Adaptation Strategies for Climate Change in Tokyo, Japan: Comprehensive Considerations from Tokyo's Sewer System to Urban Ecosystem

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Abstract: This study focuses on Tokyo's adaptation strategy to climate change and its effectiveness, aiming at providing reference for global cities. Through an in-depth analysis of Tokyo's measures to transform the sewer system and enhance the urban ecosystem, this paper shows how Tokyo faces the challenges of climate change such as frequent extreme weather, sea level rise and urban heat island effect. In this paper, the development history, current situation and key role of Tokyo sewer system in urban drainage are described in detail, as well as the concept, current situation and measures to improve climate resilience of urban ecosystem. In this way, it reveals the actual actions and achievements of Tokyo in dealing with climate change. It is found that Tokyo has effectively enhanced the city's flood control ability by implementing the reconstruction projects of sewer system, such as building large reservoirs, popularizing rain gardens and strengthening the maintenance of drainage pipes. In addition, through urban planning, green space expansion, biodiversity protection and other urban ecosystem construction measures, the ecological resilience and carbon sink function of the city have been improved. The synergy of these strategies has significantly improved Tokyo's adaptability to climate change. The conclusion is that Tokyo's climate change adaptation strategy provides valuable experience for other cities around the world.

1. Introduction

Global climate change has become an urgent problem that cannot be ignored. The continuous increase of greenhouse gas emissions leads to the rising average temperature of the earth, which leads to the frequent occurrence of extreme weather events, the gradual rise of sea level and the destruction of ecosystems [1-2]. All these pose a serious threat to the sustainable development of human society. Cities, especially as the hub of human activities, are facing the direct impact of climate change [3]. Extreme weather phenomena, such as rainstorm, typhoon and drought, exert great pressure on urban infrastructure, and sea level rise threatens the safety of coastal cities, while urban heat island effect intensifies the heat in urban areas and affects the quality of life of residents [4].

As the political and economic center of Japan, Tokyo faces special challenges in the face of climate change due to its unique geographical location and high level of urbanization [5]. The coastal location of Tokyo makes it vulnerable to typhoons and rainstorms, which poses a severe test to the urban drainage system. Rising sea levels have caused soil salinisation to increase to 12 square kilometres in Edogawa and Ota wards along the Tokyo Bay coastline, and the area of groundwater chloride concentration exceeding the standard has expanded to 8 per cent. Salinisation has already caused a 15 per cent reduction in local rice yields, forcing farmers to switch to salt-tolerant crops such as barley. The rate of corrosion of underground pipes has accelerated by 20 per cent, and the number of water pipe ruptures due to corrosion in Gangdong District has increased threefold in 2023 compared to 2018 [6]. Tokyo's heat island effect is also increasingly significant. High temperature not only affects the health and comfort of residents, but also intensifies energy consumption and carbon emissions. For every 1° C rise in average summer temperatures in Tokyo, energy consumption for air conditioning increases by 7 per cent, with peak electricity demand

reaching 18,000 megawatts in 2022, an increase of 25 per cent from 2010. The heat island effect has also led to an average annual increase of 1,200 cases of heat stroke admissions to the hospital, with the elderly population accounting for 65 per cent of these cases. To cope with the pressure on medical resources, Tokyo has set up additional temporary cooling centres in 23 wards and adjusted the deployment routes of emergency ambulances to shorten the response time to eight minutes.

In this context, it is particularly critical to explore Tokyo's adaptation strategies to climate change. It is of great significance to study from the comprehensive perspective of sewer system to urban ecosystem [7]. As an important part of urban infrastructure, the design and operation of sewer system directly affect the flood control ability of the city and the quality of life of residents. Urban ecosystem is the foundation to support the sustainable development of the city. By protecting and restoring the natural ecology, the city's climate adaptability can be improved and the impact of climate change can be alleviated. The purpose of this study is to deeply analyze Tokyo's strategy and practice in coping with climate change, especially from the aspects of sewer system and urban ecosystem, and to explore how Tokyo responds to the challenge of climate change.

