P. K. Joshi · K. S. Rao · Rahul Bhadouria ·
Sachchidanand Tripathi ·
Rishikesh Singh *Editors*

Blue-Green Infrastructure for Sustainable Urban Settlements

Implications for Developing Countries Under Climate Change

Springer

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Foreword

In the face of unprecedented urbanization and the escalating impacts of climate change, the quest for sustainable urban development has become an urgent global imperative. The anthology you hold in your hands, *Blue-Green Infrastructure for Sustainable Urban Settlements—Implications for Developing Countries Under Climate Change*, is a beacon of critical inquiry and innovative solutions. It illuminates the path toward resilient and sustainable urban futures, particularly in the context of developing nations.

As we navigate the complexities of urban resilience and sustainability, the chapters by distinguished cadre of scholars and practitioners assembled within this edited book offer a multifaceted exploration of blue-green infrastructure—a transformative paradigm that integrates natural elements into the urban fabric to enhance resilience, mitigate environmental risks, and foster sustainable development. This volume stands as a testament to the urgency and importance of embracing innovative solutions that harmonize human activity with the natural world.

In Part One, "Urban Resilience and Sustainability," the foundational principles and overarching implications of blue-green infrastructure are meticulously examined. The issues addressed by the part range from the role of the infrastructure in mitigating the urban heat island effect to its contribution toward achieving Sustainable Development Goals. The chapters in this part elucidate the manifold benefits and challenges of implementing blue-green infrastructure in the context of developing countries.

Part Two, "Management and Development of Blue-Green Infrastructure," delves into the practicalities of adopting and nurturing such innovative systems. Through invaluable insights garnered from real-world experiences, case studies and best practices across diverse geographical and cultural contexts, the contributors illuminate the challenges and opportunities inherent in integrating blue-green infrastructure into the urban landscape. In particular, they emphasize the crucial role of community engagement and vertical greening for sustainable planning.

The imperative for scaling up and assessing the impact of blue-green infrastructure is the focus of Part Three, "Scaling and Assessment for Urban Planning." From

modeling climate change-resilient urban agriculture to addressing spatial accessibility disparities including redeveloping green spaces, the chapters in this part underscore the importance of evidence-based planning and inclusive governance in realizing the full potential of blue-green infrastructure.

Finally, in Part Four, "Policy Issues and Sustainable Development," the nexus between blue-green infrastructure and policy frameworks is explored. The contributors use case studies from diverse geographical contexts in order to highlight the governance challenges and multifunctional patterns inherent in implementing blue-green infrastructure. In doing so, they underscore the need for strategic planning and policy innovation to drive sustainable urban development.

It is with great appreciation and admiration that I acknowledge the alignment of this forthcoming edited volume with the broader objectives of the URGENT (Urban Resilience and Adaptation for India and Mongolia) Project. This initiative exemplifies the collaborative spirit and transdisciplinary approach necessary to address the complex challenges facing urban settlements in the twenty-first century. By supporting blue and green infrastructure initiatives, the edited book contributes to the advancement of sustainable urban development agendas across the globe.

As we confront the challenges of an uncertain future, may the insights and perspectives presented within these pages inspire collective action and transformative change toward more resilient, equitable, and sustainable urban settlements for generations to come.

February 2024

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Preface

It is with great pleasure and anticipation that we present this comprehensive volume. As the urbanization trend continues to surge globally, the importance of sustainable development, particularly in the context of developing countries, becomes increasingly paramount. This book aims to shed light on the critical role of Blue-Green Infrastructure (BGI) in fostering urban resilience, sustainability, and climate adaptation, with a particular focus on the unique challenges and opportunities faced by cities in the developing world.

Part One of this book delves into the foundational aspects of urban resilience and sustainability, setting the stage for understanding the implications of climate change on developing countries. Chapters "Strength and Limitation of Nature-Based Solutions Towards Adaptation and Mitigation of Climate Change in Developing Countries" through "Role of Blue-Green Infrastructure in Achieving Sustainable Development Goals in Urban Centres of Developing countries" offer a comprehensive overview of the concept of BGI and its potential in mitigating the adverse effects of climate change in urban settlements. From exploring the role of BGI in addressing the Urban Heat Island (UHI) effect to its contribution toward achieving Sustainable Development Goals (SDGs), this part provides a holistic understanding of the subject matter. Chapter "Strength and Limitation of Nature-Based Solutions Towards Adaptation and Mitigation of Climate Change in Developing Countries" highlights the potential of natural methods in cities to combat climate change by promoting blue and green urban areas. It suggests using Nature-based Solutions (NbS) to mitigate climate impacts and enhance resilience. Key points include developing metrics to measure efficacy, addressing knowledge gaps, overcoming obstacles, and prioritizing socio-environmental justice in NbS implementation. Ultimately, NbS can serve as tools for climate adaptation while improving societal well-being and sustainable urban development.

Chapter "Blue-Green Infrastructure for Urban Resilience and Sustainability in Developing Countries" examines the significance of BGI in enhancing urban resilience and sustainability, particularly in developing countries. It outlines the challenges being faced, such as rapid urbanization and limited resources, and proposes BGI as a solution to promote resilience, sustainability, and social equity. It also

addresses implementation challenges, governance issues, and emphasizes the importance of community involvement and education for the long-term success of BGI initiatives.

Chapter "Integrating Blue-Green as Next-Generation Urban Infrastructure in Developing Countries" highlights the increasing importance of NbS like BGI for sustainable urban design, especially in the face of climate change and rapid urbanization. The chapter aims to review the benefits, applications, and scientific knowledge surrounding BGI to support its integration into urban planning for sustainable development, thus addressing priorities and differences in BGI development globally.

