Shalini Dhyani
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# Blue-Green Infrastructure Across Asian Countries

## Improving Urban Resilience and Sustainability

Springer

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# Foreword

Cities are expanding and so are the number of people inhabiting these cities. Following the current trend, the global urban population is expected to be 70% or 6.3 billion by 2050, nearly doubling up from the urban population in 2010, i.e. 3.5 billion. This increase will not only be concentrated in megacities, but also across small- and medium-sized cities across the world. Pressure on the urban resources is anticipated to increase manifold including, but not limited to, depleting green and blue spaces, water scarcity, air pollution, urban heat islands, increasing disaster risks, noise pollution, waste dumping, etc. Maintaining a healthy and habitable urban life is one of the major challenges facing the *Anthropocene*.

There have been quite a few studies on urban infrastructural facilities like transportation systems, wastewater treatment, solid waste disposal, water supply, electricity supply and urban settlements. On the other hand, urban ecological infrastructures like open spaces, parks, waterbodies, urban wetlands, etc., collectively referred to as 'Blue-Green Infrastructure' (BGI), are the first prey to urban expansion and, yet they fail to get ample attention. Though much has been written about the benefits provided by urban ecosystems, development of new blue-green infrastructures and their mainstreaming in urban policy planning is yet to be realized, especially in the Global South. This book *Blue-Green Infrastructure Across Asian Countries—Improving Urban Resilience and Sustainability* fills up this gap impeccably. The book clearly exemplifies the importance of the Blue-Green Infrastructures through various case studies across different Asian countries and suggests convincing ways to mainstream this infrastructure in urban policy planning.

This book not only explores the benefits and challenges of Blue-Green Infrastructures, but also explores the different advances that can be adopted like citizen science initiatives, spatial planning and socio-ecological technological approaches to monitor and implement them. Different environmental designs are proposed for the inclusion of Blue-Green Infrastructures in urban settings. For example, home gardens of Sri Lanka delineate the multifunctional role of ecological infrastructures and present a unique design where both blue- and green-infrastructures can be designed together at a relatively smaller space. The different environmental designs presented in this book provide an opportunity to replicate them to include in other urban areas with some modifications, if needed.

Blue infrastructures in urban areas find a special place in this book. Very little information on urbanization impacts on blue infrastructures is available except for spatial maps that show the shrinkage in urban waterbodies. Starting from the ancient waterbodies in India to nature-based solutions for marine and coastal ecosystems to alleviating the impacts of disasters like flood, the role of blue infrastructures is explored in detail and their implementation discussed. The book opens up new avenues of research on the roles of blue infrastructure that will ameliorate the quality of life of urban dwellers. Likewise, case studies on the importance of EcoDRR demonstrate the role of Blue-Green Infrastructure in urban resilience building and disaster risk mitigation.

Considering the urban complexities and uncertainties, it is timely and important to explore alternative interventions for a sustainable urban future, as detailed in this book. The book not only quantifies and explores the importance of Blue-Green Infrastructure, but also suggests on mainstreaming it in the urban policy planning process which will eventually help in implementing the ecological infrastructures. Academicians, policy planners, city planners, local communities and both local government and non-governmental agencies will find this book helpful as the book delivers an integrated knowledge on Blue-Green Infrastructure and makes a valuable contribution towards building a sustainable and resilient urban future.

I congratulate the authors for presenting diverse concepts, cases and novel approaches on the subject that are relevant for diverse stakeholders including urban planners and policy makers. I also warmly congratulate the editors: Shalini Dhyani, Mrittika Basu, Harini Santhanam and Rajarshi Dasgupta—for their timely efforts to produce this insightful volume of concepts, innovations and case studies. This book is an important and timely contribution to the knowledge pool of urban ecosystems, nature-based solutions, disaster risk reduction and climate change adaptations. Readers will be highly benefited from the insightful chapter content and analysis presented in this book. I wish the editors and authors all success in their endeavour.

