SHORT COMMUNICATION

Unveiling the Interactive Dynamics: Urban Ecosystem Services in the Face of Climate Change

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Abstract

This article explores the intricate connection between services provided by urban ecosystems and the risks concerning climate change. Urban ecosystems enhance human well-being by providing cleaner water and air, regulating climate, protecting biodiversity, and improving resident welfare. However, the enhancing impacts of changed climate, such as rising heat levels, floods, and habitat degradation, pose substantial risks to these services. It's imperative to take proactive measures to enhance the resilience of urban ecosystems and guarantee their ongoing support. Nature-based approaches such as green infrastructure are instrumental in mitigating the adversities of climate change and minimizing vulnerabilities. Striking a harmonious relationship between urban growth and the conservation of ecosystem services is vital for sustainable long-term goals. Integrating ecosystem services into urban policies is necessary for efficient climate change modifications in metropolitan cities, municipal built-up towns, downtown cosmopolitan and citified central areas. Nevertheless, challenges like gaps in knowledge, financial limitations, governance shortcomings, and social equity issues persist, highlighting the need for increased research, creative financing, better governance, and more inclusive decision-making processes. Collaborative efforts among stakeholders and greater investiture towards such services of ecosystems are crucial, along with factoring in climate change considerations while making policies for urban scheming and governance.

Keywords: Green infrastructure, Nature-based solutions, Urban greening, Urban planning.

Highlights:

- The study reveals intricate challenges imposed by climate change's impact on urban ecosystem services.
- The study advocates the importance of proactive measures for resilience, ensuring continued service provision.
- Nature-based solutions (NBS) for adaptation enhance urban resilience by integrating green and blue infrastructures, mitigating climate change impacts.
- Integration into governance for resilient urban growth is crucial for efficient responses to climate change challenges.

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Introduction

The current worldwide trends suggest that urban regions are home to 56% of the world's population, which amounts to 4.4 billion people. This percentage is expected to increase to about 70% by the year 2050, as per the World Bank (2023) estimate. The contribution of cities to the global GDP, which accounts for more than 80% of the total, highlights the significant impact cities have on sustainable growth and their crucial role in shaping our future (Zhang, 2016). The complicated interaction that exists between the changing climate and city ecosystems has emerged as a central topic of discussion in the sphere of global environmental policy. This is because we are witnessing rising urbanization at the same time when climate change is accelerating.

The provision of clean air and water, climate regulation, and cultural enrichment are only some of the many essential services that urban ecosystems offer. Particularly noteworthy is the fact that Bolund and Hunhammar (1999) categorized these services, highlighting the significant impact they have on ecosystem and human health. These services include micro-climatic regulation and air purification. Fig. 1 illustrates the multifaceted contributions of urban ecosystem benefits to both human well-being and environmental sustainability, highlighting the diverse services derived from metropolitan environments. Even though they play an essential role, urban ecosystems are confronted with significant challenges caused by climate change. These challenges include increased temperatures, changing patterns of precipitation, and an increase in the frequency of extreme climatic events (Thuiller, 2007). Furthermore, urban ecosystems serve as both sources