Chapter "Understanding the Role of Blue-Green Infrastructure in Abatement of Urban Heat Island Effect" discusses the effectiveness of BGI in mitigating UHI effects, showing a temperature reduction of 2 °C to 4 °C compared to built-up areas. For example, a study in Singapore reveals that an 8% increase in BGI can lower temperatures by 1.21 °C. The findings highlight the need for BGI planning in developing regions to create sustainable built environments with distributed BGI networks.

Chapter "Role of Blue-Green Infrastructure in Achieving Sustainable Development Goals in Urban Centres of Developing countries" emphasizes the role of BGI in promoting sustainable living through urban planning, ecological restoration, and fostering a connection with nature. BGI contributes to various sectors—economic, social, and environmental—by controlling ecosystems, reducing pollution, and lowering urban temperatures. It reviews BGI's applicability in achieving SDGs and discusses its implications, benefits, and challenges, highlighting its effectiveness in meeting targets for sustainable development.

Moving on to Part Two, the focus shifts toward the management and development of BGI. Chapters "Challenges and Opportunities in Adopting Blue-Green Infrastructure in Cities of the Developing World" through "Blue-Green Infrastructure for Flood Resilience: Case Study of Indonesia" delve into the practical challenges and opportunities in adopting BGI in cities of the developing world. From examining the eco-cultural legacy of Feng Shui to exploring the role of community engagement in building sustainable BGI, this part offers valuable insights and case studies to inform policymakers, urban planners, and practitioners alike. Chapter "Challenges and Opportunities in Adopting Blue-Green Infrastructure in Cities of the Developing World" explores challenges and opportunities in adopting BGI in developing world cities, emphasizing its potential as a solution to urbanization issues. It discusses BGI benefits and foundations across environmental, social, and economic aspects. Case studies illustrate successful implementation, showcasing how integrated planning and community involvement can overcome challenges. Collaboration among various stakeholders, including governments, communities, and the private sector, is highlighted as crucial for addressing institutional and financial barriers. Overall, it presents a holistic vision for transforming developing cities into greener, resilient, and inclusive spaces, tailored to their specific contexts.

Chapter "From "Human-Centered" to "System-Oriented": Eco-Cultural Legacy of Feng Shui and Scientific Principles for Establishing Modern Resilient Cities" discusses how cities face ecological challenges due to global warming, such as UHI

effects and flood hazards, hindering SDGs. It discusses Feng Shui as a traditional Chinese philosophy offering insights into interacting with nature and addressing environmental changes. By studying the application of Feng Shui in Hong Village, the chapter explores its principles and passive strategies applicable to modern urban systems. The chapter establishes a framework for modern applications of Feng Shui, citing successful projects in South Korea and China that integrate Feng Shui principles into BGI to address urban challenges. It proposes nature-based and soft intervention approaches for constructing and rehabilitating BGIs to enhance urban resilience and achieve SDGs.

Chapter "The Role of Community Engagement in Building Sustainable Blue-Green Infrastructure–Best Practices and Case Studies" discusses the emerging concept of BGI in urban planning, emphasizing its importance for addressing challenges posed by rapid urbanization and climate emergencies. It outlines BGI's multifunctional benefits, such as improving water and air quality, mitigating UHI effects, and enhancing biodiversity. The chapter proposes a framework based on evidence to prioritize community engagement in BGI projects, aiming to guide policymakers, environmentalists, and urban planners toward more holistic and socially inclusive water-sensitive urban planning.

Chapter "Contributions of Vertical Greening to Micro-Climate Control: Exploratory Case Study in a Residential Environment" discusses the benefits of vertical greening or green walls in urban areas, particularly in mitigating heat stress. An exploratory study conducted in Akure, Nigeria, evaluated a vertical greening prototype installed on a residential building. Field measurements showed a reduction in maximum and minimum temperatures compared to a typical building without a green wall. The study suggests that vertical greening contributes to temperature moderation in urban environments. It stresses on policy initiatives to promote the incorporation of vertical greening into green infrastructure in African cities experiencing urban densification. Chapter "Landscape Planning Strategies Within the Scope of Development Plans and Implementation Problems: The Case of Türkiye" discusses development plans initiated by the government since 1963, aimed at addressing various issues such as economy, health, education, and transportation. It examines urbanization problems, climate change, and disasters, particularly within the scope of BGI. The research compares plan decisions with actual implementations and highlights the need for effective execution of planning decisions to build resilient cities in the face of climate change and disasters.

Chapter "Blue-Green Infrastructure for Flood Resilience: Case Study of Indonesia" discusses the increasing risk of urban floods due to climate change, particularly in developing countries like Indonesia, which can lead to significant infrastructure damage. It highlights the importance of BGI in disaster risk reduction and flood management by integrating with urban environmental aspects. The chapter examines issues, gaps, opportunities, and BGI implementation for flood resilience in Indonesian cities such as Bandung, Balikpapan, Samarinda, and Semarang. Case studies illustrate BGI gaps, successes, and threats, identifying policy background, city characteristics, implementation methods, and effectiveness.

Part Three of the book explores scaling and assessment methodologies for urban planning in the context of BGI. Chapters "Modeling Climate Change-Resilient Urban Agriculture in Developing Nations: A Case Study" through "Spatial Accessibility Disparities and Users' Opinion Assessment of Khartoum State Public Green Spaces" present innovative approaches and case studies aimed at modeling climate-resilient urban agriculture, redeveloping open and urban green spaces (UGS), and assessing spatial accessibility disparities in public green spaces. These chapters underscore the importance of incorporating BGI into urban planning frameworks to foster sustainable and equitable development.

