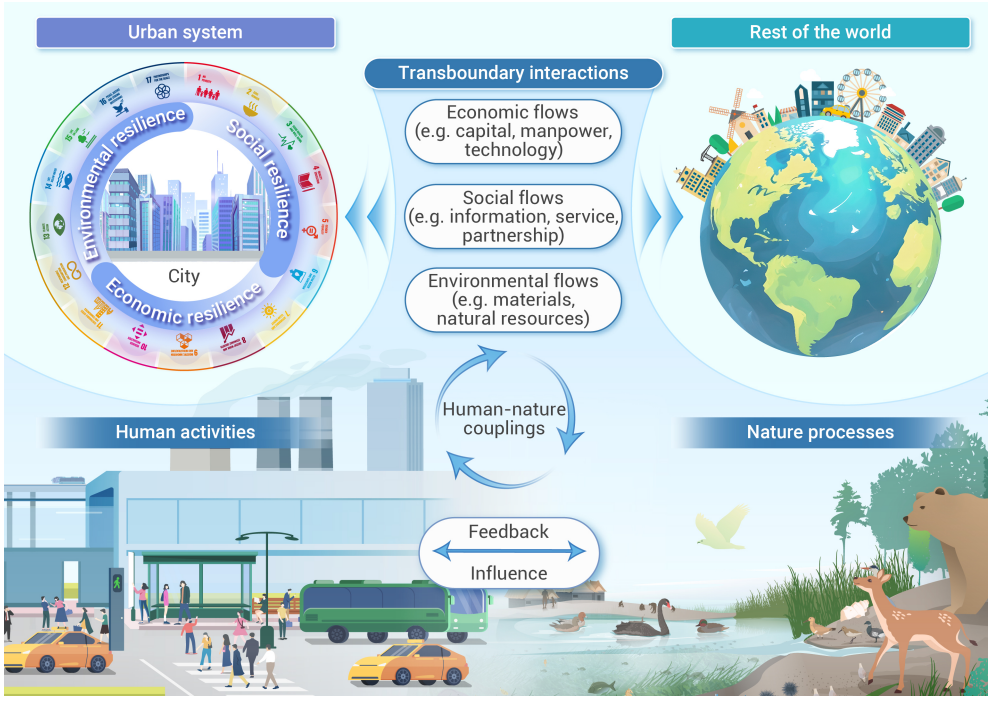

Figure 1. Illustration of urban resilience and sustainable development under impacts of transboundary interactions.

Transboundary interactions can also impact urban economic resilience (e.g. capital flow, manpower mobility, and technology transfer). For instance, supply chain diversity equips the city with flexible alternatives to respond to disruptions in its supply chains, thus buffering the economic system against shocks. Different cities collaborate through complementary industrial chains to jointly develop related industries and improve overall production efficiency and competitiveness. Indeed, transboundary economic flows do not always yield positive outcomes. While economic globalization may foster international trade and investment, stimulating economic growth, it can also lead to an imbalanced distribution of wealth and resources, resulting in economic inequality and poverty in some regions.

Transboundary interactions can also contribute to urban social resilience. During

the COVID-19 Pandemic, the epidemic information-sharing platform helps cities control the spread of the virus more effectively. Besides, receiving emergency material support, medical expert assistance, and economic support from other regions can also facilitate the faster recovery of medical service systems in vulnerable cities. However, increased connectivity among cities may facilitate the spread of diseases, such as the COVID-19 Pandemic, and further affect resilience. Cities and associated stakeholders (e.g. urban planners, policymakers, and urban communities) should adopt and manage transboundary interactions to improve economic, social, and environmental resilience to stress, challenges, or uncertainties.

Transboundary interactions, if properly managed, can not only help improve urban resilience but also contribute to urban sustainability in environmental conservation, economic development, and social equality. An explicit example is that the transboundary power transmission line from less developed Kunming city in Western China to Guangzhou city in Eastern China transmitted more than 300 billion kWh of surplus hydropower during 2010-2022, which is equivalent to 86 million tons of coal conservation, 230 million tons of CO_2 reduction, and 1.66 million tons of SO_2 reduction (https://baijiahao.baidu.com/s?id=1733859865570312204&wfr=spider&for=pc). This has facilitated the development of Kunming's power industry and Guangzhou's economic growth supported by increasing energy demand, thus contributing to promoting multiple SDGs, including economic growth and job opportunities creation (SDG 8), affordable and clean energy (SDG 7), climate action (SDG 13), etc.