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Geneva, Switzerland

Muralee Thummarukudy

# Acknowledgements

Putting together a book on a relatively futuristic topic of *Blue-Green Infrastructure Across Asian Countries: Improving Urban Resilience and Sustainability* would not have been possible without the constant support, contributions, perseverance and dedication of expert authors. We are enormously grateful to many subject experts, scientists and researchers who volunteered their precious and busy time out of their heavily engaged academic involvements and helped to critically review the book chapters. We truly appreciate their cooperation and good understanding in meeting our rather strict paper submissions and review deadlines. Many of our supporters deserve special appreciation. We sincerely thank the Director CSIR-NEERI, Nagpur, for the valuable support during the preparation of this book. We are grateful to many of our very hard working and supportive research scholars without whose critical support our efforts alone would not have been enough to bring out this book in time. We specially thank Ms. Sunidhi Singh for her keeping record of all the email communications and attachments and Ms. Kavita Bramhanwade for her help in overseeing formatting and language correction to avoid major mistakes. Finally, the production team members of Springer deserve special appreciation for guiding us through the process of publishing this work. Despite our best efforts to avoid any mistake, it is, however, possible that a very few errors, may be grammatical in nature, remain owing to the fast pace of production and strict timelines we had to adhere to. Each individual chapter included in this book was finalized with the primary responsibility of author and co-authors. The editors have gone through all the chapters included and reviewed them personally as well, with careful scrutiny following international standards including ethics of publication. We shall be immensely grateful to receive constructive comments and suggestions from readers of this book for further improvement of our publications in future. Any errors found in this book are the collective responsibility of the chapter authors and of the editors. Last but not least, we thank our family members, especially our parents, spouses and children, for their understanding, adjustments, patience and encouragement to continue and complete this mammoth task well in time.

In closing, we express our gratitude to Dr. Muralee Thummarukudy, Chief, UNEP, for writing the foreword for this book.

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**Part V BGI for Environmental Risk Management**



**Part VI Policy Concerns for BGI**

# About the Editors

**Shalini Dhyani** is a Senior Scientist in the Critical Zone Research Group of the Water Technology and Management Division at CSIR-NEERI, India. She is South Asia regional chair for IUCN-CEM (Commission on Ecosystems Management) and also serves as the lead author for IPBES Sustainable Use of Wild Species Assessment (2018–2021). She is a skilled ecologist with more than 17 years of strong experience in environmental impact assessment, ecosystem health assessment, climate change impact on natural ecosystems and species, nature-based solutions, climate-sensitive restoration and sustainability projects. She has extensively worked on the interlinkages between ecological, human and social systems through sustainability science approaches. Her research interest focuses on science-policy integration for better biodiversity and ecosystem-inclusive decision-making for impact assessment, sustainable development and disaster risk reduction. In the last few years, she has also contributed to assess the importance, threats and opportunities in fast expanding urban areas and mainstreaming blue-green infrastructure for ensuring urban resilience and sustainability. She has been involved in the gender task force of IUCN and has also helped to develop governance pathways for intergenerational partnerships in conservation. She was awarded first "IUCN-CEM Chair Young Professional Award" at the IUCN World Parks Congress 2014 in Sydney, Australia, for her excellent research and publications on forests of the Himalayan region. She is recipient of various national as well as international financial grants, viz. Indo-Italian joint bilateral research grant, Indo-Japan multilateral grant from APN, UNEP, GIZ, FAO, IUCN, UNU, European Union-LEANES, Rufford SGP and DST. She has more than 60 peer-reviewed national and international publications with many popular articles to her credit.

**Mrittika Basu** is an Assistant Professor in the Laboratory of Sustainable Rural Development, Graduate School of Global Environmental Studies (GSGES), Kyoto University, Japan. Prior to this position, she was a UNU-JSPS postdoctoral fellow in the United Nations University Institute for the Advanced Study of Sustainability (UNU-IAS), Tokyo. Her research mainly focused on understanding the change in ecosystem services, relational values and well-being among peri-urban communities affected by rapid urbanization and industrial development. She has also been a contributing author (CA) in the IPBES Global Assessment Report (2015–2018).

Currently, she is leading a project on migration decision-making in salinity-affected areas of Bangladesh and India (2020–2022), funded by Asia Pacific Network (APN) for Global Change Research. Apart from this, she is working on assessing nature connectedness and biophilia assessment among school children in India and Japan. Her research interests include, but not limited to, water ecosystem services, water resources management, ecosystem values and services and human–nature relations. She has published several peer-reviewed scientific papers in international journals.