Chapter "Modeling Climate Change-Resilient Urban Agriculture in Developing Nations: A Case Study" discusses the importance of implementing sustainable practices in rapidly urbanizing areas, particularly in developing nations vulnerable to climate change. It suggests that BGI can address climate and sustainability challenges in urban environments, including meeting SDGs related to poverty and hunger. Urban agriculture is proposed as a solution to local food security, especially in densely populated cities in Asia, South America, and Africa. The chapter introduces a sunlight-based computational approach for designating agricultural potential on urban surfaces, emphasizing the benefits of building-integrated agriculture (BIA) in minimizing external risks to food production. Hybrid lighting systems are suggested to reduce energy consumption in BIA, thus making it more sustainable for developing nations with limited energy infrastructure. The availability of solar radiation on urban surfaces is highlighted as a crucial factor in selecting BIA locations.

Chapter "Redeveloping Open and Urban Green Spaces for Climate Resilience; A Case Study of Chennai" discusses the importance of open and UGS for urban sustainability, ecosystem services, climate resilience, and human well-being. It presents a GIS-based framework for identifying potential open and UGS areas for climate resilience in Chennai, using satellite imagery. The framework identifies 63 sq. km of land parcels suitable for development as open and UGS, which can help mitigate floods and the UHI effect. The chapter emphasizes the need to incorporate these spaces into urban development master plans and discusses opportunities and barriers, including capacity gaps and governance issues, in Indian cities' efforts to enhance climate resilience through UGS.

Chapter "Spatial Accessibility Disparities and Users' Opinion Assessment of Khartoum State Public Green Spaces" examines the spatial distribution and accessibility of UGSs in Khartoum State, Sudan, given its vulnerability to excessive dry climate conditions due to climate change. Using geospatial and questionnaires, it assesses access to urban parks, community gardens, and city forests for both drivers and pedestrians. Results indicate unequal access, wherein a desire for more well-equipped parks emerges despite the majority requiring entrance fees. The study concludes that UGS accessibility does not align with international quality of life indices.

Finally, Part Four delves into policy issues and sustainable development considerations related to BGI implementation. Chapters "Multifunctional Patterns and Governance Challenges of Blue-Green Infrastructure in Puebla, Mexico" through "Systemic Action Network for Improving Blue-Green Infrastructure Based

on the Natural Capital Investigation: The Strategic Plan in Vlorë, Albania" examine multifunctional patterns and governance challenges, the role of BGI in stimulating growth, and systematic action networks for improving BGI based on natural capital investigations. These chapters provide valuable insights into the policy landscape and offer strategic recommendations for advancing BGI agendas at the local, national, and international levels.

Chapter "Multifunctional Patterns and Governance Challenges of Blue-Green Infrastructure in Puebla, Mexico" discusses the multifunctionality of BGI in urban areas, particularly in the City of Puebla and its metropolitan area in central Mexico. It highlights the potential benefits of BGIs, such as open spaces, social interaction areas, climate regulation, and economic well-being. The chapter reviews two factors influencing BGI multifunctionality: size and urban legislation. Using satellite images, it assesses the size and functions provided by BGIs, noting that larger BGIs tend to offer more functions. However, urban legislation related to BGI multifunctionality is found to be lacking across different government levels.

Chapter "Blue-Green Infrastructure as a Stimulant of Growth: Case of Ahmedabad, India" discusses the concept of BGI, which utilizes natural ecosystems and UGS to create sustainable environments. It highlights the role of BGI in enhancing the quality of life, promoting a healthy environment, and stimulating economic and social progress. Taking a case of city of Ahmedabad, it proposes to examine BGI-induced growth through examples of waterfront/riverfront development projects.

Chapter "Systemic Action Network for Improving Blue-Green Infrastructure Based on the Natural Capital Investigation: The Strategic Plan in Vlorë, Albania" explores the significance of natural capital in maintaining human well-being and urban resilience, particularly in the face of climate and Anthropocene challenges. Using the city of Vlorë in Albania as a case study, it examines the practicality of NbS and Integrated Modification Methodology (IMM) in promoting sustainable development. The case study focuses on improving blue-green infrastructure to align with United Nations SDG 11 and regional guidelines. It proposes an innovative urban model for sustainable development, emphasizing the integration of natural capital and NbS principles. The chapter discusses the transferability of IMM research and underscores the importance of multidisciplinary interventions for sustainable urban transformation.

In compiling this volume, we have endeavored to bring together contributions from leading experts and scholars in the field of urban resilience, sustainability, and climate adaptation. Through their collective expertise and interdisciplinary perspectives, we aim to provide a comprehensive resource that will inspire dialogue, inform policy, and catalyze action toward building more resilient and sustainable urban settlements in developing countries. We extend our sincere gratitude to all the contributors for their invaluable insights and scholarly contributions to this volume. We also wish to thank the reviewers for their meticulous feedback and suggestions, which have undoubtedly enhanced the quality and rigor of the chapters.

Lastly, we express our appreciation to the publisher for their support and guidance throughout the publication process. As editors, we hope that this book will serve as a catalyst for continued research, innovation, and collaboration in the field of

blue-green infrastructure and sustainable urban development. May it inspire new ideas, initiatives, and partnerships aimed at creating healthier, more resilient, and sustainable cities for generations to come.