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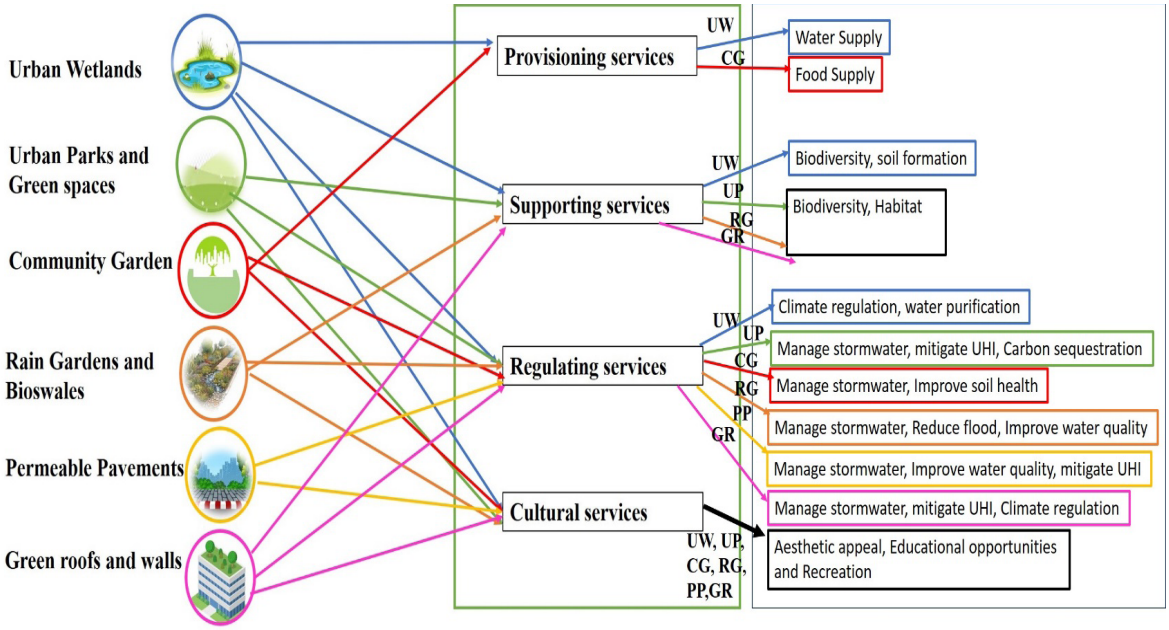

Fig. 1: Exploring Urban Ecosystem Structures and Their Diverse Ecosystem Services. The right side of the box denotes the services provided by each urban component categorized under-provisioning, supporting, regulating and cultural ecosystem services. UG: urban wetlands; UP: urban parks and green spaces; CG: community gardens; RG: rain gardens and bioswales; PP: permeable pavements; GR: green roofs and walls; UHI: Urban Heat Island

and sinks of greenhouse gases, demonstrating a dual role in the process of greenhouse gas discharge. According to Nowak and Crane (2002), urban trees, for example, play a significant part in the process of sequestration of carbon and climate regulation. The ordeals of changed climatic patterns and rising pollution, on the other hand, are becoming an increasingly serious threat to them, and there have been considerable decreases documented in several places (*Sonwani and Saxena*, 2022).

To develop cities that are both sustainable and resilient-prioritizing environmental health, resource efficiency, social equity, and the ability to adapt to and recover from adverse events, ensuring long-term viability and enhanced quality of life for all residents is of the utmost importance to acknowledge and capitalize on the complex interrelationships that exist between city ecosystems and climate change. To provide stakeholders with insights, the purpose of this assessment is to advocate for the acknowledgment of urban ecosystem services within the larger backdrop of climate change, along with championing integrated, sustainable methods to strengthen urban resilience in a world that is fast changing.

Influence of Changing Climate on Urban Ecosystem Services

Climate change exerts significant impacts on metropolitan ecosystem services, disrupting the sophisticated balance of these systems and posing multifaceted challenges to urban environments (Breuste *et al*., 2013; Lyu *et al*., 2019; Weiskopf *et al*., 2020). One notable consequence is the alteration of temperature (Moser *et al*., 2017; Moser-Reischl *et al*., 2018) and precipitation patterns (Nelson *et al*., 2013; Wang *et al*., 2017) leading to more frequent and intense heatwaves, floods, droughts, and storms. These extreme climatic incidences can degrade urban ecosystems and compromise their ability to provide essential services.

Urban green spaces, such as parks, forests, and wetlands, are particularly endangered by the atrocities of climate change. Higher temperatures and altered rainfall patterns can stress vegetation and food production (Kabisch *et al*., 2021), leading to reduced biodiversity (Habibullah *et al*., 2022), tree mortality (Landry *et al*., 2021), and increased susceptibility to pests and diseases (O'Neil-Dunne *et al*., 2014), resulting in detrimental impacts on provisioning, regulating, supporting as well as cultural services of urban ecosystems. Additionally, heatwaves can exacerbate the urban heat island effect (Pandey and Ghosh, 2023), further elevating temperatures in densely populated areas and affecting human health and well-being.