**Harini Santhanam** is an Assistant Professor with the National Institute of Advanced Studies, Bangalore, India, studying multiple aspects of natural lake systems such as biogeochemistry, hydro-geological processes and land-water-human nexus from an ecosystem perspective. She has been a long-term researcher with IISc Bangalore, working in multidisciplinary teams with a focus on analytical and modelling techniques, with implications towards influencing management measures for the resource base. Recently, she led an investigation of the hydrochemistry of Pulicat Lake in detail, as the principal investigator of a DST-funded Women Scientists project (2015–2018) at IISc. She was awarded the National Doctoral Fellowship from AICTE, India (2004–2008). Her research interests are largely multidisciplinary, bringing together the insights from aquatic biogeochemistry (especially on themes like trophic status and ecosystem indices), geomatics-based integrative modelling, paleo-ecological reconstructions and investigating the anthropogenic influence on the recycling of nutrients through the aquatic food web, among others. Her work also encompasses the development and application of novel environmental proxies and indices. Further, she investigates the challenges towards sustainable development of urban lake environments and models the lake–land interactions from the perspective of urban blue-green infrastructure development and adopting nature-based solutions for enhancing urban resilience. She has more than 20 publications in national and international journals and conferences.

**Rajarshi Dasgupta** is a Senior Researcher in the domain of natural resource and ecosystem services at the Institute for Global Environmental Strategies (IGES), Kanagawa, Japan. He holds diverse research interests in the field of landscape ecology and planning, which include Ecosystem-based Disaster Risk Reduction (Eco-DRR), spatial quantification of ecosystem services, land change simulation, development of socio-ecological scenarios, participatory conservation and social forestry. Earlier, he has worked extensively with mangrove communities in India, Bangladesh and Myanmar. Prior to joining IGES, he was working with the University of Tokyo as the Japan Society for the Promotion of Science (JSPS) postdoctoral fellow in the Graduate School of Agriculture and Life Sciences. Previously, he has worked in multiple technical and administrative capacities, including government, NGO and academia, and also served as a lead author (LA) for IPBES Asia-Pacific Regional Assessment Report. He is currently serving as the lead author for IPBES Sustainable Use of Wild Species Assessment (2018–2021), as chapter scientist/ contributing author of IPCC AR-6 (WG-II) and as a visiting associate professor in the Institute for Future Initiatives, University of Tokyo.

# Abbreviations

| | |
|---|---|
| ABC | Active, Beautiful, Clean Waters |
| ACB | ASEAN Centre for Biodiversity |
| ACCCRN | Asian Cities Climate Change Resilience Network |
| ADB | Asian Development Bank |
| AIIMS | All India Institute of Medical Sciences |
| ALI | Advanced Land Imager |
| ALOS- PALSAR | Advanced Land Observing Satellite- Phased Array type L-band Synthetic Aperture Radar |
| AMRUT | Atal Mission for Rejuvenation and Urban Transformation |
| AMS | Accelerator Mass Spectrometry |
| ANOVA | Analysis of Variance |
| AQI | Air Quality Index |
| AQMS | Air Quality Management System |
| ASDMA | Assam State Disaster Management Authority |
| ASTER | Advanced Spaceborne Thermal Emission and Reflector Radiometer |
| ATLAS | Advanced Topographic Laser Altimeter System |
| AZN | Currency of Azerbaijan: Azerbaijani Manat |
| B | Balancing loop |
| BAU | Business As Usual |
| BBA | Blue to Built-up Area |
| BDA | Bengaluru Development Authority |
| BGI | Blue-Green Infrastructure |
| BMCs | Biodiversity Management Committees |
| BMPs | Best Management Practices |
| BOD | Biological Oxygen Demand |
| C | Carbon |
| CALABARZON | Cavite, Laguna, Batangas, Rizal, Quezon |
| CAS | Climate Adaptation Summit |
| CBA | Community-Based Adaptation |
| CBD | Convention on Biodiversity |
| CBI | City Biodiversity Index |
| CCA | Climate Change Adaptation |