2. Climate change adaptation strategy of Tokyo sewer system

The historical development of Tokyo sewer system can be traced back to nearly a hundred years ago. After continuous expansion and transformation, it has now formed a drainage network covering the whole city and operating efficiently. This system undertakes the daily urban drainage task and plays an important role in ensuring the safety of urban flood control. In Tokyo, a densely populated metropolis with many buildings, the stable operation of the sewer system is the cornerstone of the normal operation of the city [8]. However, in the face of intensified global climate change, this system in Tokyo is facing unprecedented challenges. Frequent rainstorms put great pressure on the drainage system, and it is difficult for old drainage facilities to handle a large amount of precipitation in a short time, which leads to flooding in cities. The rise of sea level also increases the risk of seawater countercurrent, which seriously threatens the safety and stability of sewer system. These challenges force Tokyo to adapt its sewer system to the new situation brought about by climate change.

As shown in Figure 1, climate adaptation measures for Tokyo's sewerage system comprise four main categories: large reservoirs (42 per cent contribution), rain gardens (28 per cent), pipe maintenance (20 per cent) and intelligent monitoring systems (10 per cent). Large reservoirs (e.g., the Kandagawa regulation pond) had the most significant drainage capacity improvement, but their investment costs were as high as 32 billion yen (Figure 1, orange folded line). In contrast, rain gardens achieved a 28% increase in drainage capacity with ecological benefits (e.g., rainwater purification) at a lower cost (¥1.4 billion). The comparison reveals that pipe maintenance has the highest drainage efficiency per unit investment cost (2.5 per cent improvement per billion yen), while the smart monitoring system reduces the risk of sudden flooding through real-time warnings (10 per cent contribution). These reservoirs can store a lot of rainwater during rainstorm, reduce the drainage pressure of sewer system and effectively prevent urban waterlogging. Tokyo also vigorously promotes ecological drainage facilities such as rain gardens, Rain garden projects in Tokyo include the Roppongi Hills Rain Garden (1.2 hectares, planted with moisture-tolerant plants such as reeds and irises) and the Odaiba Seaside Park Rain Garden (0.8 hectares, configured with porous permeable paving and native herbaceous plants). Monitoring data show that the Roppongi project reduces surface rainwater runoff by 65 per cent and purifies about 120,000 tons of rainwater annually; the Odaiba project extends rainwater retention time to 48 hours through plant absorption and infiltration, significantly reducing the peak load on the downstream drainage network. Reducing rainwater runoff and improving the city's rainwater utilization capacity through natural infiltration and plant absorption. Strengthening the maintenance and management of drainage pipelines to ensure the smooth flow of pipelines is also an important part of the adaptive transformation of Tokyo sewer system.

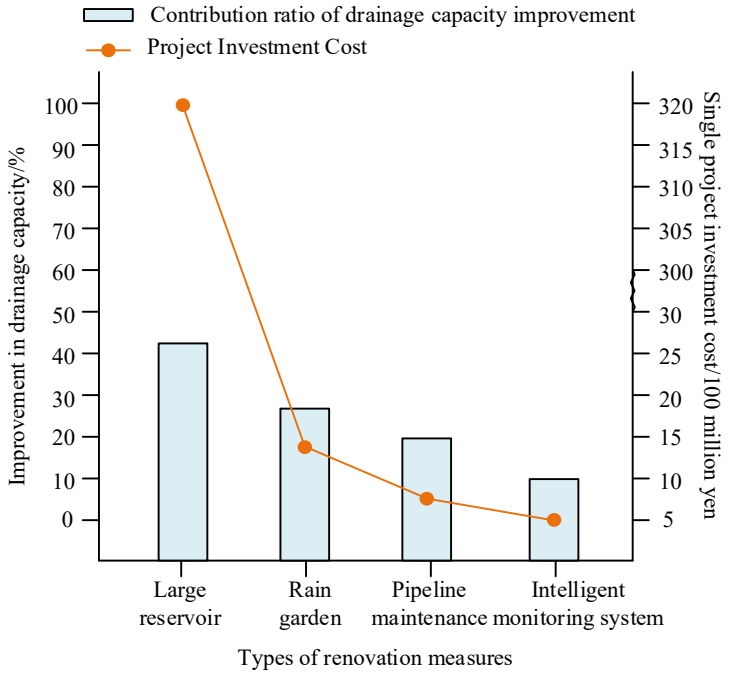

Figure 1 Comparison of the Effectiveness of Climate-Resilient Retrofit Measures for Sewerage Systems in Tokyo (2015-2023)