Shifts in precipitation patterns can also disrupt water availability and quality in urbanized areas. Intense rainfall events can overwhelm drainage systems, leading to urban flooding and water pollution (Fowler and Ali, 2022). Conversely, prolonged droughts can deplete water resources, affecting ecosystems dependent on freshwater sources and exacerbating water scarcity for human consumption and irrigation (*Trenberth*, 2005). Moreover, rising sea levels and increased storm surges pose significant risks to coastal cities, threatening infrastructure, habitats, and communities (Mishra *et al*., 2021). Coastal erosion, saltwater intrusion into freshwater systems, and the loss of coastal wetlands further compound the challenges faced by urban ecosystems.

The consequences of climate change on urbanized ecosystem services are not restricted to environmental factors but also extend to socioeconomic aspects. Recreational services, especially those associated with extramural sports in the winter season or tropical holidays, are significantly vulnerable to the

effects of global warming, as highlighted by Khan *et al.* (2013). Cultural festivals and events often occur outdoors, serving as platforms for residents and tourists to come together and commemorate diversity and communal spirit. However, the impact of climate change poses a significant threat to these gatherings, as it heightens the likelihood of intense weather incidents like storms, heavy rainfall, and heatwaves, disrupting the festivities (Pandey and Ghosh, 2023). As a result, disruptions in these ecosystem services can disproportionately impact vulnerable communities, exacerbating pre-existing inequalities.

Climate Change Abatement and Adaptation Strategies in Urbanised Areas

Metropolitans face increasing challenges due to the shift in climate patterns, which threatens their sustainability, resilience, and livability (Amini Parsa *et al.,* 2019; Pandey and Ghosh, 2023). To address such climatic provocations, it is imperative to implement comprehensive strategies that not only alleviate greenhouse gas discharge but also enhance the adaptive capacity of cities. Urban ecosystem services play a decisive role in both diminution and adaptation efforts (Elmqvist *et al.,* 2015), offering multiple benefits such as carbon sequestration, temperature regulation, water management, and biodiversity conservation. The stage for exploring the intertwined nature of climate change abatement and adaptation strategies in downtown areas, with a specific focus on the critical role of urban ecosystem amenities in building climate-resilient cities of the future, is set to be discussed as follows:

Climate-Resilient Infrastructures

Climate-resilient infrastructure is essential for urban areas to withstand the increasing frequency and intensity of extreme weather events driven by climate change. In response to the heightened risks of floods, storms, heatwaves, and other climate-related hazards, cities must prioritize the design and retrofitting of infrastructure to enhance their resilience (Elser, 2022). Upgrading drainage systems is crucial to alleviate the impacts of heavy rainfall and reduce the risk of urban flooding (Carter *et al.,* 2015*; Mak et al.,* 2017). This may involve the expansion of stormwater management networks and the installation of green infrastructure elements such as permeable pavements and rain gardens. Additionally, it includes the maintenance of natural drainage features like wetlands and riparian buffers. For example, the Thames Barrier is a movable flood barrier across the River Thames in London (Richardson and Soloviev, 2021). It serves not only as a flood protection infrastructure but also as a guardian of urban ecosystem services. By preventing flooding in London, the barrier helps safeguard the natural habitats along the Thames River, including wetlands, marshes, and estuaries. These ecosystems provide essential services such as water filtration, flood regulation, and habitat for wildlife, contributing to the overall resilience and ecological health of the urban environment (Richardson and Soloviev, 2021). Additionally, elevating critical infrastructure, such as power plants, transportation systems, and water treatment facilities, helps minimize the risk of damage and disruption during flooding events. Incorporating nature-based approaches, such as coastal wetlands and green buffers, can provide additional protection against storm surges and erosion while enhancing biodiversity and ecological services. The Seawalls in Tokyo, Japan, are a prime example. They serve to protect urban areas from coastal flooding and storm surges, and they also influence coastal ecosystems and their services (Kurosawa, 2021). The incorporation of green infrastructure elements into seawall designs, such as planting vegetation on seawalls or creating adjacent habitats to enhance biodiversity and ecosystem services, has been attempted in Japan (Furuta and Seino, 2016; Kurosawa, 2016). Overall, investing in climate-resilient infrastructure is essential for urban areas to adapt to the influence of climate change and ensure the safety, functionality, and sustainability of urbanized areas for current and future generations.