New Delhi, India — P. K. Joshi
New Delhi, India — K. S. Rao
New Delhi, India — Rahul Bhadouria
New Delhi, India — Sachchidanand Tripathi
Mohali, India — Rishikesh Singh

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Urban Resilience and Sustainability

Strength and Limitation of Nature-Based Solutions Towards Adaptation and Mitigation of Climate Change in Developing Countries

Asma Ben Amor, Hadia Hemmami, Soumeia Zeghoud, and Ilham Ben Amor

Abstract Natural methods provide considerable potential for curtailment cities' susceptibility to climate change and boosting their resilience by promoting the growth of blue and green urban region. Consequently, they may help mitigate the worst consequences of climate change and provide municipalities proactive possibilities for adaptation. We examine the numerous states in which nature-based solutions are pertinent for reducing climate alteration and adapting to it in urban environments, and we develop metrics for gauging their efficacy and corresponding knowledge gaps. We also examine current obstacles and prospective openings for expanding the scope and efficiency of the implementation of nature-based solutions (NbS). In this chapter, we emphasize three key necessarily for future scientific and policy agendas when addressing NbS: (1) create more convincing evidence for natural climate change adaptation and extenuation strategies and increase implementation to increase awareness; (2) Reflexive techniques, which comprise bringing together new networks of society, practitioners, and NbS ambassadors, can be used to adjust for governance issues in putting NbS into practice; (3) When implementing nature-based solutions, take into mind socio-environmental justice and societal cohesion by employing integrated governance strategies that take into account the integrative and transdisciplinary participation of different actors. Taking these requirements into account, NbS may act as tools for climate mitigation and adaptation that also enhance societal well-being, making them excellent choices for investments in sustainable urban development.

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1 Introduction

The traces of climate change are already being touched about the world, with the most notable effects being increased severe weather events, altered rainfall patterns, and rising temperatures (Kabisch et al., 2016). Because of the concentration of infrastructure, property, and population, urban areas are particularly vulnerable. Despite the global north producing over 92% of all GHG emissions (Hickel, 2020), the most affected areas are in the developing world (Change, 2014). According to the most modern Intergovernmental Panel on Climate Change (IPCC) report (Change, 2014), the effects are intensifying as tipping points are being reached, and governments fail to take sufficient action. Even low amounts of warming can have disastrous effects, even if we are facing scenarios of significant temperature increases (Kemp et al., 2022). The sixth mass extinction of life on Earth is a direct result of the biodiversity problem and climate change (Cowie et al., 2022). Nature-based solutions (NbS) has been endorsed more frequently as an alternative to conventional urban infrastructure and for urban adaptation (Arias et al., 2021; Frantzeskaki, 2019; Seddon et al., 2020). The term "Nature-based Solutions" was originally used in a 2008 World Bank study (Sowińska-Świerkosz et al., 2021; Weltbank, 2012) that identified projects addressing the biodiversity and climate problems with a focus on adaptation and vulnerable populations. The International Union for Conservation of Nature (IUCN) defines NbS as initiatives that support biodiversity and human wellbeing in addition to protecting, managing, and restoring natural or modified ecosystems (Cohen-Shacham et al., 2016). The European Commission (EC) offers a more expansive definition of NbS, defining it as cost-effective, nature-inspired, nature-supported solutions that concurrently benefit the society, economy, and environment while promoting resilience (Faivre et al., 2017). Since the impression of NbS is motionless relatively new, there are still several information gaps, including how to promote its applicability to cities (Kabisch et al., 2016). Additionally, there are obstacles to its execution that must be recognized and removed. The goal of this chapter is to fill in any information gaps regarding the usage of NbS for application in an urban setting while also contributing to the assessment of the problem's dimensions. The applied chapter technique focuses on the most relevant published papers with an emphasis on NbS and its adaptation to the urban environment. Several reports from pertinent organizations having a worldwide influence, such as the World Bank, were analyzed in order to comprehend how various governments, agents, and sectors are implementing/supporting these solutions.

2 The Role of NbS in Climate Change

In order to comprehend the significance of NbS within the framework of climate change, our attention is directed toward the following aspects: (a) What are NbS, and how do they differ from urban greening? (b) In addition to addressing the climate crisis, what other challenges can be tackled using these solutions? (c) To what degree can NbS contribute to urban adaptation? (d) How meaningful are these remedies for populations at risk? (e) What challenges and opportunities arise from the transdisciplinary nature of NbS? (f) Lastly, the various typologies of NbS are delineated.

2.1 Basic Ideas and Definitions

NbS refers to strategies that utilize the inherent capabilities of the natural environment to deliver a variety of advantages, encompassing both environmental and societal welfares (Sowińska-Świerkosz & García, 2022). The uncertainty of the notion has been emphasized by several authors (Potschin et al., 2015; Sowińska-Świerkosz & García, 2022), and other organizations offer their own definitions. As per EC, the idea in question is described as an overarching term, incorporating many methodologies such as urban green substructure, ecosystem-based version, blue-green infrastructure, and ecosystem-based disaster danger reduction (Dumitru & Wendling, 2021; Frantzeskaki et al., 2022). NbS encompasses a range of interventions and typologies of land use, spanning natural, rural, and urban settings. These interventions include the establishment and preservation of wetlands, forests, parks, and green belts inside and around metropolitan areas. Additionally, NbS involves the implementation of plants that naturally cleanse wastewater, green walls, green roofs, ecological corridors, and other forms of blue, green, and hybrid substructures. These proposed solutions have the potential to enhance urban pliability, mitigate the hazards associated with urban floods, minimize losses, and promote economic benefits while also providing crucial social and ecological services (Smart, 2021). Significantly, NbS plays a crucial role in fostering sustainable resolutions to enduring environmental predicaments (Eggermont et al., 2015; Bauduceau et al., 2015). The idea of NbS has gained recognition in the discourse surrounding climate change and the biodiversity crisis (Kemp et al., 2022; MacKinnon et al., 2011). While NbS are commonly linked to these issues, it is significant to note that their application is not imperfect to this domain. NbS can also be employed to tackle other challenges, including pest management, food production enhancement, and wastewater treatment (Haines-Young & Potschin, 2014). The capacity of NbS to concurrently accomplish climate adaptation and mitigation goals is one of its main advantages. Numerous scientific evaluations and reports have emphasised this feature, such as the Intergovernmental Panel on the Global Adaptation Commission Report's Climate Change and Land Report (Seddon et al., 2020), Climate Change (Kabisch et al., 2016), and the more

recent Sharm El-Sheikh Implementation Plan (Bakošová, 2023). Furthermore, the various advantages they offer are characterized by their relatively affordable nature since they have the potential to yield a cost–benefit ratio exceeding 100:1 (Munang et al., 2013). The adaptability of NbS renders them a very effective method for addressing what may, at times, appear to be an insurmountable task (Arias et al., 2021). It is imperative to acknowledge that they do not possess omnipotent capabilities, and within the framework of mitigation, their influence is significantly less pronounced compared to the substantial decrease in the use of fossil fuels (Anderson et al., 2019).

