1 Blue-Green Infrastructure for Addressing Urban Resilience and Sustainability in the Warming World

Shalini Dhyani, Sunidhi Singh, Mrittika Basu, Rajarshi Dasgupta, and Harini Santhanam

Abstract

Urban blue-green infrastructure (UBGI) has been recognized as vital component of urban environment management, disaster risk reduction, and climate change adaptations. There has been growing consensus and advancement in the conceptualization, research, implementation, and mainstreaming of UBGI in urban policy planning to enhance urban resilience to increasing disaster risks and climate change. Despite the growing interest in UBGI, most of the global research on UBGI has been carried out in the Global North, while uncertainty linked with the performance of UBGI in the Global South has resulted in lack of confidence, and public acceptance has limited its adoption and implementation in many developing Asian countries. This edited book volume investigates the issues, gaps, opportunities, and advances related to UBGI from the diverse perspectives of researchers and experiences of professionals from various science and policy disciplines to enhance and enrich the existing knowledge on effective mainstreaming of UBGI across Asia. Case studies highlighting UBGI successes, gaps, opportunities, and threats from different Asian countries are presented in

S. Dhyani (✉) · S. Singh
CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur, Maharashtra, India
e-mail: s_dhyani@neeri.res.in

M. Basu
Laboratory of Sustainable Rural Development, Graduate School of Global Environmental Studies, Kyoto University, Kyoto, Japan

R. Dasgupta
Institute for Global Environmental Strategies, Kanagawa, Japan

H. Santhanam
National Institute of Advanced Studies, Bengaluru, India

S. Dhyani et al. (eds.), *Blue-Green Infrastructure Across Asian Countries*,
https://doi.org/10.1007/978-981-16-7128-9_1

this volume. However, all the cases discussed in the book stress on identifying and managing biophysical and sociopolitical threats for enhancing and ensuring the mainstreaming of UBGI as practical and scientifically sound sustainable solutions that involve multi-stakeholder groups. The volume especially highlights the potential of UBGI in providing ecosystem services for addressing emerging urban environmental risks, enhancing climate change adaptation, and urban disaster risk reduction. The thematic and cross-cutting chapters bring in scientific evidence-based innovations to enhance the prospects of UBGI (environmental, economic, and social benefits).

Keywords

Urban ecosystems · Disaster · Climate change · Urban blue-green infrastructure · Resilience · Sustainability

1.1 Introduction

Uncertainty, unpredictability, and transformation are considered crucial features of the Anthropocene. It was observed for the very first time, in the year 2009, that a comparatively lesser number of people were living in rural areas than urban expansions. More than 70% of the population of the world is projected to live in urban areas by the year 2025. Urbanization is rapidly occurring in secondary cities of Africa and Asia, and these secondary cities are projected to be the future urban centers of growth and massive expansion (Cissé et al. 2011). Presently, Anthropocene has entered the urban century having multiple urban sustainability challenges as these urban centers are contributors of more than 70% of global greenhouse gas emissions and 90% of them are close to coastal areas (Elmqvist et al. 2019). Urban areas and urbanization have severely altered the society-environment relationship by disturbing the sustainability and resilience at alarming rates by enhancing the complexities (Romero-Lankao et al. 2016). Larger impacts of climate change, despite being a global problem, are observed locally, and cities are emerging as new hotspots of risks and disasters (Hordijk and Baud 2011; Dhyani and Thummarukuddy 2016; Dhyani et al. 2018). Megacities of the south are extremely susceptible to these ongoing and emerging challenges due to exponential growth in population, poor living conditions due to poverty, and climate change (Wilhelm 2011). Globally, urban population ratio has surpassed 50% in 2007 and is continuously rising following Northam's "S"-curve theory (Shen et al. 2016). Several fast-growing urban areas in the developing and underdeveloped countries of the Global South, due to rampant urbanization and insufficient enforcement of urban planning guidelines, are vulnerable to floods (Drosou et al. 2019). Urbanization through its rapid developmental projects has changed permeable open surfaces to hard impermeable concretized surfaces. These changes on soil surface have drastically affected and changed the hydrological cycle and enhanced flash floods in fast-expanding urban areas (Shafique et al. 2018). Shrinking green and blue spaces and increasing built-up and concretized surfaces has enhanced urban heat islands and reduced groundwater infiltration (Lahoti et al. 2019). Urban areas worldwide are facing drainage issues, enhanced flood incidences, and heat and water stress (Liu et al. 2014; Majidi et al. 2019). Concepts like natural capital, ecosystem services, and nature's contributions (benefits and disbenefits) define the numerous profits people receive from nature. Rapid and often unplanned urbanization across the world has been the key factor behind the deterioration and loss of natural capital universally (Ncube and Arthur 2021). Urban resilience and nature-based solutions (NbS) are globally acknowledged and endorsed in different international agreements and targets (SDGs, Paris COP, CBD, Ramsar Convention, etc.) for their additional co-benefits in disaster risk reduction and climate adaptations (Suárez et al. 2018). Climate change and uncontrolled urban sprawls can bring multiple challenges to urban planning with special reference to water management. In order to counter these challenges, NbS and resilience building need to be promoted as balancing approaches to counter the emerging issues in urban areas of the world (Suárez et al. 2018). The conceptual development of sustainable urban infrastructure has been intensifying ever since the UN proposed the idea of sustainability in the year 1982 (Du et al. 2019). Sustainable urban development is interspersed with eco-action that leads to socio-ecosystems and green infrastructure for building ecological resilience (Vargas-Hernández and Zdunek-Wielgołaska 2021). Urban environmental concerns have their deep roots in ecology as well as urbanism perspectives (Masnavi et al. 2019). In academic and policy discourses, the conception of urban resilience is flourishing (Meerow and Newell 2019). Sustainability and resilience have emerged as important ideas that focus on understanding the essential urban dynamics to address the challenges and ensuring habitable urban futures (Romero-Lankao et al. 2016). Considerable optimism is being attributed to the capacity of resilience building to balance environmental risks in the warming world (Borie et al. 2019). "Resilience" as a concept is relevant in urban planning and practice as it can offer innovative and progressively appropriate concepts and approaches for addressing the complexities of the urbanized world to safeguard communities from diverse emerging risks and hazards (Coaffee and Clarke 2015). Resilience building can also be advantageous when the internal and external system sustainability components are considered while planning suitable nature-based solutions (Dhyani et al. 2021a). Enhancing urban socioeconomic and spatial vulnerabilities and loss of natural environment reflect the growing requirement of resilience thinking in urban planning and development (Masnavi et al. 2019). Urban areas present exceptional challenges as well as opportunities for sustainability and resilience. Urban expansion relates to the socio-ecosystem that is itself a complex human-dominated system having erratic ecological resilience that experiences continuous interaction of physical, structural, engineering, social, psychological, natural, and environmental components that can influence each other for developing resilient city (Vargas-Hernández and Zdunek-Wielgołaska 2021). Understanding, supporting, and promoting diverse knowledge types, stimuli abilities, and aims of diverse members and their networks are considered vital for developing sustainable and resilient cities (Romolini et al. 2016). For transforming existing social-ecological systems, the transformative capability needs to be strengthened by supporting its three pillars, i.e., reconnecting life-support systems, agency, and social interconnections (Ziervogel et al. 2016). However, it is important to note that there is no simple "spatial fix" for overconsumption that is prevalent in growing urban areas. Hence, the crucial role of urban planning in the warming world will be for adaptation and not mitigation (Gleeson 2008). Enhancing and improving education opportunities followed by access to information, improving awareness, endorsing transfer of innovative technologies, strengthening connections and collaborations among organizations, improving convergence, decentralized governance, and reassuring citizen involvement can be advantageous for steering the theoretical complications along with other diverse perspectives of multiple stakeholder groups. A transdisciplinary approach can ensure co-production of key knowledge for resilience building that also connects the science-policy interface (Aldunce et al. 2016). Despite having global endorsement of the concept urban resilience and their need for human well-being, it has not been appropriately addressed in different national contexts especially for the countries in the South. "Resilience thinking" along with the "community-based adaptation" has been endorsed globally, but the scientific evidences of the successes of the approach are confined to regional levels from rural areas for natural resources management (NRM) within social-ecological systems. Still, there exists a major gap in urban resilience praxis to connect the resilience theories with actual implementation. Sustainable urban growth can only be achieved when resilience building is considered in suitable urban planning (Zhang and Li 2018). Climate and increasing pandemic risks have enhanced the need to integrate blue-green infrastructure (BGI) in urban areas as a pressing call for practical and sustainable urban areas of present and futures. The potentials of BGI have already been highlighted in many scientific studies for their diverse ecosystem benefits in ensuring human well-being and urban sustainability (Staddon et al. 2018) especially to solve urban climate and health crises (Pamukcu-Albers et al. 2021). There is growing global demand need to expand and improve BGI, especially for the countries of Global South following an integrative and participatory approach (Fig. 1.1).