Water management

Water management plays a significant role in framing climate resilience in urban areas by addressing challenges such as flooding, water scarcity, and water pollution. Implementing sustainable water management practices not only helps relieve the ordeals of climate change but also enhances the overall quality and availability of water resources.

- *Rainwater Harvesting*

Rainwater harvesting involves collecting and storing rainwater for various uses, such as irrigation, toilet flushing, and groundwater recharge. In urbanized areas, harvesting systems can range from simple rain barrels to complex cisterns and underground storage tanks. For example, in Singapore, the Marina Barrage serves as both a freshwater reservoir and a flood control mechanism, capturing rainwater runoff from upstream areas and preventing flooding in the city center (Yap and Koh, 2010; Schmid, 2012). Another example is Melbourne, Australia, where the city's Water Sensitive Urban Design (WSUD) strategies incorporate rainwater harvesting systems to manage stormwater, reduce flooding, and improve water quality (Nasrin, 2018). These strategies include green roofs, permeable pavements, and rain gardens that enhance the urban ecosystem while providing valuable water resources.

- *Permeable Pavements*

Permeable pavements represent a practical and effective solution for managing stormwater, reducing urban flooding, and improving groundwater recharge. Integrating these systems into urban infrastructure projects contributes to sustainable urban development and resilience against climate change. Permeable pavements are surfaces that allow water to permeate into the ground instead of running off into storm drains (*EPA*, 2016). These pavements are typically made of porous materials such as pervious concrete, permeable pavers, or gravel. By reducing stormwater runoff, permeable pavements help alleviate flooding and replenish groundwater supplies. For instance, in Portland, Oregon, the Green Streets Program incorporates permeable pavements into street design to manage stormwater and upgrade water quality (Zhou *et al.,* 2018). Similarly, Chicago's Green Alley Program uses permeable pavements to retrofit alleys throughout the city, reducing localized flooding and improving urban resilience (Newell *et al*., 2013). In another example, Seattle, Washington, has implemented permeable pavements in residential neighborhoods through its street

edge alternatives (SEA) program (Baals, 2020). This initiative not only manages stormwater but also enhances neighborhood aesthetics and fosters community engagement. Innovative permeable pavement designs are emerging, such as modular interlocking pavers that can be easily installed and maintained. These systems offer flexibility in design and application, making them suitable for a variety of urban settings, including parking lots, sidewalks, and public plazas.

- *Green Stormwater Infrastructure*

Green stormwater infrastructure refers to natural or devised systems that imitate natural hydrological processes to manage stormwater runoff. Examples include bioswales, rain gardens, constructed wetlands, and green roofs (EPA, 2016). These systems help reduce the volume and velocity of runoff, filter pollutants, and recharge groundwater. One notable example is the High Line in New York City, where green roofs and vegetated swales are integrated into the elevated park design to manage stormwater runoff from adjacent buildings and streets (Salih *et al.,* 2021).