Differentiating NbS from broader greening initiatives is of utmost significance. In the literature assessment conducted by Sowińska-Świerkosz and García (2022), a set of 11 exclusion criteria for green substructure to be classified as NbS is identified.

1. The absence of operational ecosystems necessitates that NbS encompass natural procedures rather than being just "inspired by nature." This might manifest in several ways, such as the utilization of solar and wind energy or the use of biomimicry.
2. The implementation of NbS necessitates a structured approach, wherein activities are not arbitrary but instead guided by well-defined objectives, intended beneficiaries, and governance mechanisms. It is imperative to reject actions that are devoid of a comprehensive assessment of the prevailing social, economic, and environmental conditions prior to their execution. For instance, creative projects, including plants, would be excluded.
3. The absence of post-implementation goals is problematic, as NbS should be targeted towards addressing pre-existing issues. This would include the exclusion of historical gardens, as one illustrative example.
4. The exclusion of practices such as monoculture and the reduction of "greenwashing" methods would ensure that there is no negative or negligible influence on biodiversity.
5. The benefits of green infrastructure are comparable to those of grey infrastructure. This observation is of special significance as it underscores the necessity for NbS to offer additional advantages compared to alternative approaches. It emphasizes that the extent of human engagement should not be the main determining factor when evaluating the effectiveness of an intervention. Hybrid methods are frequently seen as most appropriate for metropolitan environments (Seddon, 2022).
6. Inequitable allocation of advantages. NbS should provide the concurrent attainment of environmental preservation, human well-being, and economic advantages without prioritizing any one objective above the others.
7. The technique of copy-paste implementation. NbS are contingent upon the unique environment in which they are implemented, and their design necessitates a certain level of knowledge. The implementation of adaptive management and design principles can facilitate the replication of solutions.
8. Adopting a top-down form of governance is indispensable for the successful implementation of NbS, as it necessitates active community engagement.

9. The use of a dynamic management strategy is recommended for NbS, wherein adaptive management and innovation are integral components throughout its duration, grounded in the theory of change. The importance of slide in decision-making cannot be overstated, particularly with regard to the inclusion of public input.
10. It is crucial for NbS to exhibit cost-effectiveness due to the presence of disproportionate financial expenditures in relation to the advantages it provides.
11. Point-scale methods, such as NbS, entail the integration of social and ecological variables at a landscape size, resulting in cumulative consequences. It is significant to note that NbS should not be viewed as separate interventions but rather as interventions that involve interactions across several dimensions.

The United Nations (UN) Organisation is a significant advocate for NbS. At the 2019 United Nations Climate Action Summit, NbS has been designated as one of the nine main action tracks. Following this realization, more than 20 nations and countless organizations have pledged to use nature's resources to combat climate change. These commitments primarily emphasis on the preservation, reforestation, and restoration of ecosystems (Gielen et al., 2019). The enhanced significance of their relevance is seen in the Nationally Determined Contributions (NDCs) that have been presented to the United Nations Framework Convention on Climate Change (UNFCCC). In the year 2015, a mere 66% of the signatories of the Paris Agreement incorporated NbS in their Nationally Determined Contributions (NDCs) (Roemer et al., 2023). However, this figure has significantly increased to 92% in 2021, with NDCs explicitly referencing NbS in relation to both adaptation and mitigation efforts (Castelo et al., 2023).

2.2 The Crisis Era

The global community is presently confronted with a plethora of crises that are emerging concurrently (Herman, 2016). The increase in human activities and population growth is placing an unsustainable burden on the natural environment, leading to many crises, such as the deterioration of ecosystems, the destruction of forests, the loss of biodiversity, and the acceleration of climate change (Díaz et al., 2019). The decline of biodiversity is occurring at unprecedented magnitudes within the annals of human history (Hughes et al., 2022), as evidenced by the current endangerment of around one million class (Brondizio et al., 2019). In addition to the aforementioned obstacles, society is confronted with social crises, namely inequality and public health concerns. NbS provides the advantageous capability to effectively tackle these pressing issues as well (Lin et al., 2021).

In 2009, Technical Expert Group 1, the Convention on Biological Diversity, initially acknowledged the interconnections among biodiversity crises and climate change. Subsequently, the IPCC and Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) have emphasized the significance

of these interlinkages, asserting that addressing them in isolation is not feasible (Pörtner et al., 2021). The recognition of heightened risks arising from interconnected crises is evident across many levels and diverse organizations, including the World Economic Forum (WEF). The annual global dangers report published by WEF serves to identify and classify risks based on five distinct areas, namely: (a) geopolitical risks, (b) environmental risks, (c) technical risks, (d) societal risks, and (e) economic risks. According to a study conducted in 2022, the primary hazards anticipated for the upcoming decade are environmental concerns. These risks include the potential failure to address climate change adequately, the incidence of dangerous weather events, and the ongoing issue surrounding biodiversity (Björnsdottir et al., 2022). Although NbS possess versatility, their primary advantages in urban contexts lie in their ability to mitigate climate effects, enhance urban biodiversity, improve public health, and foster social cohesion and equality (Ulmer et al., 2016). Numerous methods that prioritize biodiversity, such as the implementation of green corridors to facilitate species migration and the expansion of core conservation areas, might also provide advantages for adaptation (Field & Barros, 2014).