INTEGRATING TRANSBOUNDARY SPATIAL SCIENCE FOR STUDYING URBAN RESILIENCE AND SUSTAINABILITY

Efforts to leverage transboundary interactions for improving urban resilience and sustainability are hindered by a limited understanding of transboundary influences, lack of advanced conceptualization of urban dynamics and scientific barriers. Currently, the concept and measurement approaches of urban resilience and sustainability are diverse, making comparisons difficult.[4] The understanding of drivers, patterns, and roadmap for transboundary interactions, however, remains scarce.

The major unrecognized gap is that a lack of understanding of spatial synergies and trade-offs within transboundary interactions is far too common. Another limitation is that resilience and sustainability are measured mainly using the comprehensive evaluation method based on the evaluation index system. In rapidly changing conditions with complex transboundary interactions, the urban system's responses are nonlinear and interconnected. Thus, the academic community could develop innovative and non-linear approaches for robust and harmonized assessment of urban resilience and sustainability integrating with transboundary interactions.

It is crucial to develop technologies and methods for monitoring, collecting, sharing, and analyzing transboundary data, as well as evaluating data quality, contributing to uncovering the interconnectedness between cities, surrounding regions, countries, and even the global scope. Emerging technologies such as artificial intelligence approaches can help predict the effects of disaster incidences on infrastructure and potential risks that cities may face, including the hotspots of vulnerabilities, the possible impacts and the occurrence of disasters,[5] informing urban planners, policymakers, and other stakeholders to take more adaptive or transformative actions to optimize urban planning and management, enhance urban resilience, and improve urban sustainability. These methods, in particular, enable analysis of high-throughput data, thereby making evidence-based decisions. In addition, digital technologies, digital intelligence and Cyber Physical Social Systems (CPSS) contribute to deep transboundary interactions between both adjacent and distant regions. For example, blockchain technology enables secure and tamper-proof data sharing among different stakeholders, such as government agencies, private organizations, and citizens. This promotes trust and cooperation across sectors and geographical regions, contributing to more effective collaboration in addressing urban challenges.

FOSTERING TRANSBOUNDARY INTERACTIONS MANAGEMENT PRACTICES FOR URBAN RESILIENCE AND SUSTAINABILITY

By advancing the above in-depth transboundary interactions science and technologies and integrating them with coupled systems, we can improve urban resilience management and develop more effective policies for instructing sustainable development and securing our planet. As SDG 17 revitalizes global partnerships for sustainable development, policymakers and stakeholders should strengthen actions in transboundary interactions for urban resilience and sustainability. The transboundary interactions between urban systems and other areas can be enhanced by establishing a multi-level cross-domain cooperation mechanism that spans environmental, economic, and social dimensions. For instance, the United States Conference of Mayors (USCM), the official non-partisan organization of cities with significant populations, provides a platform for mayors to exchange and discuss best practices in addressing various challenges across different areas, and contributes to collaboratively addressing these challenges and enhancing urban resilience.

From an international perspective, transboundary interactions generate amplified implications for urban resilience and sustainability. The C40 Cities Climate Leadership Group unites the world's leading cities to concertedly confront the climate crisis, generating significant synergistic implications for enhancing urban resilience and sustainability by reducing cities' vulnerability to climate risks (e.g., extreme weather events and sea-level rise). Moreover, the Water Safe Cities Accelerator by the C40 aims to collaboratively address water-related hazards and ensure the availability and sustainable management of water.

In conclusion, transboundary interactions necessitate considerable attention in urban governance in the era of rapid urbanization and globalization. Transboundary interactions play a crucial role in urban resilience and sustainable development, with multidimensional integration of environmental-economic-social flows. It is suggested that scientific advancement, applicable emerging technologies and extensively collaborative engagement should be enhanced to leverage transboundary interactions towards more robust urban resilience and sustainable urban development.

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AUTHOR CONTRIBUTIONS

B.Y. and X.Z. conceived and organized the manuscript. B.Y., Z.J., and X.Z. supervised and wrote the manuscript. R.Z., A.W., and H.Z. conducted formal analysis and validation. All authors contributed to editing and revising the manuscript.

DECLARATION OF INTERESTS

The authors declare no competing interests.