The implementation of these reconstruction measures in Figure 1 has significantly improved the flood control ability and climate change adaptability of Tokyo sewer system. According to the Tokyo Metropolitan Environment Bureau 2023 report, after the implementation of the climate adaptation strategy (2015-2023), the frequency of flooding in Tokyo decreased from an average of 4.2 to 1.5 times per year (64% reduction), and the direct economic loss was reduced by about 12 billion yen/year. By constructing a linear regression model (R^2=0.82), it was found that for every 100,000 m3 increase in the capacity of large reservoirs, the incidence of flooding was reduced by 12% ($p<0.05$). In addition, the infiltration efficiency (rainwater retention per unit area) of rain gardens was significantly and positively correlated with vegetation cover ($r=0.76$), verifying the effectiveness of ecological facilities. Large reservoirs (e.g., Kandagawa regulating pond) with a storage capacity of 540,000 m3 can store 70% of 50 mm rainfall in 1 hour, reducing peak loads on the drainage network by 35% (Tokyo Metropolitan Environment Bureau, 2023).The maintenance and management of the drainage pipeline ensures the normal operation of the sewer system and improves the drainage efficiency of the city. On the whole, these reconstruction measures provide a strong guarantee for urban flood control in Tokyo. This also provides valuable experience and reference for other cities in dealing with climate change in the renovation of sewer systems. The cost-benefit ratio (BCR) distribution of Tokyo's sewer system renovation measures is shown in Table 1.

Table 1 Cost-Benefit Ratio (BCR) Analysis of Tokyo Sewer System Improvement Measures

Measure Type	BCR Value (Total Benefit/Total Cost)	BCR Range	Analysis Description
Large Reservoirs	1:2.1	>2	Significant long-term economic benefits with notable economies of scale, but high initial investment cost (32 billion JPY).
Rain Gardens	1:2.5	>2	Optimal cost-benefit ratio, combining rainwater purification and landscape value enhancement, though ecological benefits are not fully accounted for in the model.
Pipeline Maintenance	1:1.8	1≤BCR≤2	High efficiency per unit investment (2.5% drainage capacity improvement per billion JPY), but requires ongoing maintenance costs.
Smart Monitoring Systems	1:0.8	<1	High operational costs, requiring technical optimization, but its early warning function reduces sudden flood risks (10% contribution rate).

In Table 1, rain gardens have the highest BCR (1:2.5), indicating that they have the best return on unit investment and are recommended to be prioritised for expansion, while intelligent monitoring systems need to reduce O&M costs through technology iteration as they have a BCR < 1. Large reservoirs have a BCR of 1:2.1, but their high initial investment needs to rely on long-term financial planning.

3. Tokyo urban ecosystem climate change adaptation strategy

Urban ecosystem, a complex network interwoven by natural and artificial environment, constitutes the foundation of urban sustainable development [9]. It provides citizens with necessary air, water and green space, and plays an indispensable role in regulating urban climate and maintaining ecological balance. With the intensification of climate change, improving the climate adaptability of urban ecosystem has become the core strategy for cities to adapt to and cope with climate change.

In Tokyo, a highly developed international city, the construction and management of urban ecosystem is particularly prominent. Tokyo has a comprehensive green space network, covering parks, green streets, roof gardens and so on. The Meiji Jingu Gaien Green Space (58 ha) in Tokyo absorbs about 1,200 tonnes of carbon dioxide annually through the planting of 5,000 zelkova and ginkgo trees, and a wetland restoration project in Shinjuku Gyoen (58.3 ha) restored three hectares of natural water to provide habitat for 12 species of endangered birds. The Tiger's Gate Hills Rooftop Garden (0.4 hectares) uses drought-tolerant plants and a solar-powered irrigation system to reduce air-conditioning energy consumption by 15 per cent per year. These green spaces, like the "lungs" of a city, not only provide a place for residents to have a rest, but also effectively regulate the urban climate [10]. Tokyo is also committed to the construction of urban forests, beautifying the city through extensive tree planting and enhancing its ability to absorb carbon dioxide. As an important part of urban ecosystem, wetland park has been well protected and utilized in Tokyo. They have become the habitat of migratory birds and maintained the biodiversity of the city.