Chapters in this book are authored by invited expert professionals, scientists, and practitioners who have decades of research experience related to urban BGI (UBGI). These experts have also contributed novel ideas to improve existing BGI-based solutions to reduce disaster risks and enhance climate adaptations for good quality of life of urban residents. The edited book volume is an effort to showcase the context, concept, issues, cases, relevance, and growing need to mainstream BGI in fast-expanding urban sprawls of Asia. Despite urban areas of Asia facing extreme disaster risks and climate vulnerabilities, the importance and role of ecosystem-based approaches or BGI in addressing climate as well as disaster risks are either ignored or have not received sufficient recognition so far. Under the different subheadings of this opening chapter of the book, we not only bring the concepts of BGI but also showcase ongoing developments and novel approaches for implementing BGI. Chapters in different sections of this book volume provide a broader overview of scientific advances in the field of BGI followed by the key gaps and issues to mainstream and implement them. A dedicated last section of the book

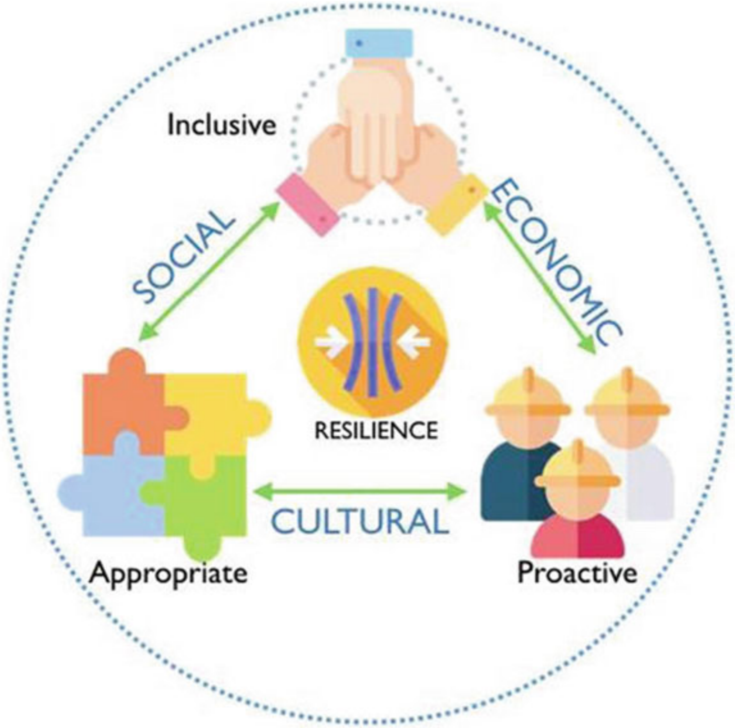

Fig. 1.1 Community-centered approach to enhancing flood resilience with blue-green infrastructure (BGI) *(Adapted from (*Drosou et al. 2019*)*

volume discusses the opportunities and pathways to mainstream BGI in urban policies and urban planning in developing countries of Asia.

1.1.1 Urban Blue-Green Infrastructure—Examples

Rapid urbanization is leading to an exponential rise in population densities in risk-prone zones (Andersson et al. 2017). Habitat loss and modification as a probable environmental impact of urbanization warrant the incorporation of ecologically sensitive strategies into urban planning (Evans et al. 2019). Predictions of rampant urban expansion and increasing water hazards and risks in Asia require substantial investments in NbS, viz., urban green spaces and ecosystem-based engineered systems. Most of the awareness and scientific research on BGI is emerging from the Global North, overseeing the multiplicity of global urban issues and contexts (Hamel and Tan 2021). Adaptation capacity is a vital essential for urban resilience. Considering the establishment of open green spaces that are accessible by the local public can enhance urban resilience (Ni'mah and Lenonb 2017). BGI is a recognized approach to develop resilience to counteract growing urban vulnerabilities because of climate change and disaster risks (Thorne et al. 2018). BGI significantly depends on the ecosystem services of urban green spaces and natural water flows for urban hazards and risks (Lamond and Everett 2019; Dhyani et al. 2020). The multi-functionality of BGI and its several co-benefits can lead to mutual efforts to develop an infrastructure that can help to achieve the strategic goals of both public and private organizations (O'Donnell et al. 2018). Integration of BGI concepts and approaches for developing urban landscapes has the potential to increase flood resilience and offer broader environmental benefits (Drosou et al. 2019). BGI is an ecosystem-based approach that depends on biophysical measures, e.g., confinement, stowage, permeation, and biological uptake of contaminants, to achieve urban floodwater quantity as well as quality. BGI as an innovative approach involves urban water management and green infrastructure to regulate natural water cycles for improving and restoring urban ecology (Drosou et al. 2019). Rain gardens, bioswales, biopores, infiltration wells, retention ponds, sponge gardens and cities, constructed wetlands, permeable pavements, rainwater harvesting, and green roofs are examples of some commonly used BGI infrastructures unlike the gray civil engineering structures intended to take away stormwater (e.g., drainpipes, culverts) (Sidek et al. 2013; Li et al. 2016; Metcalfe et al. 2018; Malaviya et al. 2019; Santhanam and Majumdar 2020; Ekka et al. 2021). BGI is different than single-functioned gray engineering infrastructure, and these landscapes are capable of delivering multiple ecosystem services. BGI also provides other eco-benefits like disaster risk reduction and climate change adaptation and also includes flood risk reduction, improving water quality, and reducing the temperature while conserving and protecting urban ecosystems and biodiversity (Liao et al. 2017) (Fig. 1.2).

Constructed wetlands (CWs) are helpful in sustainably treating urban wastewater. CWs are biological systems that have been globally well studied in the last three decades. The selection of appropriate plant species and their combinations have been proven to significantly enhance the bioremediation potential of the performance of CWs (Licata et al. 2019). Thus, CWs are promising ecosystem-based wastewater treatment systems, having exceptional treatment ability and an eco-friendly appeal; their cost-effectiveness has made them relevant to scientists and urban planners to be explored as sustainable technologies especially for developing countries of the Global South (Stefanakis 2016; Rousseau 2018). Hotels, guest houses, lodges, and resorts worldwide are adopting different CWs that include surface as well as subsurface flow in unconventional ecosystem-based wastewater management systems (Makopondo et al. 2020). Out of many BGI as best management practices (BMPs), rain gardens (also referred to as "bio-retention systems") are widely used to decrease nonpoint source contamination to urban water bodies. Physicochemical and biological characteristic of rain gardens reduce contaminants and help in the storage of runoff water by reducing peak flow. Rain gardens have also improved nutrient cycling and decontamination of heavy metal and are an additional source of recreation (Malaviya et al. 2019). Rain gardens area well-known green technology to ensure stormwater management in Malaysia. Integrated efforts in managing stormwater in fast-expanding urban areas have been well utilized in Malaysia that