Urban greening

Enhancing vegetation cover with strategies such as afforestation, urban reforestation, and green corridor development helps mitigate heat stress, provide shade, and improve air quality. Urban green spaces also serve as wildlife habitats and recreational areas. Millennium Park, Chicago, USA is an iconic example of urban greening in a densely developed urban area (Gamble, 2016). The park incorporates sustainable design elements including green roofs, permeable pavements, and rain gardens to manage stormwater outflow and lessen the urban heat island impact. Additionally, Millennium Park provides a habitation for birds and insects, offers recreational opportunities for residents and visitors, and serves as a cultural hub with outdoor art installations and performance venues. Another pioneering example is Bosco Verticale, or Vertical Forest, Milan, Italy, which incorporates vertical greenery into urban development. Designed by architect Stefano Boeri, these residential towers in Milan are covered with thousands of trees, shrubs, and plants, creating a "forest" in the heart of the city (Visser, 2019; Bixio and D'Angiulli, 2021; Ishween, 2021). Bosco Verticale not only enhances the aesthetic outlook of the skyline but also contributes to air purification, noise reduction, and thermal insulation. The vegetation helps relieve the urban heat island consequences, provides shade for residents, and creates a habitat for birds and insects.

Furthermore, Singapore is renowned for its ambitious efforts to integrate green spaces into its urban fabric through its initiatory work such as the Garden City vision and the development of parks, gardens, and nature reserves across the island (Friess, 2017). The city-state prioritizes urban greening to enhance livability, biodiversity, and adaptability to climate change. Examples include Gardens by the Bay, a futuristic park featuring iconic Supertrees (Konijnendijk, 2019) and conservatories showcasing tropical flora, and Pulau Ubin, a rustic island in Singapore with mangrove forests, wetlands, and hiking trails preserved for biodiversity conservation and eco-tourism (Grupp, 2023).

Community Engagement and Education

Empowering communities through education and engagement fosters resilience and encourages the adoption of sustainable behaviors. This includes raising awareness about climate change impacts, providing training on disaster preparedness, and promoting community-led initiatives (Pandey and Ghosh, 2023). One such example cited is the 'Citizen Science Projects' in Melbourne, Australia (Parks Victoria, 2024). The projects engage residents in monitoring and conserving local ecosystems, including urban waterways, wetlands, and green spaces. By collecting data on water quality, biodiversity, and ecological health, participants contribute valuable information that informs ecosystem management decisions and enhances the provision of ecosystem services such as water disinfection, flood regulation, and habitat provision. Another example is Climate Action Workshops, Portland, Oregon, USA (https://www.effectiveclimateaction.org/about/). These workshops raise awareness about climate change impacting urban ecosystems, for instance, increased temperatures, shifts in precipitation trends, and impacts on biodiversity. By educating residents regarding the significance of mitigating climate change, these initiatives indirectly support urban ecosystem services such as air quality regulation, temperature regulation, and habitat provision.

Integration of Nature-Based Outcomes and Approaches

Incorporating nature-based outcomes, such as wetlands restoration, coastal protection through mangrove planting, and urban agriculture, enhances ecosystem resilience and provides multiple benefits, including flood mitigation, carbon sequestration, and food security.

Paris has implemented a comprehensive green infrastructure strategy to enhance urban resilience, mitigate climate change impacts, and improve the attributes of lifestyle for residents (Liu *et al.,* 2022). As part of this strategy, the city has integrated nature-based outcomes, e.g., green roofs, rain gardens, and permeable pavements into urban planning and development projects. These green infrastructure elements help reduce stormwater runoff, alleviate the urban heat island effect, and enhance biodiversity in the city. For example, the Parc Rives-en-Seine project transformed former expressway lanes along the Seine River into pedestrian-friendly green spaces, incorporating vegetation, water features, and recreational amenities (Othmen *et al.,* 2022). By prioritizing nature-based solutions, Paris aims to create more sustainable and resilient urban environments that benefit both people and nature.

The growing recognition of the importance of incorporating nature-based solutions, or green infrastructure, in flood risk management and climate adaptation strategies has been highlighted in several studies across the globe (Dong *et al.,* 2017; Chausson *et al.,* 2020; *La* Rosa *et al.,* 2021). Traditionally, flood management relied heavily on grey infrastructure like dykes and seawalls, but there's a shift towards integrating green structures such as protecting and restoring habitats, creating green spaces, and managing catchments more sustainably. Chausson *et al.,* (2020) stress the benefits of safeguarding and preserving dwellings along shorelines and in upper catchments for mitigating flooding and erosion, sequestering carbon,

and preserving biodiversity. Dong *et al.,* (2017) advocate for enhancing grey infrastructure with green elements to improve ecological conditions and strengthen urban drainage resilience, a concept termed "greening the grey infrastructure." Alves *et al.,* (2019) suggest that a combination of green, blue (water-based), and grey infrastructures offers the most effective adaptation strategy against climate change impacts.