When it comes to mitigating climate effects, NbS has the potential to contribute to the regulation of microclimates (Lindén et al., 2016), management of stormwater runoff, and mitigation of the impact of sea level increase (Field & Barros, 2014). NbS have the potential to enhance human welfare (Seddon et al., 2020), including improvements in public health and social advantages. The issue of public health has garnered significant attention, as seen by the World The Health Organization's (McGuire, 2016) attention on the threat presented by climate change. The Lancet study on climate change (Romanello et al., 2021) highlights the impact of climate change on health. Due to rising temperatures, changed rainfall patterns, and an increase in extreme weather events, it has been discovered that climate change has a major negative impact on health. These factors, especially among the world's most vulnerable people, are undoing the centuries-long progress gained in tackling food and water insecurity. According to the study, climate change is exacerbating the ecological factors that facilitate the transmission of various viruses through water, air, food, and vectors. This phenomenon has the potential to meaningfully contribute to the proliferation of illnesses. The established advantages of urban green spaces, irrespective of their classification as NbS, mostly pertain to public health. These benefits include improvements in cardiovascular health, blood pressure regulation, respiratory health, obesity prevention, and diabetes management (Donovan et al., 2013). Additionally, urban trees have a significant role in mitigating air pollution, as shown by existing research (Bhadouria et al., 2022).

Research has demonstrated that being exposed to natural surroundings has positive belongings on mental well-being, including the reduction of stress levels and enhancement of attention abilities (Bratman et al., 2012). There is a correlation between the availability of outdoor green spaces and the overall well-being of children residing in densely populated metropolitan regions (Haaland and Bosch, 2015). Urban green spaces have been found to have a positive influence on public health due to their promotion of physical activity and enjoyment (Haaland and Bosch,

2015). Additionally, at a regional level, NbS can production a crucial part in safeguarding water, sanitation, and hygiene (WASH), which are interconnected with health and have implications across all sectors (Castelo et al., 2023). Additionally, they have the potential to mitigate the occurrence of zoonotic illnesses, like COVID-19, that are frequently associated with the deterioration or loss of ecosystems (Castelo et al., 2023). Recent scientific research has demonstrated that climate change has the potential to augment the incidence of these illnesses since it can lead to the emergence of novel species interactions (Gilbert, 2022). In relation to societal advantages, NbS have been found to mitigate inequality, foster social cohesiveness, decrease instances of violence, and contribute to aesthetic appreciation (Soares et al., 2011). The impact of the aesthetic component on health has been demonstrated to be beneficial, primarily in relative to the visual aspects of the environment (Seresinhe et al., 2015). The initial investigation specifically addressing this matter was published in 1984. Urban green areas have been found to have an impact on the apparent thermal ease, extending beyond their ability to reduce effective temperature (Klemm et al., 2015).

2.3 Urban Adjustment

The urgency of climate change, defined as the procedure of adapting to present or anticipated climatic impacts, is widely recognized due to its global occurrence (Field & Barros, 2014). The allocation of climate money has, nonetheless, exhibited a preference for mitigation efforts somewhat than adaptation measures (Halimanjaya & Papyrakis, 2012). Despite the mandate of the Cancun Adaptation Framework to prioritize adaptation on par with mitigation, current statistics indicate a growing disparity between the financing allocated for adaptation and the actual need for adaptation (Neufeldt et al., 2021). According to the Paris Agreement, a yearly transfer of USD 100 billion is mandated, commencing in 2020, from affluent countries to poor nations (UNFCCC, 2015). According to recent studies, it has been determined that the current measures in place would not be enough. This is due to estimations suggesting that the yearly expenses of adaptation in poor nations will vary between USD 155 billion and USD 330 billion by the year 2030 (Neufeldt et al., 2021). In accordance with this particular worry, the Glasgow Climate Pact highlights the need to increase the financial resources allocated by wealthy nations to poor nations, especially for the purpose of adaptation, with the goal of doubling these sums by the year 2025.

Cities are especially susceptible to the effects of climate change (White et al., 2005). According to the UN Secretary-General's remarks at the C40 World Mayors Meeting in 2019, cities play a vital role in the mitigation of climate change due to their significant contribution to carbon emissions. Consequently, the achievement or failure of addressing climate change primarily hinges on the actions taken inside urban areas (Castelo et al., 2023). There will be several impacts arising from the situation, encompassing the loss of infrastructure as well as significant implications

for public health. The latter is particularly influenced by weather patterns and various interconnected factors, including a decrease in labor productivity (Smith et al., 2015). The urban heat island (UHI) effect refers to the occurrence of greater temperatures in cities associated to the surrounding natural or rural zones, with a potential temperature difference of up to 8 °C. This is mostly attributed to the high concentration of hard materials inside urban environments (Yan et al., 2020). Moreover, recent studies have revealed that urban areas are experiencing a 29% higher rate of warming compared to rural regions. This observation suggests an uneven amplification of the UHI phenomenon. Urban regions are the primary locations where the mainstream of the global population resides, as evidenced by the fact that 55% of the world's population now inhabits cities. Projections indicate that this figure is anticipated to rise to 68% by the year 2050 (Nations, 2018). The majority of global urban development is projected to occur in the developing world, specifically in the American, Asian, and African continents, accounting for almost 90% of the anticipated expansion. Urban growth has been found to have detrimental effects on the environment, including the reduction of soil permeability and the heightened danger of flooding, in addition to the UHI effect (Skrydstrup et al., 2020). The compounding effect of this phenomenon is further amplified when it is coupled with climate change, interconnected stressors, and the deterioration of natural ecosystems (Kabisch et al., 2016). Hence, the prioritization of urban adaptation in emerging nations is of considerable significance.