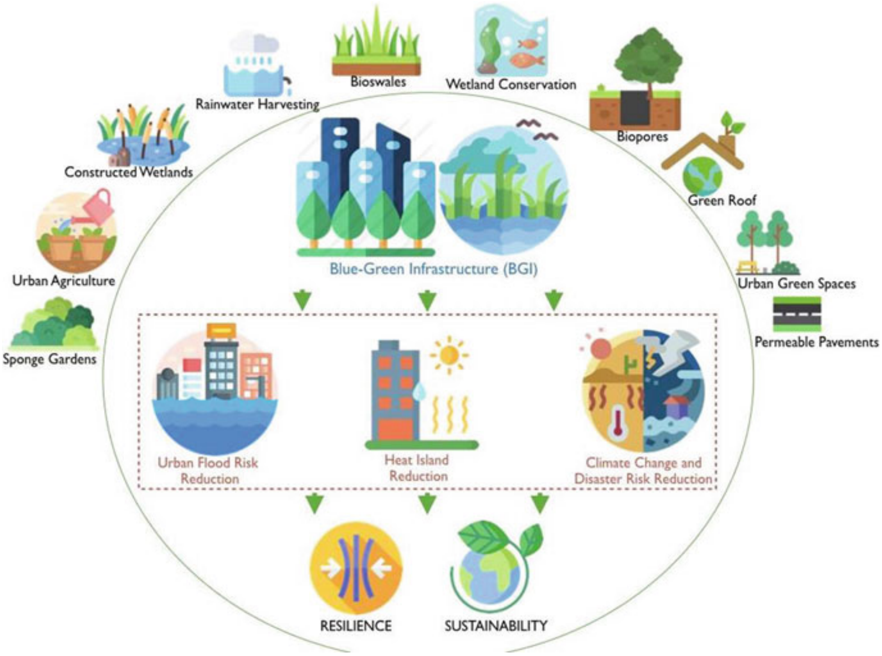

Fig. 1.2 Blue-green infrastructure to mitigate risks and hazards and develop urban resilience and sustainability

ensures reducing peak discharge followed by reducing diverse stormwater pollutants (Sidek et al. 2013).

Swales as one of the oldest green technologies or BGI help in controlling flash floods by treating the roadway runoff. Swales are also evolving into flash flood treatment options and as a vital part of BGI to develop resilient cities (Ekka et al. 2021). Bioswales as a critical constituent of water-sensitive or a low-impact urban design include trees as a novel approach to release the water from flash floods to the atmosphere following the ecophysiological process of transpiration loss. Trees in bioswales lead to 46–72% of water outputs from transpiration that helps in reducing the runoff. Plants with high stomatal conductance contribute the greatest to the bioswale function (Scharenbroch et al. 2016). Bioswales are considered extremely noticeable interventions that demand support from urban locals as well as urban planners to implement and preserve them suitably (Everett et al. 2018).

Biopore infiltration holes are found an effective solution for mitigating flood disasters. Biopores as infiltration holes are used in dense urban areas having marginal water catchment zones, and by enhancing the absorption of groundwater, they reduce the intensity and impact of flooding on urban areas (Khusna et al. 2020). Wet retention ponds can temporarily store as well as slowly release the floodwater to moderate peak flow rates of the flood and also can help to eliminate particulate-bound contaminants. Having sandy underlying soils, wet retention ponds are reported to deliver surplus co-benefits by enhancing the infiltration and recharging the groundwater by supporting the base flow of small streams (Baird et al. 2020). Investigation of infiltration well use indicates that they are capable of reducing flood peaks by up to 50% compared to without wells (Kusumastuti et al. 2017).

Permeable Pavement Systems (PPS) are sustainable drainage systems that can help to improve water security. Substantial research has been carried out on the functions of PPS as sustainable drainage systems for enhancing water quality (Imran et al. 2013). Construction of PPS in urban sidewalks is a low-impact development (LID) to reduce and control the stormwater runoff volume for decreasing the pollutants in urban blue spaces (Kamali et al. 2017; Santhanam and Majumdar 2020). PPS including full depth permeable pavement (FDPP) is expected to be part of the integrated sustainable transportation program (Kayhanian et al. 2019). Evaporation-enhancing PPS are known for their potential to mitigate UHI than conventional permeable pavement (Liu et al. 2018). PPS can function hydraulically to remove particulate pollutants if they are maintained and cleaned annually (Kamali et al. 2017).

Green roofs are another UBGI that can enhance the urban biodiversity and reduce the storm peak to the drainage systems by reducing the runoff quality as well as quantity while also reducing the air pollutants (Li and Yeung 2014). Green roofs address diverse urban environmental and socioeconomic problems and ensure unrestricted flow of ecosystem services by acting as multifunctional and decentralized units. Depending on the specific urban challenges that a city expects, diverse green roof configurations can be considered (Calheiros and Stefanakis 2021; Dhyani et al. 2021a). Covering the external concretized urban built-up surfaces with green vegetation can address many socioeconomic and ecological issues. Urban Green Spaces, especially, significantly improves indoor thermal issues by reducing the temperatures and enhancing comfort (Abass et al. 2020).

1.1.2 Global Recognition and Acceptance of UBGI

To address the growing environmental and human well-being challenges of urban areas, urban policies are gradually shifting their attention from civil engineering interventions to NbS and UBGI (Raymond et al. 2017). Green infrastructure (GI) as a practical physical structure is increasingly been acknowledged as the most profitable approach to adapt and mitigate the social-ecological and climate challenges using multifunctional ecosystem services of urban green spaces (Liu et al. 2020). The emerging importance of BGI in the Global South has a focus on sustainable development in fast-expanding urban areas. This development targets to address concerns of urban vegetation, land use plans, nutritional security, and poverty reduction (Valente de Macedo et al. 2021). While managing urban water woes, BGI has been unanimously appreciated for its co-benefits that can help to improve quality of life and ensure human well-being (O'Donnell et al. 2021). While exploration of urban agriculture dominates in Africa, urban green spaces and parks are more frequently discussed and implemented in Asian, Latin American, and Caribbean countries (Valente de Macedo et al. 2021). The prospects of UBGI that include ecological engineering, natural infrastructure, green infrastructure, urban forests, urban green spaces, urban agriculture, etc. have been widely endorsed and acknowledged by researchers, scientists, academicians, bureaucrats, urban planners, as well as policymakers (Armson et al. 2013; Dhyani and Thummarukuddy 2016; Raymond et al. 2017; Dhyani et al. 2020, 2021a). UBGI have proven air quality (Calfapietra et al. 2015), biodiversity, and ecosystem services (Connop et al. 2016; Tan and Jim 2017; de Oliveira and Mell 2019), mitigate heat island (Makido et al. 2019), reduce urban flash flood risks (Majidi et al. 2019), and provide solutions to many urban sustainability issues and challenges (Perez and Perini 2018) that include public health and human well-being (Bennett et al. 2015).

The "Sponge City Concept" (SCC) has enhanced curiosity and interest in urban planning. Chinese cities, especially, are recognizing the benefits of Sponge Cities technologies. At the national level itself in China, the State Council has set an advanced target to implement SCC initiatives by 2030 (Zevenbergen et al. 2018). Sponge City (SPC) as an urban water management program was projected in 2014 by China to reduce urban flood inundation and water shortage (Li et al. 2016). A total of 16 cities have been selected in 2015 by China as SPC's pilot cities including Wuhan (Zhang et al. 2018).