Challenges and Opportunities for Upgrading Urban Ecological Services amidst Changing Climatic Conditions

Cities confront a myriad of challenges in upgrading urban ecosystem services amidst the pressures of altering climate and rapid urbanization. The burgeoning urban population strains natural habitats, resulting in their loss, fragmentation, and degradation, thereby compromising their ability to provide crucial services such as purifying air and water, regulating floods, and mitigating climate impacts (Luederitz *et al.,* 2015). Furthermore, the intensifying implications of climate change, from intense precipitation to extreme weather phenomena, pose additional threats by disrupting ecosystems, diminishing biodiversity, and weakening the resilience of green spaces in cities (Dai *et al.,* 2023). Many cities, compounded by limited resources and spatial constraints, struggle to provide adequate green space and infrastructure, hindering efforts to bolster ecosystem services and foster biodiversity within urban landscapes. Moreover, access to these services is often unequal, with marginalized communities disproportionately lacking access to clean air, water, and green spaces (Lara-Valencia and Garca-Pérez, 2015; *Forbes*, 2016). Addressing these equity concerns is imperative to guarantee that all inhabitants can enjoy and contribute to the rewards of urban ecosystem services equitably.

Amidst the challenges imposed by changing climate and rapid urbanization, there exist significant opportunities for enhancing ecosystem services to build resilience and sustainability within cities. Nature-based solutions offer a promising avenue by leveraging the inherent resilience of nature to mitigate climate impacts and improve urban environments (Almenar *et al*., 2021). Integrating green frameworks, such as parks, green roofs, and urban forests, presents opportunities to enhance biodiversity, ameliorate urban heat islands, and regulate water flows. Furthermore, initiatives like ecological restoration and sustainable land management can revitalize degraded urban ecosystems, unlocking their potential to provide vital services such as air purification, carbon sequestration, and flood regulation (Pandey and Ghosh, 2023). Engaging city dwellers in the planning and implementation of these solutions not only fosters a sense of proprietorship and stewardship but also strengthens social cohesion and equity. Additionally, advancements in technology and interdisciplinary collaboration offer innovative approaches to monitor and manage urban ecosystems effectively.

Furthermore, investing in green infrastructure and ecosystem restoration projects generates economic benefits, including job creation, increased property values, and cost savings from ecosystem services provision (Abramowicz and Stępniewska, 2020). By aligning economic incentives with environmental goals, cities can harness the potential of nature-based solutions to enhance resilience and promote sustainable development

Strong policy frameworks and governance structures are essential for promoting the conservation, restoration, and sustainable supervision of urban ecosystem services. By integrating ecosystem-based approaches into urban planning policies, zoning regulations, and development plans, cities can