Certain regions of the globe are unable to tolerate delays, as exemplified by South Asia, which is projected to witness an increase of around 49 million individuals being thrust into the depths of extreme poverty by the year 2030 (Bank, 2020). The heatwave that occurred in March–April 2022 is considered to be one of the most significantly affected regions globally. It has been determined that climate change has augmented the likelihood of this heatwave by a issue of 30 (Coleman, 2022). The efficacy of NbS in urban adaptation has been extensively validated, resulting in the mitigation of climate-related consequences and the provision of a multitude of public health advantages (Zwierzchowska et al., 2019). NbS holds significant importance in the context of urban adaptation in impoverished countries due to its high cost-effectiveness, ease of implementation, and reduced maintenance costs compared to technical alternatives (Seddon, 2022). The significance of NbS for the Least Developed Countries (LDCs) is particularly pronounced due to their substantial economic reliance on natural resources. The adoption of NbS plays a pivotal role in the protection of natural resources, hence ensuring the well-being of communities. This is of utmost importance since the deterioration of ecosystems intensifies human vulnerability to climate-related consequences and hampers admission to essential resources such as food, water, and clean water. According to the United Nations Framework Convention on Climate Change (UNFCCC), the LDC 2050 Climate Change Vision emphasizes the potential of NbS to enhance the pliability of landscapes and ecosystems in LDCs. The existing information suggests that despite the fact that 45 out of the 46 Nationally Determined Contributions (NDCs) of these countries specifically include nature-related projects, NbS in LDCs are not given significant priority in climate finance (Castelo et al., 2023). According to a recent study, the distribution of

funds for climate adaptation projects in LDCs for the period of 2014 to 2018 revealed that nature-related initiatives received less than 10% of the total funding (Roe et al., 2023). In certain regions, such as Bangladesh, there is a tendency to prioritize engineering solutions over NbS in climate adaptation initiatives. This is evident in the fact that 88% of such projects in Bangladesh are engineered solutions, while NbS accounts for just 12%. Despite the results of Narayan et al. (Narayan et al., 2019) in that particular country, it is evident that engineering solutions exhibit a comparatively inferior performance when compared to NbS. One illustrative instance is mangrove forests, which effectively mitigate the adverse impacts of sea level rise, a prominent vulnerability faced by the nation, as opposed to the implementation of seawalls.

2.4 Application to Vulnerable Communities

Low-income areas experience a disproportionate impact from climate change in relation to public health. This is evident via the adverse effects of extreme weather events and increasing temperatures, which have instant ramifications on public health (Beggs et al., 2019). This phenomenon can be attributed not just to a diminished ability to adapt. Low-income people often reside in regions that are prone to flooding and have limited access to green spaces (Deria et al., 2020). These locations not only mitigate UHI impact but also facilitate the absorption of stormwater runoff. The phenomenon of climate change is expected to contribute to a rise in the global population of individuals who are susceptible to adverse impacts. According to the World Bank, if left unattended, climate change has the capacity to cause a rise in poverty levels for a range of 68 million to 132 million individuals by the year 2030 (Jafino et al., 2020). Given the significant social advantages of NbS, such as their capacity to mitigate inequities, they appear to hold special relevance for marginalized groups and developing countries. NbS may be viewed as a sustainable and low-risk strategy that can be implemented in many settings and communities. NbS have the potential to contribute to the mitigation of poverty through the safeguarding of livelihoods (Hou-Jones et al., 2021).

According to the research conducted by Friends of Ecosystem-based Adaptation (FEBA) in 2021, it has been seen that NbS has the potential to mitigate the vulnerability of communities that are at risk of exposure to various hazards. This reduction in vulnerability may be achieved through three distinct mechanisms. There are three key strategies that can be employed to heading the effects of climate change. Firstly, the development of resilience, similar to the principles of agroecology, can enhance both food security and income. Secondly, the frequency of floods and landslides may be successfully reduced by protecting and restoring forests and streams. Last but not least, mangrove growth and restoration in coastal ranges may greatly decrease the susceptibility of towns to tempest flows. Exposed communities have the ability to duplicate the successful solutions offered by NbS, therefore assuming ownership and promoting them (Walz et al., 2021). This process enhances the autonomy and resilience of these communities. The World Bank has highlighted increasing food

costs as the primary consequence of climate change that will have the highest influence on severe poverty by the year 2030 (Bank, 2020). Regional differences are expected to occur, with the primary danger in South Asia and Sub-Saharan Africa being related to food costs, whereas in Latin America and East Asia, the Caribbean, and the Pacific, the major risk is associated with health. The development of adaptation programs should prioritize addressing the following threats: urban gardening initiatives in cities can serve as a means to assist low-income groups in mitigating food security problems (Bank, 2020). The involvement of the general public is crucial. Multiple studies have provided empirical evidence supporting the notion that the successful implementation of NbS requires the active involvement of local vulnerable populations, ensuring their full participation in both the long-term and short-term adaptation efforts. It is imperative to safeguard the participation of susceptible communities in climate-related decision-making processes, with a preference for their leadership wherever feasible. The energetic participation of Indigenous groups in the implementation procedure is critical since they possess valuable information about the local natural environment (Seddon, 2022).