1.1.3 Opportunities and Challenges

There are examples and proven evidence that BGI is capable of enhancing flood damage control; improving water quality, size of habitats, and carbon sequestration potential; and reducing noise pollution. Using BGI for multiple co-benefits can enable partnerships for the execution of multifunctional BGI (O'Donnell et al. 2018). Exploration and identification of air pollutant-tolerant tree and shrub species in the plantation zones to reduce and control air pollution; spreading bioswales to improve urban connectivity by enhancing green spaces; and using green roofs for noise attenuation and carbon sequestration are some of the important co-benefits and opportunities (Fenner 2017). BGI has progressively been recognized as a vital mechanism and approach for managing urban floods. However, there is a lot of uncertainty about their hydrologic outputs and lack of public acceptance that are important challenges that have so far limited its widespread adoption (Thorne et al. 2018). For example, insufficient knowledge and technical care; off-season low volume discharge; limited land availability; and the approach of urban planners for including CS are few of the major challenges (Makopondo et al. 2020). There is limited field-based practical knowledge to mainstream BGI in urban planning despite the significant amount of research been carried out on the subject. However, greater insights on the performances of existing BGI along with urban gray engineering infrastructure are needed for objective assessments of their capabilities. There is a need for more primary data on the impacts of BGI on hydrology along with societal and environmental impacts (Hamel and Tan 2021). Urban planners, bureaucrats, policymakers, and scientists should mainstream urban resilience and sustainability in decision-making (Zhang and Li 2018). There is clear evidence that urban green spaces along with blue spaces improve the effectiveness of urban risk resiliency (URR). Still mainstreaming and inclusion of urban green spaces (UGS) has been significantly limited in developing and underdeveloped countries. A dearth of integrated approaches, insufficient understanding or expertise in green-engineering designs, lack of regular monitoring, and management are some of the key challenges to mainstream BGI in fast-growing urban areas (Mukherjee and Takara 2018). Determination of the zones facing UGS degradation can help urban planners in proactive planning by efficient allocation of finances for conserving and restoring degraded UGS (Bardhan et al. 2016). The instrument of open green space provision for the growing urban sprawls should be endorsed for developing "urban green commons" as an organized approach for collective participation in land management in urban areas (Ni'mah and Lenonb 2017). However, the valuation of the prospective environmental profits from urban green space is challenging because of the irregularities in management practices and their dissimilar nature (Pudifoot et al. 2021). Performance-based monitoring can be an important approach to improve the effectiveness of UGS to address urban heat and water stress (Mukherjee and Takara 2018). It has also been observed that national and regional statutes do not identify adaptation arrangements for urban areas (García Sánchez et al. 2018). Cities are the most active entities in the implementation of adaptation strategies. The vital need of adapting urban sprawls to climate risks demands robust political and administrative action at the local level. Local adaptive actions can address the explicit requirements and capabilities of local communities and socioeconomics. It is important to understand that climate change adaptations at a local level may initiate new and exceptional challenges for the local administration and this might exceed their existing capacities regarding the risks, understanding, economic requirements, and legal accountability. This case is more observed in developing and underdeveloped countries (Garschagen and Kraas 2011). However, in developed countries like the USA and many European countries, municipal sovereignty helps to regulate and integrate climate change adaptation in their plans and actions. For example, Red Hook in New York and Zorrotzaurre in Bilbao City have taken up the initiatives to outline adaptation plans without even waiting for the state statutory act or policies (García Sánchez et al. 2018). Transformative changes in policy and enforcement concerning strictly multifunctional setup are required to enhance the provisions of numerous BGI profits for fulfilling priorities and strategic aims of respective cities. BGI uptake is expected to improve by enhancing awareness of urban planners and policymakers concerning multifunctional BGI. BGI has global significance for other expanding urban areas that are on the way to ecological and sustainable futures (O'Donnell et al. 2021).

1.1.4 Progress and Developments in UBGI on the Science Front

The urban adaptation issue has largely been a physical one and focuses on protecting the existing infrastructure and urban form of cities. In the last few decades, significant attention has been dedicated to the protection of critical urban infrastructures to safeguard cities from sea-level rise, floods, droughts, increasing temperatures, and other associated impacts of climate change (Tusinski and Balbo 2011). Ongoing urban expansion globally on priority requires integration and establishment of adaptation strategies against climate change (Mathey et al. 2011). It is important to note that BGI has still not been realized as a low-impact advanced plan to address urban risks, excluding in China, where investigators are working on numerous cases of systematic inclusiveness of BGI in urban planning and ecosystem-based disaster risk reduction (EcoDRR; Valente de Macedo et al. 2021). Transitional "hybrid" approaches, which include both blue and green as well as gray approaches, have been most effective in reducing urban hazards and risks (Depietri and McPhearson 2017).

1.1.4.1 Urban Green Spaces for Increasing Resilience

Urban green spaces (UGS) are of great benefit to growing urban areas. UGS can enable and support nutritional security, social connections, human well-being, livelihoods, and many other direct and indirect benefits. UGS has proven potential to ensure resilience and refuge of energy security, health benefits, water security, food and nutrition, ecosystem services, and biodiversity systems (Mukherjee and Takara 2018). Urban green spaces have also been highly endorsed as NbS that can help to alleviate the negative impacts of climate change (Pudifoot et al. 2021). To develop resilience against extreme events, place and composition of urban green spaces are expected to be the key adaptive strategy of fast-expanding urban areas facing climate vulnerabilities (García Sánchez et al. 2018) (Fig. 1.3).

1.1.4.2 UBGI to Manage Urban Heat Islands

Increasing temperature conditions are intensified by climate change that has enhanced urban heat islands having serious implications on human well-being in urban areas. In the last more than a decade, there is growing concern that by following the preventative attitude, urban designs and infrastructure must address the changes in the urban climate to make the urban areas comfortable and habitable for the future (Katzschner 2011). Urban heat island (UHI) is a threat to urban areas and the world over; the ongoing efforts are targeting to solve the issue by integrating UBGI (Liu et al. 2018). Green infrastructure has proven potential to improve urban climate and has a critical role in reducing and mitigating heat islands (Mathey et al. 2011). UGS are complementary substitutes to engineered infrastructures to enhance and enrich the urban quality of life by mitigating urban heat islands (UHI) and urban water management (Mukherjee and Takara 2018). Stand-alone green roofs, as well as hybrid green roof systems as a BGI with other established techniques, are also proven to substantially reduce heat islands (Vijayaraghavan 2016). The extent of water and green zones, leaf area index (LAI) of roads, and hydration degree of green roofs, along with the location of green walls, are essential BGI factors for UHI mitigation (Antoszewski et al. 2020).

A study in Medellin Metropolitan Area, Colombia, projected carbon sink potential and emission offsets by urban green spaces (Reynolds et al. 2017). Considering

Fig. 1.3 Urban blue-green infrastructure for disaster risk reduction, socio-ecological and economic benefits, and human well-being

the available space for plantations, carbon offsets can be even more inexpensive, ensuring an unrestricted supply of co-benefits that can help in the socioeconomic upliftment of urban poor. Nowak, Dhyani, and Zheng have also endorsed the importance of urban green forests in the carbon sequestration of urban and community areas in the USA, India, and China (Zheng et al. 2013; Nowak et al. 2013; Dhyani et al. 2021b). Urban and peri-urban green areas were found to have a profound impact on biomass-based vegetation carbon stocks, and the density of plants enhances these positive impacts (Yao et al. 2017). Similarly, lined parks along the city waterways were observed to improve the well-being and helped developing community resilience (Giannakis et al. 2016). Urban green space design for climate adaptation for urban areas in India also endorses the NbS and UBGI approach for climate adaptations and mitigations (Govindarajulu 2014). Another study from India has also provided sufficient evidence of how depletion of green spaces in urban areas may jeopardize the flow of ecosystem services and associated co-benefits (Padigala 2012; Imam and Banerjee 2016).

A historic analysis of urban green spaces in Tokyo confirmed remarkable resilience, especially the ability to adjust and reconstruct to address consecutive key disturbances. UGS in Tokyo is reported to be flexible, but is an increasingly declining resource across the city. Tokyo case highlights the risks due to reduction of green spaces that are helpful in indirect recovery by accommodating development and short-term resilience (Kumagai et al. 2015). In another study in the city of Kolkata, it was detected that the small green spaces were significantly influenced by the high built-up area around them that reflected that the older Kolkata zone was vulnerable to risks, whereas the zones bordered by wetlands were the firmest having high resilience to urban risks (Bardhan et al. 2016). In another city of Asia, Karachi one of the biggest cities of Pakistan is extremely vulnerable to climate change and extreme weather events. A noteworthy decline in UGS and enhanced infrastructure buildup were reported between 1984 and 2016. Despite this, the study observed that forests around the city are capable of absorbing up to 55.4 million tons of carbon emissions stressing the need of mainstreaming UGS and BGI in urban planning (Arshad et al. 2020).