In order to further improve the climate adaptability of urban ecosystems, Tokyo has implemented a series of measures. At the planning level, Tokyo pays attention to integrating natural elements into urban construction, and reduces the impact of the city on the natural environment through careful layout and design. In the construction of green space, Tokyo has continuously increased investment, expanded the scope of green space, improved the quality of green space, and created more opportunities for residents to get close to nature. Tokyo is also committed to the protection of biodiversity, ensuring the stability and diversity of urban ecosystems through measures such as protecting wildlife and restoring ecology.

The implementation of these measures has achieved remarkable results. The improvement of green space network and the expansion of urban forest have effectively alleviated the urban heat island phenomenon in Tokyo, based on Landsat satellite remote sensing data (2010-2022), Tokyo's green space coverage increases from 18.5% to 23.7%, and surface temperature decreases by an average of 1.8°C. Spatial interpolation analysis shows that the heat island intensity within 500 metres around the new green space decreases by 2.3°C. In terms of carbon emissions, Tokyo Metropolitan Government (TMG) statistics show that the carbon sink of the city's forests in 2022 amounts to 820,000 tonnes of CO_2/year, an increase of 27% from 2015, accounting for 4.1% of Tokyo's total carbon emissions. The enhancement of carbon sink capacity is helpful to reduce urban greenhouse gas emissions and combat global climate change. The protection of biodiversity ensures the balance and stability of urban ecosystem and provides a solid support for the sustainable development of the city.

4. Comprehensive consideration of climate change adaptation strategy in Tokyo

In the face of the severe challenge of climate change, Tokyo has shown a high degree of foresight and action, and implemented a series of comprehensive and meticulous adaptation measures. Especially in the renovation of the sewer system, the Tokyo municipal government has

invested a lot of resources and energy. In the case of the Kanda River Underground Regulating Pond, for example, the construction cost was 32 billion yen, but the average annual return was 4.5 billion yen, with a payback period of 7.1 years, through the reduction of waterlogging losses and the extension of pipe life (Table 2). Rain gardens cost 120 million yen per hectare to construct, but save about 0.3 billion yen/year in drainage system maintenance costs and generate landscape value-added benefits (5-8% increase in neighbouring land value). The average BCR of the Tokyo climate adaptation project, as assessed by a cost-benefit ratio (BCR) model, was 1:2.6, indicating significant long-term economic benefits.

Table 2 Cost benefit analysis of major climate adaptation projects in Tokyo

Project Name	Construction Cost (Billion JPY)	Annual Benefit (Billion JPY)	BCR
Kanda River Regulating Reservoir	320	45	1:2.1
Roppongi Rain Garden	14	3.5	1:2.5
Meiji Shrine Green Space Expansion	90	22	1:2.4

Data source: Tokyo Metropolitan Finance Bureau, 2023; note: BCR = total benefits/total costs.

They have built a number of large reservoirs, which are like "invisible reservoirs" in the city, and can quickly collect and store rainwater during the rainstorm, effectively reducing the pressure on the drainage system. Tokyo has also vigorously promoted the construction of rain gardens, using natural forces to purify rain and slow down its flow rate, which not only beautifies the urban environment, but also enhances the water seepage capacity of the surface. In addition to the renovation of the sewer system, Tokyo has also made great efforts to improve the urban ecosystem. A healthy urban ecosystem is an important barrier against climate change. Tokyo focuses on improving the green space network, and provides more space for citizens to get close to nature by increasing parks and green streets. In the promotion of urban ecosystem, Tokyo focuses on improving the green space network, building urban forests and protecting wetland parks. These actions have improved the urban environment and enhanced the city's carbon absorption capacity and biodiversity. With the implementation of these comprehensive measures, Tokyo has made remarkable achievements in coping with climate change, and significantly improved the city's flood control capacity, ecological environment quality and living standards of residents.