| | |
|---|---|
| CCBA | Climate Community and Biodiversity Alliance |
| CCC | Chittagong City Corporation |
| CDA | Chittagong Development Authority |
| CDD | Cooling Degree Days |
| CER-GI-CON | Ceramic-Galvanized Iron-Concrete |
| CER-GI-WD | Ceramic-Galvanized Iron-Wood |
| CER-LS-MXD | Ceramic-Long Span-Mixed Materials |
| CER-TEG-CON | Ceramic-Tegula-Concrete |
| CFD | Computational Fluid Dynamics |
| C-HED | Centre for Heritage, Environment and Development |
| CICES | Common International Classification of Ecosystem Services |
| CIS | Coupled Infrastructure System |
| Cl | Chlorine |
| CLD | Causal Loop Diagrams |
| $CO_2$ | Carbon Dioxide |
| COD | Chemical Oxygen Demand |
| CON-GI-CON | Concrete-Galvanized Iron-Concrete |
| CON-GI-WD | Concrete-Galvanized Iron-Wood |
| CON-TEG-BR | Concrete-Tegula-Brick |
| CON-TEG-CON | Concrete-Tegula-Concrete |
| COP | Conference of the Parties |
| CPCB | Central Pollution Control Board |
| CSO | Combined Sewer Overflow |
| CSO | Civil Society Organisation |
| CV | Contingent Valuation |
| CWs | Constructed Wetlands |
| DADP | Detailed Area Development Planning |
| DAP | Detailed Area Plan |
| DEM | Digital Elevation Model |
| DMDP | Dhaka Metropolitan Development Plan |
| DN | Digital Numbers |
| DO | Dissolved Oxygen |
| DPSIR | Driver Pressure State Impact Response Framework |
| DRM | Disaster Risk Management |
| DRR | Disaster Risk Reduction |
| DSM | Digital Surface Models |
| DSP | Dolphin Space Programme |
| EAF | Ecosystem Approach to Fisheries |
| EbDRR | Ecosystem-based Disaster Risk Reduction approaches |
| EBM | Ecosystem-Based Management |
| EMR | Electro Magnetic Radiation |
| EnMAP | Environmental Mapping and Analysis Program |
| ENPHO | Environmental Public Health Organization |
| ERI | Ecological Risk Index |
| ESS | Ecosystem Services |

| | |
|---|---|
| ESZ | Eco-Sensitive Zone |
| ETM | Enhanced Thematic Mapper |
| EV | Egyptian Vultures |
| EWS | Early Warning System |
| FAO | Food and Agricultural Organization |
| FD | Forest Department |
| FDPP | Full Depth Permeable Pavement |
| FEMA | Federal Emergency Management Agency |
| FGD | Focus Group Discussions |
| FPI | Fabry-Pérot Interferometer |
| GBA | Greater Baku Area |
| GBR | Green-to-Blue Ratio |
| GCDA | Greater Cochin Development Authority |
| GCF | Green Climate Fund |
| GDP | Gross Domestic Product |
| GE | Google Earth |
| GEDI | Global Ecosystem Dynamics Investigation |
| GEE | Google Earth Engine |
| GGF | Green Growth Framework |
| GHGs | Greenhouse Gases |
| GI | Green Infrastructure |
| GIM | National Mission for Green India |
| GIS | Geographical Information Systems |
| GLAS | Geoscience Laser Altimeter System |
| GMC | Guwahati Municipal Corporation |
| GMDA | Guwahati Metropolitan Development Authority |
| GPS | Global Positioning Systems |
| GR-GI-BAM | Ground-Galvanized Iron-Bamboo |
| GR-GI-MXD | Ground-Galvanized Iron-Mixed Materials |
| GR-GI-WD | Ground-Galvanized Iron-Wood |
| GR-NIP-MXD | Ground-Nipa-Mixed Materials |
| GR-NP-BAM | Ground-Nipa-Bamboo |
| GR-NP-WD | Ground-Nipa-Wood |
| GS | Guwahati-Shillong |
| HAC | Hoi An City |
| HDD | Heating Degree Days |
| HHMI | Hard Human-Made Infrastructure |
| HI | Human Infrastructure |
| HRIDAY | Heritage City Development and Augmentation Yojana |
| HySIS | Hyper Spectral Imaging Satellite |
| ICAP | India Cooling Action Plan |
| ICCC | Integrated Command and Control Center |
| ICELI KCC | ICLEI Kaohsiung Capacity Center |
| ICZM | Integrated Coastal Zone Management |
| IFM | Integrated Flood Management |