1.1.4.3 UBGI to Manage Urban Flood Risks

Urban poor settlements close to water bodies (rivulets, ponds, rivers, wetlands, and coastal areas) are getting more prone to flooding due to climate change and increasing frequency of extreme climate events (Cissé et al. 2011). Conventional urban flood management approaches have been of low sustainability; hence, there has been increasing interest and inclusion of nontraditional drainage BGI measures (Alves et al. 2018). Researchers have given enough evidence to showcase the impacts of gray engineering infrastructures that include trenches, channels, catch basins, and concrete drains that are most commonly employed for reducing urban floods. These gray engineering structures are however not effective to provide the co-benefits that are associated with NbS and UBGI (Watkin et al. 2019). In a study on indicating the demand for NbS using IPCC Risk Framework to generate flood risk carried out in Bandung City of Indonesia, it was observed that distribution of UGS in the city is not equally distributed and hence these green space locations are not capable to support resilience against the urban flood protection (Afriyanie et al. 2020). BGI implementation in Ayutthaya, Thailand, stressed the involvement of diverse stakeholders and giving importance to locally required co-benefits along with flood risk reduction (Alves et al. 2018). In another study in Semarang, Indonesia, the adoption of local BGI was found to be facilitated by following the core principles of inclusiveness, appropriateness, and proactiveness as preconditions for augmenting local resilience to urban flooding (Drosou et al. 2019). Liu et al. (2014) endorsed the benefits of UBGI through their community-scale simulation models that projected reduction of urban floods by reducing their volume and peak flow. However, the study stressed that integrated GIs will be required to reduce the intensity of impacts of larger rainstorms as single GI is not sufficient for harnessing the larger benefits (Liu et al. 2014). Identifying and managing biophysical as well as sociopolitical concerns can help to expand applied, scientifically sound, and locally supported application of BGI (Thorne et al. 2018).

1.1.5 Structure of the Book

This book volume has 23 chapters on diverse topics of BGI and is divided into 6 sections. The book volume includes a detailed introductory chapter providing background on mainstreaming of BGI for improving resilience and sustainability in the warming world by Dhyani et al. (Chap. 1). Chapter 1 covers insights on the global recognition of urban BGI followed by opportunities and constraints to implementing them. Chapter 1 also deliberates on the progress and developments on the core themes of UBGI. Part I of the book highlights “opportunities and advances” for mainstreaming BGI under the same title of the section and discusses the opportunities by implementing UBGI under six important chapters (Chaps. 1–6). Thammadi et al. (Chap. 2) present an overview on regional trends in Social-Ecological-Technological (SET) approaches to sustainable urban planning and discuss the SET approaches with an exclusive focus on Asia. Bartlett (Chap. 3) bring in the risk assessment approach in the volume to urban resilience for addressing the risk of planting trees that cannot adapt and continue to provide the services under future conditions that will be more obvious because of the changing climate and increasing urban risks. Murthy and Khalid (Chap. 4) provide an overview and relevance of citizen science initiatives for mainstreaming and promoting BGI in fast-expanding urban areas of India. This is a sought-out area of work that can potentially revolutionize the conservation of existing BGI in urban areas. The chapter by Chien et al. (Chap. 5) addresses the question if ensuring the sustainable implementation of BGI is possible. It brings in the systems thinking approach for considering and acknowledging the urban rivers as socio-ecological systems. Chapter 6 by Francis et al. elaborates on the importance and contribution of remote sensing (RS) and GIS technology and explains the growing interest in spatial maps to map and design the BGI in growing urban areas. Integration of RS and GIS tools is necessary for systematic mapping of urban green spaces and can also help in understanding the loss and gain as a key indicator of urban ecosystem health. Part II of the book under the title “Challenges and Constraints” is comprised of three chapters (Chaps. 7–9). The opening chapter in the section by Bhaskar et al. (Chap. 7) presents a case of a protected area in the peri-urban Bengaluru Metropolitan Region of South India. The chapter highlights the changing people-nature linkages around green infrastructure in rapidly urbanizing landscapes. Chapter 8 by Bhat et al. showcases the need of understanding the urban ecological risks for harnessing the benefits and co-benefits of nature-based solutions. Scandizzo and Abbasov (Chap. 9) throw light on an important question to understand if urban residents appreciate the economic value of water. The chapter presents a case of Baku City from Azerbaijan and how understanding the economic value of urban blue ecosystems and water can help urban communities to conserve them. Part III of the volume considers the importance of “multiscale environmental design for BGI.” The section covers four important chapters (Chaps. 10–13), and the opening chapter of this section is by Jayakody and Basu (Chap. 10) that uses the case of home gardens as an important multiscale environmental design which is a sustainable urban agroforestry system. Home gardens of Sri Lanka are highlighted in the chapter as a sustainable urban agroforestry system to promote urban household well-being. Kanchana C.B. in Chap. 11 of this section discusses the need for enhancing tree cover so that urban liveability can be improved and showcases this through a case of fast-expanding city of Kochi on the west coast of India. Misra and Hussain in Chap. 12 conceptualize and elaborate on remodeling urban spaces for integrating and mainstreaming the blue-green infrastructure and use the case of Guwahati a fast-expanding urban area in northeast

India. The concluding chapter of this section is by Gopalan and Radhakrishnan (Chap. 13) that talks of hidden connections between built form and life in cities. This chapter discusses how important biodiversity is for the growing urban sprawls of India and what are hidden socio-ecological connections in concrete jungles. Part IV of the book volume includes the chapters with a focus on “BGI for Sustainable Water Management.” This section has four relevant chapters (Chaps. 14–17). Chapter 14 by Kimura in Part IV discusses the potential of nature-based solutions for restoring an urban Abukuma River in Japan. After the typhoon Hagibis, it was important to explore long-term solutions to reinstate the ecological conditions for the river. Santhanam and Kundu in Chap. 15 of this section bring insight into the vulnerability of the coastal area and highlight the need to plan for and use of NbS for coastal regions. In Chap. 16, deLeon and Magcale-Macandog investigate the physical vulnerability of residential houses to flooding through a case study from the coastal area of Sta. Rosa City in Laguna, Philippines. The last chapter of this section (Chap. 17) by Suganya et al. covers the importance of degrading urban ancient water systems and sacred groves that have been a core foundation of healthy ecosystems and biodiversity conservation in these urban landscapes. Urban expansion has taken a toll on these water bodies and the remaining refuge of biodiversity. The second last section of this volume (Part V) is centered around concepts, advances, and case studies on including BGI in urban environmental risk management with the same title of the section. This section has four relevant chapters (Chapters 18–21) to address the issue. The opening chapter (Chap. 18) of the section by Kadaverugu et al. broadly addresses the potential of BGI in air pollution reduction and mitigation in fast-expanding urban sprawls. The chapter draws attention through a case of an urban expansion where BGI can be implemented and mainstreamed in urban planning for urban sustainability and resilience building. Chapter 19 by Parvin et al. covers the role of BGI in disaster risk reduction and resilience building in urban areas of Bangladesh. Das et al. in Chap. 20 stress the importance of assessing ecosystem health in urban sprawls for EcoDRR inclusive urban planning. Authors endorse and discuss the need for mainstreaming the Singapore Index or City Biodiversity Index (CBI) for improving the BGI in urban areas. Waste management and treatment is one of the most neglected areas of work in urban management. The last chapter of the section (Chap. 21) by Pham Phu et al. covers the case of greenhouse gas mitigation by integrating waste treatment systems toward the low-carbon city in Vietnam. The last section of this book volume (Part VI) is “Policy Concerns for BGI” which further comprises two pertinent chapters (Chaps. 22 and 23). Chapter 22 by Chiang et al. addresses the relevance of nongovernmental actors in facilitating the inclusion and mainstreaming of BGI. Citing an example from Taipei City of Taiwan in Northeast Asia, it provides a comparative overview of the community initiatives for mainstreaming BGI. The last and concluding chapter (Chap. 23) by Ramananda et al. addresses the relevance of mainstreaming BGI in urban policy planning to positively contribute to SDG 11 that is mostly missing from developing and underdeveloped countries in Asia. The chapter stresses facilitating new pathways for localizing and achieving SDG 11 that is interconnected with so many other SDGs as a transformative approach in urban sustainability and resilient building. Through this book volume, editors, as well as authors, expect a satisfactory response and if also possible feedback from readers belonging to diverse backgrounds and fields for encouraging productive critiques that facilitates intuitive and foresighted professional discussions for mainstreaming BGI in urban areas and identification of new research issues to fill the existing gaps.