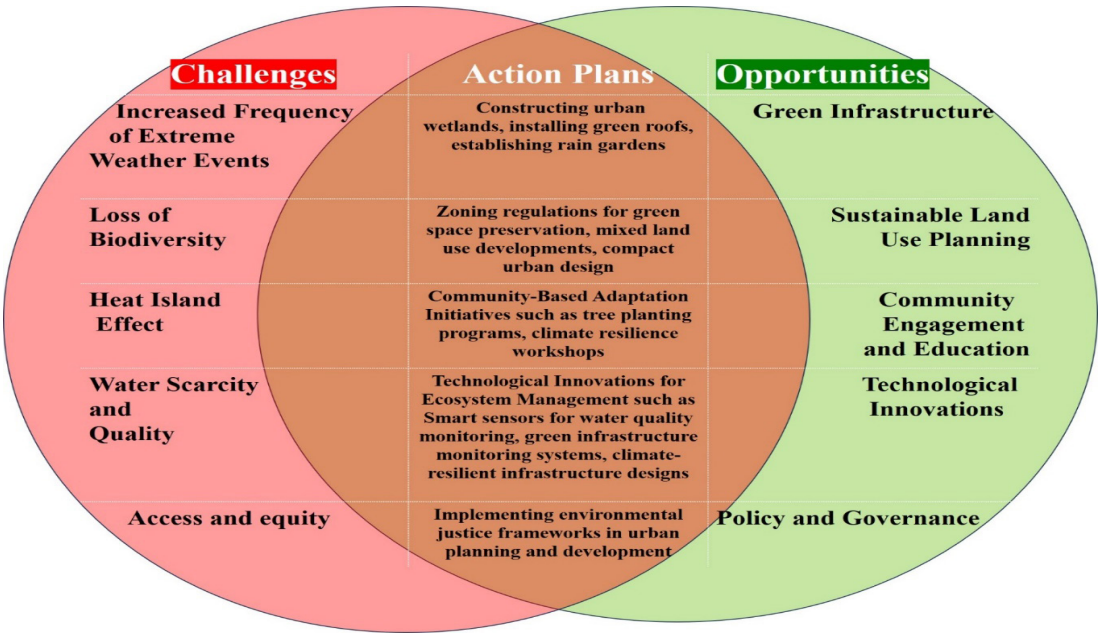

Fig. 2: Navigating Challenges and Opportunities: Enhancing Urban Ecosystem Services in a Changing Climate. The red circle represents the challenges faced in enhancing urban ecosystem services in the context of climate change. The green circle depicts the opportunities available for enhancing urban ecosystem services despite the challenges posed by climate change. The overlap area represents the synergies between addressing challenges and leveraging opportunities.

mainstream the protection and strengthening of ecosystem services into decision-making processes (Fig. 2). Acknowledging the potential of urbanized areas to mitigate their own impacts and enhance the standard of life for residents, it is crucial for mitigation strategies to emphasize the dual role of downtown areas in fostering both local and global sustainability and resilience, as highlighted by Elmqvist *et al*., (2015) and Luederitz *et al*., (2015). Crafting effective strategies necessitates a deep understanding of the intricate social, environmental, and economic conditions specific to each urban context.

Conclusion

The review emphasizes urban ecosystem services' vital role amid climate change, advocating for their enhancement to aid effective adaptation. While providing benefits like upgrading air and water standards, climate regulation, biodiversity preservation, and improved well-being, urban ecosystems face challenges such as heat stress, water stress (drought and flooding), and habitat loss owing to altered climatic patterns. Proactive measures are essential to bolster resilience and ensure continued service provision. Nature-based solutions like green and blue infrastructures can ameliorate such consequences and promote adaptation, requiring an equilibrium between urban development and ecosystem preservation. Integrating ecosystem services into governance and strategic frameworks is crucial for fostering resilient urban growth and enabling efficient responses to climate change challenges.

Tackling challenges in metropolitan ecosystem services requires exploration, inventive funding, improved governance, and broader inclusivity in decision-making. This necessitates a comprehensive strategy, blending scientific inquiry, policy formulation, financial strategies, and community involvement, alongside fortified cooperation among stakeholders and expanded support for urban ecosystem services, all while incorporating climate change factors into urban planning and governance.

Looking forward, the future of sustainable and resilient urban development hinges on our ability to innovate and adapt. Embracing advanced technologies, fostering interdisciplinary research, and nurturing public-private partnerships will be pivotal. Policymakers and urban planners must prioritize long-term environmental sustainability while ensuring social equity and economic stability. By continually enhancing urban ecosystem services and integrating them into strategic planning, cities can better navigate the uncertainties of climate change, securing a healthier, more resilient future for all residents.

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Author contribution

Annesha Ghosh: Material preparation, data collection and writing original draft; Bhanu Pandey: Material preparation, data collection and writing original draft; Madhoolika Agrawal: Writing review and Editing; Shashi Bhushan Agrawal: Conceptualization and Editing**.** All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that they have no conflict of interest

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