| | |
|---|---|
| IISD | International Institute for Sustainable Development |
| IMFFS | Integrated Mangroves Fisheries Farming System |
| INCOIS | Indian National Centre for Ocean Information Services |
| IPBES | Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services |
| IPCC | Intergovernmental Panel on Climate Change |
| IPZ | Island Protection Zone |
| IRS LISS | Indian Remote Sensing Satellite Linear Imaging Self Scanning Sensor |
| ISA | Percentage Impervious Surface Area |
| ISRO | Indian Space Research Organisation |
| IUCN | International Union for Conservation of Nature |
| IUWM | Integrated Urban Water Management |
| JNNURM | Jawaharlal Nehru National Urban Renewal Mission |
| KDA | Khulna Development Authority |
| KHGs | Kandyan Homegardens |
| KSDMA | Kerala State Disaster Management Authority |
| KUIDFC | Karnataka Urban Infrastructure Development Finance Corporation |
| LAI | Leaf Area Index |
| LaP | Local Area Planning Authority |
| LBSAP | Local Biodiversity Strategy Action Plan |
| LBV | Long-Billed Vultures |
| LCS | Low-Carbon Society |
| LID | Low-Impact Development |
| LiDAR | Light Detection and Ranging |
| LLDA | Laguna Lake Development Authority |
| LPG | Liberalisation-Privatisation-Globalisation |
| LST | Land Surface Temperature |
| LULC | Land Use Land Cover |
| MFAs | Marine Fishery Advisories |
| MFF | Mangroves for the Future |
| MIMAROPA | Mindoro, Marinduque, Romblon, Palawan |
| MIMES | Multiscale Integrated Model of Ecosystem Services |
| MLC | Maximum Likelihood Classifier |
| MLIT | Ministry of Land, Infrastructure, Transport and Tourism, Japan |
| MNDWI | Modified Normalized Difference Water Index |
| MODIS | Moderate Resolution Imaging Spectroradiometer |
| MoE | Ministry of the Environment, Japan |
| MoEFCC | Ministry of Environment, Forest and Climate Change |
| MoES | Ministry of Earth Sciences |
| MONRE | Ministry of Natural Resources and Environment |
| MoUD | Ministry of Urban Development |
| MS | Multi Spectral |
| MSS | Multispectral Scanner System |

| | |
|---|---|
| MSWM | Municipal Solid Waste Management |
| MXD-GI-MXD | Mixed Materials-Galvanized Iron-Mixed Materials |
| MXD-TEG-BR | Mixed Materials-Tegula-Brick |
| N | Nitrogen |
| NAPCA | National Association for the Promotion of Community Universities, Taiwan |
| NAPCC | National Action Plan on Climate Change |
| NASA | National Aeronautics and Space Administration |
| NAT | NbS Assisting Technologies |
| NBA | National Biodiversity Act |
| NBS | Nature-Based Solutions |
| NCAER | National Council of Applied Economic Research |
| NCR | National Capital Region |
| NDC | Nationally Determined Contributions |
| NDMA | National Disaster Management Agency |
| NDRRMC | National Disaster Risk Reduction and Management Council |
| NDRRMP | National Disaster Risk Reduction and Management Plan |
| NDVI | Normalized Difference Vegetation Index |
| NDWI | Normalized Difference Water Index |
| NE | North East |
| NFCP | Natural Forest Conservation Program |
| NFPP | Natural Forest Protection Program |
| NGOs | Non-Governmental Organisations |
| NI | Natural Infrastructure |
| NIR | Near Infrared |
| NMEEE | National Mission of Enhanced Energy efficiency |
| $NO_3$ | Nitrate |
| NRC | National Research Council |
| NRM | Natural Resources Management |
| NSCB | National Statistics Coordination Board |
| NSSL | National Severe Storms Laboratory |
| NTFP | Non-Timber Forest Products |
| OLI | Operational Land Imager |
| OP | Oriented-plan |
| OSF | Ocean State Forecast |
| OTH-GI-WD | Others-Galvanized Iron-Wood |
| OTH-TEG-BAM | Others-Tegula-Bamboo |
| PA | Protected Areas |
| PAGASA | Philippine Atmospheric, Geophysical and Astronomical Services Administration |
| PAN | Panchromatic |
| PBL | Planetary Boundary Layer |
| PFZ | Potential Fishing Zone |
| PHI-2 | Push broom Hyperspectral Imaging II |
| PI | Public Infrastructure |