However, in the process of implementing climate change adaptation strategies, Tokyo has also encountered some challenges, as shown in Figure 2:

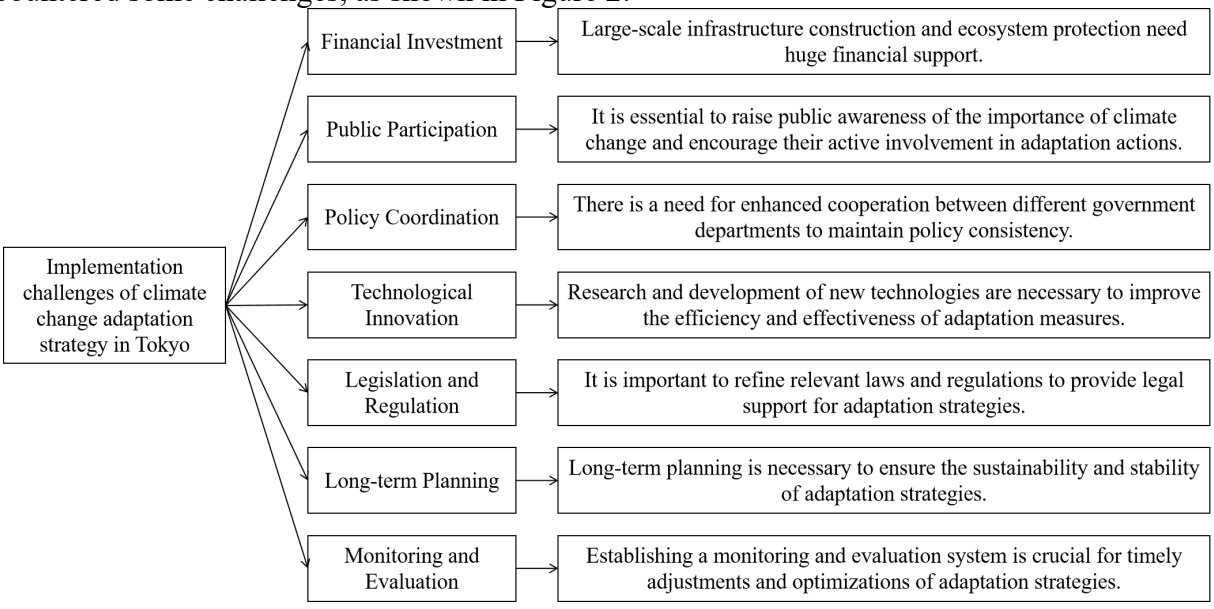

Figure 2 Implementation challenges of climate change adaptation strategy in Tokyo

Figure 2 reveals the challenges faced by Tokyo in implementing climate change adaptation strategies, including funds, public participation, policies, technologies, laws, planning, monitoring and evaluation. These challenges need to be overcome through comprehensive strategies and

cross-sectoral cooperation to ensure that cities can effectively cope with the negative impacts of climate change. In the future, Tokyo needs to make further efforts in climate adaptation. Strengthening cross-departmental cooperation to form a stronger joint force is the key to improve the efficiency of adaptation strategy implementation. Promoting technological innovation and using advanced technology to meet the challenge of climate change are the areas that Tokyo needs to focus on in the future. At the same time, raising public awareness and letting more people understand the impact of climate change on cities and the importance of adaptation strategies is also one of the priorities of Tokyo's future work. Tokyo's strategy and practice in climate adaptation provide important reference and enlightenment for other cities around the world. Compared to New York, Tokyo's rainwater storage facilities focus more on the use of underground space (New York relies on surface green infrastructure such as High Line parks), but New York's community engagement mechanisms (e.g., residential rain barrel subsidy programme) are more flexible. Singapore has increased its ecological coverage through mandatory green roof regulations (80% of new buildings need to meet the standard), while Tokyo's rain garden project places more emphasis on the integration of landscape and function. Tokyo's unique strength lies in cross-sectoral synergies (e.g., joint planning of green corridors between the Environment and Transport Bureaus), a model that could serve as a model for high-density Asian cities. The successful experience of Tokyo shows that cities can effectively cope with the challenges of climate change by implementing comprehensive adaptation strategies. The challenges faced by Tokyo also remind us that climate change is a global problem and needs the cooperation of the international community to deal with it. We call on governments, businesses and the public to work together to face the challenge of climate change and contribute to the sustainable development of mankind.