Acknowledgments The authors are grateful to Knowledge Resource Centre (KRC) CSIR-NEERI for extending help for using software iThenticate under the number CSIR-NEERI/KRC/2021/NOV/WTMD/3 for avoiding plagiarism.

Conflict of Interest Statement The authors report no conflict of interest for this publication.

References

Abass F, Ismail LH, Wahab IA, Elgadi AA (2020) A review of green roof: definition, history, evolution and functions. IOP Conf Ser: Mater Sci Eng 713:012048. https://doi.org/10.1088/1757-899X/713/1/012048

Afriyanie D, Julian MM, Riqqi A et al (2020) Re-framing urban green spaces planning for flood protection through socio-ecological resilience in Bandung City, Indonesia. Cities 101:102710. https://doi.org/10.1016/j.cities.2020.102710

Aldunce P, Bórquez R, Adler C et al (2016) Unpacking resilience for adaptation: incorporating practitioners' experiences through a transdisciplinary approach to the case of drought in Chile. Sustainability 8:905. https://doi.org/10.3390/su8090905

Alves A, Patiño Gómez J, Vojinovic Z et al (2018) Combining co-benefits and stakeholders perceptions into green infrastructure selection for flood risk reduction. Environments 5:29. https://doi.org/10.3390/environments5020029

Andersson E, Borgström S, McPhearson T (2017) Double insurance in dealing with extremes: ecological and social factors for making nature-based solutions last. In: Kabisch N, Korn H, Stadler J, Bonn A (eds) Nature-based solutions to climate change adaptation in urban areas: linkages between science, policy and practice. Springer International Publishing, Cham, pp 51–64

Antoszewski P, Świerk D, Krzyżaniak M (2020) Statistical review of quality parameters of blue-green infrastructure elements important in mitigating the effect of the urban Heat Island in the temperate climate (C) zone. Int J Environ Res Public Health 17:7093. https://doi.org/10.3390/ijerph17197093

Armson D, Stringer P, Ennos AR (2013) The effect of street trees and amenity grass on urban surface water runoff in Manchester, UK. Urban For Urban Green 12:282–286. https://doi.org/10.1016/j.ufug.2013.04.001

Arshad A, Ashraf M, Sundari RS et al (2020) Vulnerability assessment of urban expansion and modelling green spaces to build heat waves risk resiliency in Karachi. Int J Disaster Risk Reduct 46:101468. https://doi.org/10.1016/j.ijdrr.2019.101468

Baird JB, Winston RJ, Hunt WF (2020) Evaluating the hydrologic and water quality performance of novel infiltrating wet retention ponds. Blue-Green Syst 2:282–299. https://doi.org/10.2166/bgs.2020.010

Bardhan R, Debnath R, Bandopadhyay S (2016) A conceptual model for identifying the risk susceptibility of urban green spaces using geo-spatial techniques. Model Earth Syst Environ 2:144. https://doi.org/10.1007/s40808-016-0202-y

Bennett EM, Cramer W, Begossi A et al (2015) Linking biodiversity, ecosystem services, and human well-being: three challenges for designing research for sustainability. Curr Opin Environ Sustain 14:76–85. https://doi.org/10.1016/j.cosust.2015.03.007

Borie M, Pelling M, Ziervogel G, Hyams K (2019) Mapping narratives of urban resilience in the global south. Glob Environ Chang 54:203–213. https://doi.org/10.1016/j.gloenvcha.2019.01.001

Calfapietra C, Barbati A, Perugini L et al (2015) Carbon mitigation potential of different forest ecosystems under climate change and various managements in Italy. Ecosyst Health Sustain 1:1–9. https://doi.org/10.1890/EHS15-0023

Calheiros CSC, Stefanakis AI (2021) Green roofs towards circular and resilient cities. CircEconSust 1:395–411. https://doi.org/10.1007/s43615-021-00033-0

Cissé G, Koné B, Bâ H et al (2011) Ecohealth and climate change: adaptation to flooding events in riverside secondary cities, West Africa. In: Otto-Zimmermann K (ed) Resilient cities. Springer Netherlands, Dordrecht, pp 55–67

Coaffee J, Clarke J (2015) On securing the generational challenge of urban resilience. Town Plan Rev 86:249–255

Connop S, Vandergert P, Eisenberg B et al (2016) Renaturing cities using a regionally-focused biodiversity-led multifunctional benefits approach to urban green infrastructure. Environ Sci Pol 62:99–111

de Oliveira FL, Mell I (2019) Planning cities with nature: theories, strategies and methods. Springer, Cham, Switzerland

Depietri Y, McPhearson T (2017) Integrating the grey, green, and blue in cities: nature-based solutions for climate change adaptation and risk reduction. In: Kabisch N, Korn H, Stadler J, Bonn A (eds) Nature-based solutions to climate change adaptation in urban areas: linkages between science, policy and practice. Springer, Cham, pp 91–109

Dhyani S, Thummarukuddy M (2016) Ecological engineering for disaster risk reduction and climate change adaptation. Environ Sci Pollut Res 23:20049–20052. https://doi.org/10.1007/s11356-016-7517-0

Dhyani S, Lahoti S, Khare S et al (2018) Ecosystem based disaster risk reduction approaches (EbDRR) as a prerequisite for inclusive urban transformation of Nagpur City, India. Int J Disaster Risk Reduct 32:95–105. https://doi.org/10.1016/j.ijdrr.2018.01.018

Dhyani S, Karki M, Gupta AK (2020) Opportunities and advances to mainstream nature-based solutions in disaster risk management and climate strategy. In: Dhyani S, Gupta AK, Karki M (eds) Nature-based solutions for resilient ecosystems and societies. Springer, Singapore, pp 1–26

Dhyani S, Majumdar R, Santhanam H (2021a) Scaling-up nature-based solutions for mainstreaming resilience in Indian cities. In: Mukherjee M, Shaw R (eds) Ecosystem-based disaster and climate resilience: integration of blue-green infrastructure in sustainable development. Springer, Singapore, pp 279–306

Dhyani S, Singh A, Gujre N, Joshi RK (2021b) Quantifying tree carbon stock in historically conserved Seminary Hills urban forest of Nagpur, India. Acta Ecol Sin 41:193–203. https://doi.org/10.1016/j.chnaes.2021.01.006

Drosou N, Soetanto R, Hermawan F et al (2019) Key factors influencing wider adoption of blue–green infrastructure in developing cities. Water 11:1234. https://doi.org/10.3390/w11061234

Du H, Liu D, Lu Z et al (2019) Research development on sustainable urban infrastructure from 1991 to 2017: a bibliometric analysis to inform future innovations. Earth's Future 7:718–733. https://doi.org/10.1029/2018EF001117

Ekka SA, Rujner H, Leonhardt G et al (2021) Next generation swale design for stormwater runoff treatment: a comprehensive approach. J Environ Manag 279:111756. https://doi.org/10.1016/j.jenvman.2020.111756

Elmqvist T, Andersson E, Frantzeskaki N et al (2019) Sustainability and resilience for transformation in the urban century. Nat Sustain 2:267–273. https://doi.org/10.1038/s41893-019-0250-1

Evans AJ, Firth LB, Hawkins SJ et al (2019) From ocean sprawl to blue-green infrastructure – a UK perspective on an issue of global significance. Environ Sci Pol 91:60–69. https://doi.org/10.1016/j.envsci.2018.09.008

Everett G, Lamond JE, Morzillo AT et al (2018) Delivering green streets: an exploration of changing perceptions and behaviours over time around bioswales in Portland, Oregon. J Flood Risk Manag 11:S973–S985. https://doi.org/10.1111/jfr3.12225