| | |
|---|---|
| PIP | Public Infrastructure Provider |
| PM | Particulate Matter |
| PMCG | Pembrokeshire Marine Code Group |
| PPP | Public–Private Partnership |
| PPS | Permeable Pavement Systems |
| PSA | Philippine Statistics Authority |
| PUB | Public Utilities Board |
| PV | Proportion of Vegetation cover |
| QGIS | Quantum GIS |
| R | Reinforcing Loop |
| RADAR | Radio Detection and Ranging |
| RBP | Reference Behaviour Pattern |
| RBTS | Reed Bed Treatment System |
| RCM | RADARSAT Constellation Mission |
| RDA | Rajshahi Development Authority |
| RF | Reserve Forest |
| RMDP | Rajshahi Metropolitan Development Plan |
| RMP | Revised Master Plan |
| RPI | River Pollution Index |
| RS | Remote Sensing |
| RS | Resource System |
| RU | Resource User |
| RVS | Ramadevarabetta Vulture Sanctuary |
| S | Scenario |
| S&T | Science and Technology |
| SAR | Synthetic Aperture Radar |
| SAVi | Sustainable Asset Valuation |
| SCC | Sponge City Concept |
| SCP-Asia | Sustainable Cities Programme-Asia |
| SDGs | Sustainable Development Goals |
| SDWF | Shannon Dolphin and Wildlife Foundation |
| SESs | Social-Ecological Systems |
| SET | Social-Ecological Technological |
| SHMI | Soft Human-Made Infrastructure |
| SIDS | Small Islands Developing States |
| SMCE | Spatial Multi-Criteria Evaluation |
| SNC | Second National Communication |
| SOI | Survey of India |
| SPC | Sponge City Program |
| SS | Suspended Solids |
| SSNN | Self-Adapting Selection of Multiple Artificial Neural Networks |
| SuDS | Sustainable Urban Drainage Systems |
| SUNRM | Sustainable Urban Natural Resources Management |
| SW | Southwest Monsoon |
| SWIR | Short-Wave Infrared |

| | |
|---|---|
| SWM | Solid Waste Management |
| TCPO | Town and Country Planning Organisation |
| TIR | Thermal Infrared |
| TIRS | Thermal Infrared Sensor |
| TM | Thematic Mapper |
| TSS | Total Suspended Solids |
| UAV | Unmanned Aerial Vehicle |
| UBGI | Urban Blue-Green Infrastructure |
| UCCR | Urban Climate Change Resilience |
| UCI | Urban Cooling Islands |
| UDA | Urban Development Authority |
| UESs | Urban Ecosystem Services |
| UGI | Urban Green Infrastructure |
| UGS | Urban Green Spaces |
| UHI | Urban Heat Islands |
| UN | United Nations |
| UNDESA | United Nations Department of Economic and Social Affairs |
| UNEP | United Nations Environment Programme |
| UNFCCC | United Nations Framework Convention on Climate Change |
| UNFPA | United Nations Fund for Population Activities |
| UNHABITAT | United Nations Human Settlements Programme |
| UNICEF | United Nations International Children's Emergency Fund |
| URR | Urban Risk Resiliency |
| UT | Union Territories |
| UV | Ultraviolet |
| VC | Ventilation Coefficient |
| VI | Vegetation Index |
| VNIR | Visible and Near-Infrared |
| WD-TEG-BAM | Wood-Tegula-Bamboo |
| WHO | World Health Organization |
| WI | Water Index |
| WRF | Weather Research and Forecasting |
| WSUD | Water Sensitive Urban Design |
| WTP | Willingness to Pay |
| WWT | Wastewater Treatment |