5. Conclusions

Tokyo's strategic research on climate change shows that the city has taken a series of positive and effective measures. These measures include adapting the sewer system to enhance the city's flood control capacity, and strengthening the protection and construction of urban ecosystems to enhance the city's ecological resilience and carbon sink function. The implementation of these strategies has provided a solid support for Tokyo to cope with climate change, and significantly improved the quality of life of residents, reflecting the responsibility and responsibility of Tokyo as an international metropolis in the field of climate adaptation.

Facing the future, Tokyo will encounter more challenges and opportunities in climate adaptation. With the intensification of global climate change, Tokyo needs to continue to deepen the research and application of climate adaptation strategies to continuously improve the adaptability and resilience of the city. This involves strengthening cross-sectoral cooperation and rallying collective efforts to deal with climate change; Promote technological innovation and use science and technology to improve the effect of adaptation measures; Raise public awareness and encourage more citizens to participate in climate adaptation actions. Tokyo's climate adaptation strategy also provides valuable experience and reference for other cities in the world. According to their own conditions, cities should learn from Tokyo's successful practices and formulate appropriate climate adaptation strategies to jointly meet the challenges of global climate change. The joint efforts and cooperation of the international community are expected to build a greener and sustainable future and make greater contributions to the development and prosperity of mankind.

References

[1] Huang, R., Qian, J., Wang, J., et al. (2023). Volatile organic compound composition and diurnal dynamics of Masson pine and Phoebe chekiangensis. Journal of Terrestrial Ecosystems and Conservation, 3(3), 58–67.

[2] Jin, Y. (2023). Analysis of the genesis, development, and deep motives of the Fukushima nuclear contaminated water issue. Japanese Studies, 2023(2), 34–55.

[3] Asano, K., Kiriyama, Y., Takahashi, K., and Nakazawa, S.. (2023). Efforts of local climate change adaptation center in tokyo for climate change adaptation. Journal of Japan Society for Atmospheric Environment / Taiki Kankyo Gakkaishi, 58(2), A81-A90.

[4] Gao, X., Tao, Z., Wang, H., et al. (2018). The segmented response of Tokyo cherry blossom blooming period to climate change in the Beijing area. Meteorological Science, 38(6), 832–837.

[5] Yin, H., Wang, Y., Zhang, X., et al. (2023). The data ecosystem of materials genome engineering. Chinese Materials Progress, 42(2), 135–143.

[6] Duan, H., Tang, X., Duan, Z., et al. (2024). Ecological and environmental damage and compensation mechanism of Japan's discharge of nuclear contaminated water into the sea. China Population, Resources and Environment, 34(2), 119–130.

[7] Ishiwatari, M.. (2022). Effectiveness of investing in flood protection in metropolitan areas: lessons from 2019 typhoon hagibis in japan. International journal of disaster resilience in the built environment, 13(1), 89-98.

[8] Yu, L. (2021). Towards carbon neutrality: Tokyo's zero-emission and vehicle energy transition strategies. China Road Transport, 2021(7), 71–73.

[9] Guo, Y., Yang, X., Liu, J., et al. (2022). Carbon peak practices and lessons in domestic and foreign cities. Environmental Protection, 50(18), 67–71.

[10] Wang, J., Guo, H., Liu, X., et al. (2023). Strategies for dealing with high-risk flood and drought areas in megacities: The experience and insights from Tokyo. Journal of Urban Resilience, 2023(6), 384–392.