Fenner R (2017) Spatial evaluation of multiple benefits to encourage multi-functional design of sustainable drainage in blue-green cities. Water 9:953. https://doi.org/10.3390/w9120953

García Sánchez F, Solecki WD, Ribalaygua Batalla C (2018) Climate change adaptation in Europe and the United States: a comparative approach to urban green spaces in Bilbao and New York City. Land Use Policy 79:164–173. https://doi.org/10.1016/j.landusepol.2018.08.010

Garschagen M, Kraas F (2011) Urban climate change adaptation in the context of transformation: lessons from Vietnam. In: Otto-Zimmermann K (ed) Resilient cities. Springer Netherlands, Dordrecht, pp 131–139

Giannakis E, Bruggeman A, Poulou D et al (2016) Linear parks along urban rivers: perceptions of thermal comfort and climate change adaptation in cyprus. Sustain For 8:1023. https://doi.org/10.3390/su8101023

Gleeson B (2008) Critical commentary. Waking from the dream: an Australian perspective on urban resilience. Urban Stud 45:2653–2668. https://doi.org/10.1177/0042098008098198

Govindarajulu D (2014) Urban green space planning for climate adaptation in Indian cities. Urban Clim 10. https://doi.org/10.1016/j.uclim.2014.09.006

Hamel P, Tan L (2021) Blue–green infrastructure for flood and water quality management in southeast Asia: evidence and knowledge gaps. Environ Manag. https://doi.org/10.1007/s00267-021-01467-w

Hordijk M, Baud I (2011) Inclusive adaptation: linking participatory learning and knowledge management to urban resilience. In: Otto-Zimmermann K (ed) Resilient cities. Springer Netherlands, Dordrecht, pp 111–121

Imam AUK, Banerjee UK (2016) Urbanisation and greening of Indian cities: problems, practices, and policies. Ambio 45:442–457. https://doi.org/10.1007/s13280-015-0763-4

Imran HM, Akib S, Karim MR (2013) Permeable pavement and stormwater management systems: a review. Environ Technol 34:2649–2656. https://doi.org/10.1080/09593330.2013.782573

Kamali M, Delkash M, Tajrishy M (2017) Evaluation of permeable pavement responses to urban surface runoff. J Environ Manag 187:43–53. https://doi.org/10.1016/j.jenvman.2016.11.027

Katzschner L (2011) Urban climate strategies against future heat stress conditions. In: Otto-Zimmermann K (ed) Resilient cities. Springer Netherlands, Dordrecht, pp 79–89

Kayhanian M, Li H, Harvey JT, Liang X (2019) Application of permeable pavements in highways for stormwater runoff management and pollution prevention: California research experiences. Int J Transp Sci Technol 8:358–372. https://doi.org/10.1016/j.ijtst.2019.01.001

Khusna NI, Amin S, Sekarrini CE (2020) The effect of using biopore on flood reduction in district of Besuki, Tulungagung Regency

Kumagai Y, Gibson RB, Filion P (2015) Evaluating long-term urban resilience through an examination of the history of green spaces in Tokyo. Local Environ 20:1018–1039. https://doi.org/10.1080/13549839.2014.887060

Kusumastuti D, Jokowinarno D, Khotimah S, Dewi C (2017) The use of infiltration wells to reduce the impacts of land use changes on flood peaks: an Indonesian catchment case study. Pertanika J Sci Technol 25:407–424

Lahoti S, Lahoti A, Saito O (2019) Benchmark assessment of recreational public urban green space provisions: a case of typical urbanizing Indian City. ScienceDirect, Nagpur

Lamond J, Everett G (2019) Sustainable blue-green infrastructure: a social practice approach to understanding community preferences and stewardship. Landsc Urban Plan 191:103639. https://doi.org/10.1016/j.landurbplan.2019.103639

Li WC, Yeung KKA (2014) A comprehensive study of green roof performance from environmental perspective. Int J Sustain Built Environ 3:127–134. https://doi.org/10.1016/j.ijsbe.2014.05.001

Li X, Li J, Fang X, et al (2016) Case studies of the sponge city program in China. 295–308. https://doi.org/10.1061/9780784479858.031

Liao K-H, Deng S, Tan PY (2017) Blue-green infrastructure: new frontier for sustainable urban stormwater management. In: Tan PY, Jim CY (eds) Greening cities: forms and functions. Springer, Singapore, pp 203–226

Licata M, Gennaro MC, Tuttolomondo T et al (2019) Research focusing on plant performance in constructed wetlands and agronomic application of treated wastewater – a set of experimental studies in Sicily (Italy). PLoS One 14:e0219445. https://doi.org/10.1371/journal.pone.0219445

Liu W, Chen W, Peng C (2014) Assessing the effectiveness of green infrastructures on urban flooding reduction: a community scale study. Ecol Model 291:6–14. https://doi.org/10.1016/j.ecolmodel.2014.07.012

Liu Y, Li T, Peng H (2018) A new structure of permeable pavement for mitigating urban heat island. Sci Total Environ 634:1119–1125. https://doi.org/10.1016/j.scitotenv.2018.04.041

Liu Z, Xiu C, Ye C (2020) Improving urban resilience through green infrastructure: an integrated approach for connectivity conservation in the Central City of Shenyang, China. Complexity 2020:e1653493. https://doi.org/10.1155/2020/1653493

Majidi AN, Vojinovic Z, Alves A et al (2019) Planning nature-based solutions for urban flood reduction and thermal comfort enhancement. Sustainability 11:6361. https://doi.org/10.3390/su11226361

Makido Y, Hellman D, Shandas V (2019) Nature-based designs to mitigate urban heat: the efficacy of green infrastructure treatments in Portland, Oregon. Atmos 10:282. https://doi.org/10.3390/atmos10050282

Makopondo ROB, Rotich LK, Kamau CG (2020) Potential use and challenges of constructed wetlands for wastewater treatment and conservation in game lodges and resorts in Kenya. Sci World J 2020:e9184192. https://doi.org/10.1155/2020/9184192

Malaviya P, Sharma R, Sharma PK (2019) Rain gardens as Stormwater management tool. In: Shah S, Venkatramanan V, Prasad R (eds) Sustainable green technologies for environmental management. Springer, Singapore, pp 141–166

Masnavi MR, Gharai F, Hajibandeh M (2019) Exploring urban resilience thinking for its application in urban planning: a review of literature. Int J Environ Sci Technol 16:567–582. https://doi.org/10.1007/s13762-018-1860-2

Mathey J, Rößler S, Lehmann I, Bräuer A (2011) Urban green spaces: potentials and constraints for urban adaptation to climate change. In: Otto-Zimmermann K (ed) Resilient cities. Springer Netherlands, Dordrecht, pp 479–485

Meerow S, Newell JP (2019) Urban resilience for whom, what, when, where, and why? Urban Geogr 40:309–329. https://doi.org/10.1080/02723638.2016.1206395

Metcalfe CD, Nagabhatla N, Fitzgerald SK (2018) Multifunctional wetlands: pollution abatement by natural and constructed wetlands. In: Nagabhatla N, Metcalfe CD (eds) Multifunctional wetlands: pollution abatement and other ecological services from natural and constructed wetlands. Springer, Cham, pp 1–14

Mukherjee M, Takara K (2018) Urban green space as a countermeasure to increasing urban risk and the UGS-3CC resilience framework. Int J Disaster Risk Reduct 28:854–861. https://doi.org/10.1016/j.ijdrr.2018.01.027

Ncube S, Arthur S (2021) Influence of blue-green and grey infrastructure combinations on natural and human-derived capital in Urban Drainage Planning. Sustainability 13:2571. https://doi.org/10.3390/su13052571

Ni'mah NM, Lenonb S (2017) Urban greenspace for resilient city in the future: case study of Yogyakarta City. IOP Conf Ser Earth Environ Sci 70:012058. https://doi.org/10.1088/1755-1315/70/1/012058

Nowak DJ, Greenfield EJ, Hoehn RE, Lapoint E (2013) Carbon storage and sequestration by trees in urban and community areas of the United States. Environ Pollut 178:229–236. https://doi.org/10.1016/j.envpol.2013.03.019