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# 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

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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

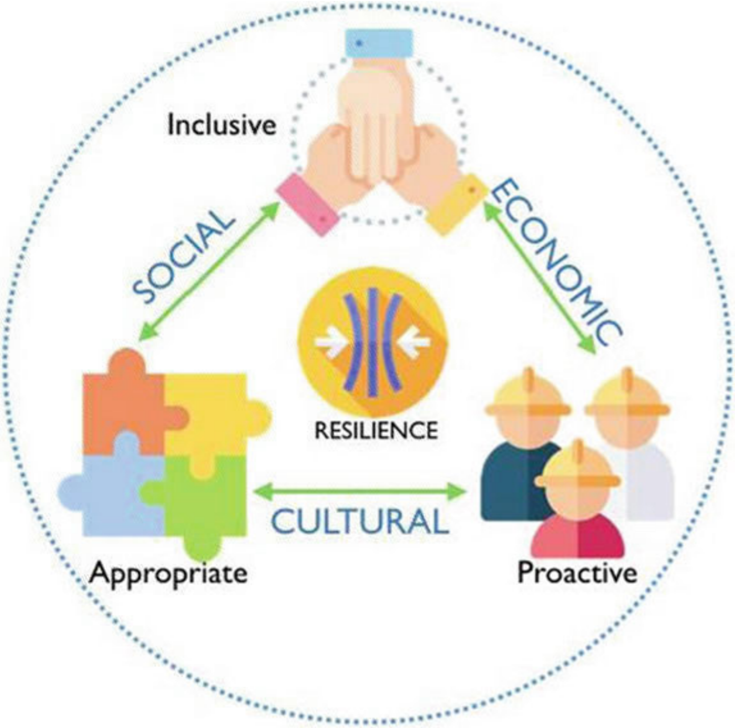


**Fig. 1.1** Community-centered approach to enhancing flood resilience with blue-green infrastructure (BGI) *(Adapted from (*Drosou et al. 2019*)*

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

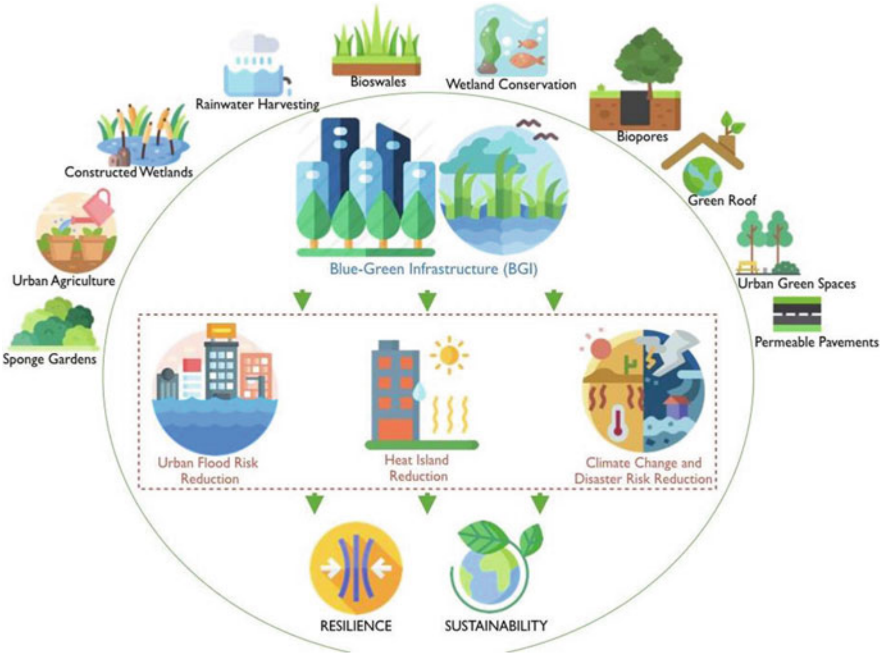


**Fig. 1.2** Blue-green infrastructure to mitigate risks and hazards and develop urban resilience and sustainability

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