O'Donnell EC, Woodhouse R, Thorne CR (2018) Evaluating the multiple benefits of a sustainable drainage scheme in Newcastle, UK. Proc Inst Civ Eng Water Manag 171:191–202. https://doi.org/10.1680/jwama.16.00103
O'Donnell EC, Netusil NR, Chan FKS et al (2021) International perceptions of urban blue-green infrastructure: a comparison across four cities. Water 13:544. https://doi.org/10.3390/w13040544
Padigala B (2012) Urbanization and changing green spaces in Indian cities (Case study – city of Pune). Int J Geol Earth Environ Sci 2:148–156
Pamukcu-Albers P, Ugolini F, La Rosa D et al (2021) Building green infrastructure to enhance urban resilience to climate change and pandemics. Landsc Ecol 36:665–673. https://doi.org/10.1007/s10980-021-01212-y
Perez G, Perini K (2018) Nature based strategies for urban and building sustainability. Butterworth-Heinemann, Oxford
Pudifoot B, Cárdenas ML, Buytaert W et al (2021) When it rains, it pours: integrating citizen science methods to understand resilience of urban green spaces. Front Water 3:33. https://doi.org/10.3389/frwa.2021.654493
Raymond CM, Frantzeskaki N, Kabisch N et al (2017) A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. Environ Sci Pol 77:15–24. https://doi.org/10.1016/j.envsci.2017.07.008
Reynolds CC, Escobedo FJ, Clerici N, Zea-Camaño J (2017) Does "greening" of neotropical cities considerably mitigate carbon dioxide emissions? The case of Medellin, Colombia. Sustainability 9:785. https://doi.org/10.3390/su9050785
Romero-Lankao P, Gnatz DM, Wilhelmi O, Hayden M (2016) Urban sustainability and resilience: from theory to practice. Sustainability 8:1224. https://doi.org/10.3390/su8121224
Romolini M, Bixler RP, Grove JM (2016) A social-ecological framework for urban stewardship network research to promote sustainable and resilient cities. Sustainability 8:956. https://doi.org/10.3390/su8090956
Rousseau DPL (2018) Full-scale applications of constructed wetlands in Africa. In: Artificial or constructed wetlands, 2nd edn. CRC Press, Boca Raton, FL
Santhanam H, Majumdar R (2020) Permeable pavements as sustainable nature-based solutions for the management of Urban Lake Ecosystems. In: Dhyani S, Gupta AK, Karki M (eds) Nature-based solutions for resilient ecosystems and societies. Springer, Singapore, pp 329–345
Scharenbroch BC, Morgenroth J, Maule B (2016) Tree species suitability to bioswales and impact on the urban water budget. J Environ Qual 45:199–206. https://doi.org/10.2134/jeq2015.01.0060
Shafique M, Kim R, Kyung-Ho K (2018) Green roof for stormwater management in a highly urbanized area: the case of Seoul, Korea. Sustainability 10:584. https://doi.org/10.3390/su10030584
Shen L, Shuai C, Jiao L et al (2016) A global perspective on the sustainable performance of urbanization. Sustainability 8:783. https://doi.org/10.3390/su8080783
Sidek LM, Muha NE, Noor NAM, Basri H (2013) Constructed rain garden systems for stormwater quality control under tropical climates. IOP Conf Ser: Earth Environ Sci 16:012020. doi: https://doi.org/10.1088/1755-1315/16/1/012020
Staddon C, Ward S, De Vito L et al (2018) Contributions of green infrastructure to enhancing urban resilience. Environ Syst Decis 38:330–338. https://doi.org/10.1007/s10669-018-9702-9
Stefanakis AI (2016) Constructed wetlands: description and benefits of an eco-tech water treatment system. Impact of water pollution on human health and environmental sustainability. https://www.igi-global.com/chapter/constructed-wetlands/www.igi-global.com/chapter/constructed-wetlands/140180. Accessed 7 Jul 2021
Suárez M, Manuel BFD, Méndez-Fernández L et al (2018) Nature-based solutions and resilience as complementary strategies for urban governance and planning: a review of assessment methodologies 1. https://doi.org/10.3390/ifou2018-05959
Tan PY, Jim CY (2017) Greening cities: forms and functions. Springer, Singapore

Thorne CR, Lawson EC, Ozawa C et al (2018) Overcoming uncertainty and barriers to adoption of blue-green infrastructure for urban flood risk management. J Flood Risk Manag 11:S960–S972. https://doi.org/10.1111/jfr3.12218

Tusinski O, Balbo A (2011) Introduction: frameworks for local action – challenges and proactive recommendations. In: Otto-Zimmermann K (ed) Resilient cities. Springer Netherlands, Dordrecht, pp 109–110

Valente de Macedo LS, Barda Picavet ME, Puppim de Oliveira JA, Shih W-Y (2021) Urban green and blue infrastructure: a critical analysis of research on developing countries. J Clean Prod 313: 127898. https://doi.org/10.1016/j.jclepro.2021.127898

Vargas-Hernández JG, Zdunek-Wielgołaska J (2021) Urban green infrastructure as a tool for controlling the resilience of urban sprawl. Environ Dev Sustain 23:1335–1354. https://doi.org/10.1007/s10668-020-00623-2

Viecco M, Vera S, Jorquera H et al (2018) Potential of particle matter dry deposition on green roofs and living walls vegetation for mitigating urban atmospheric pollution in semiarid climates. Sustainability 10:2431. https://doi.org/10.3390/su10072431

Vijayaraghavan K (2016) Green roofs: a critical review on the role of components, benefits, limitations and trends. Renew Sust Energ Rev 57:740–752. https://doi.org/10.1016/j.rser.2015.12.119

Watkin LJ, Ruangpan L, Vojinovic Z et al (2019) A framework for assessing benefits of implemented nature-based solutions. Sustainability 11:6788. https://doi.org/10.3390/su11236788

Wilhelm M (2011) The role of community resilience in adaptation to climate change: the urban poor in Jakarta, Indonesia. In: Otto-Zimmermann K (ed) Resilient cities. Springer Netherlands, Dordrecht, pp 45–53

Yao X, Zhao M, Escobedo FJ (2017) What causal drivers influence carbon storage in Shanghai, China's Urban and Peri-Urban forests? Sustain For 9:577. https://doi.org/10.3390/su9040577

Zevenbergen C, Fu D, Pathirana A (2018) Transitioning to sponge cities: challenges and opportunities to address urban water problems in China. Water 10:1230. https://doi.org/10.3390/w10091230

Zhang X, Li H (2018) Urban resilience and urban sustainability: what we know and what do not know? Cities 72:141–148. https://doi.org/10.1016/j.cities.2017.08.009

Zhang S, Zevenbergen C, Rabé P, Jiang Y (2018) The influences of sponge city on property values in Wuhan, China. Water 10:766. https://doi.org/10.3390/w10060766

Zheng D, Ducey MJ, Heath LS (2013) Assessing net carbon sequestration on urban and community forests of northern New England, USA. Urban For Urban Green 12:61–68. https://doi.org/10.1016/j.ufug.2012.10.003

Ziervogel G, Cowen A, Ziniades J (2016) Moving from adaptive to transformative capacity: building foundations for inclusive, thriving, and regenerative urban settlements. Sustainability 8:955. https://doi.org/10.3390/su8090955

Shalini Dhyani is a Senior Scientist at Critical Zone Group (CZO) of Water Technology and Management Division (WT&MD), CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur, India.

Sunidhi Singh is a Researcher and Project Associate at Critical Zone Group (CZO) of Water Technology and Management Division (WT&MD), CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur, India.

Mrittika Basu is an Assistant Professor in the Laboratory of Sustainable Rural Development, Graduate School of Global Environmental Studies, Kyoto University, Japan.

Rajarshi Dasgupta is a Senior Policy Researcher in the Institute for Global Environmental Strategies (IGES), Kanagawa, Japan.

Harini Santhanam is an environmental scientist working as an Assistant Professor with the School of Natural Sciences and Engineering at the National Institute of Advanced Studies (NIAS), Bengaluru, India.