2.5 Dimension of Transdisciplinarity

The usage of NbS in the setting of urban adaptation is intrinsically characterized by its transdisciplinary and intersectoral nature. Transdisciplinarity is a prominent feature of NbS, as evidenced by scholarly sources (Albert et al., 2019). This characteristic is notably evident in the collaborative processes of cocreation, co-development, and coimplementation of initiatives aimed at addressing various difficulties. The use of natural processes to tackle social difficulties is a longstanding practice well rooted in landscape architecture and planning theory. This approach has been significantly impacted by McHarg's seminal work, "Design with Nature," published in 1969. NbS also derives significant insights from the fields of urban planning, engineering, and environmental sciences (BenDor et al., 2017). In order to effectively apply NbS, it is imperative for urban planning to embrace a fresh and innovative approach towards urban greening. This strategy may be evaluated through the implementation of initiatives aimed at expansion and urban regeneration. The successful execution of NbS necessitates intersectoral cooperation, a task that can prove to be arduous, particularly for municipal administrations in poor nations (Castelo et al., 2023). The inclusion of multi-level governance introduces a heightened level of intricacy to the procedural framework. The oversight of natural resource implementation and management is carried out by a range of varied organizations, leading to the emergence of several co-benefits, including those at the social level (Castelo et al., 2023). Multi-level governance facilitates collaboration and readiness, both of which are crucial for enhancing the ability to tackle climate-related issues. The utilization of these procedures for the purpose of equipping local governments with the ability to effectively address forthcoming crises may be advantageous. However, their current execution

may offer difficulties due to the presence of sectoral divisions that commonly occur within their organizational frameworks.

2.6 NbS Typologies

NbS may be classified into several types based on three key factors: (a) the extent of human involvement, (b) the specific problems being treated, and (c) the kind of environment in which they are implemented. The initial typological classification for NbS, which was published in 2015 (Halimanjaya & Papyrakis, 2012), outlined three distinct types based on the level of human interference. Type 1 encompasses interventions that involve negligible or no human interference in ecologies. Type 2 pertains to activities that strive to found ecosystems and sceneries that are both sustainable and multifunctional. Lastly, Type 3 encompasses measures that concentrate on the conception of novel ecosystems or the intensive management of current ones. NbS can also be classified based on the difficulties they aim to tackle. The identification of socioeconomic vulnerability dimensions and the specific climatic impacts being addressed may be categorized into three main strategies: (1) the reduction of exposure, (2) the reduction of sensitivity, and (3) the support of adaptive capacity. IUCN and EC classify NbS based on the specific difficulties they aim to tackle. The International Union for IUCN has identified five key areas that are encompassed by NbS. These categories are human health, food security, water security, disaster menace reduction, and climate change (Frantzeskaki et al., 2022). EC has categorized seven distinct types of NbS based on their respective areas of innovation and investigation. These categories include (a) bolstering coastal resilience; (b) carbon sequestration; (c) regeneration and enhancement of well-being in urban areas; (d) promotion of sustainable utilization of matter and energy; (e) restoration of ecosystems; (f) effective management of watersheds; and (g) insurance of the value provided by ecosystems (Bauduceau et al., 2015). There exists a degree of overlap among these categories. An alternative approach to classifying typologies for NbS is through the categorization of landscape types, as planned by Skrydstrup et al. (2022) in the situation of urban flood management.

1. One example of maintainable urban drainage organizations is the implementation of tiny green spaces, such as accessible rain gardens, green roofs, and swales. The aforementioned systems possess a high degree of flexibility, necessitating little or negligible spatial requirements. The standard spatial scale is smaller than 1 hectare.
2. City parks are expansive green spaces that offer many recreational opportunities and may include natural water features such as lakes. According to the cited study, a city park typically spans an area ranging from 1 to 50 hectares.
3. Nature areas refer to green spaces that provide opportunities for many forms of recreational activities and may include bodies of water, such as wetlands. In contrast to urban parks, peri-urban green spaces exhibit a greater degree of

naturalness, fostering enhanced biodiversity. These areas surpass a minimum size threshold of 50 hectares and are commonly situated in close proximity to urban centers, often taking the form of forests or similar ecosystems.

4. Rivers and streams are predominantly composed of water, hence including riverbanks or floodplains that are accessible to individuals. In general, the focus is on certain segments of the river that accommodate urban recreational activities, often ranging in size from 1 to 60 hectares.

3 Knowledge Gaps

As a nascent discipline, there exists a considerable amount of research that remains to be conducted on NbS. Despite garnering growing attention and serving as a focal point of scholarly investigation (Seddon, 2022), several gaps in knowledge persist and have been duly recognized. In their study, Kabisch et al., (2016) delineate four distinct categories of knowledge gaps pertaining to NbS. These categories include (a) the efficacy of NbS, (b) the social dynamics associated with NbS; (c) the design considerations for NbS; and (d) the application challenges of NbS. The study conducted by FEBA (2021) highlights the importance of data, research, policy coherence, assessment, and the development of instruments that promote the preservation of ecosystems and the implementation of NbS in humanitarian settings. The evaluation of NbS's ability to provide advantages is of significant importance, as it has not yet been comprehensively assessed. In 2022, research was started by Network Nature, a source for NbS financed by the European Commission. The project, created together by ICLEI Europe, IUCN, Oppla, BiodivERsA, and Steinbeis 2i, aimed to identify 142 knowledge gaps across 27 overarching subjects (Calliari et al., 2022). A study conducted by Network Nature (2021) revealed the existence of 29 distinct gaps in knowledge and execution (Calliari et al., 2022). The research paper highlights four distinct categories of knowledge gaps in NbS pertaining to (a) technical designing, (b) assessment, (c) governance, and (d) capability building. These categories are visually shown in Fig. 1.

While there may be variations in the categorization of knowledge gaps among different authors, there is a general consensus on two types: technical design and assessment of efficacy. In addition to the knowledge gaps particular to NbS, there exist some gaps in understanding linked to adaptation despite the significant advancements made in this field over the previous twenty years. Based on the examination of existing scholarly works, this current study delineates four distinct categories of knowledge deficiencies that hold significant relevance in the context of employing NbS for urban adaptation. The topic of discussion pertains to the climate conditions that are anticipated to occur in the future. There exists a degree of ambiguity within the field of climate research as well as in the realm of policy-making, pertaining to the appropriate courses of action to be undertaken by national governments. This phenomenon gives rise to uncertainty and necessitates the continuous revision of estimations. The World Meteorological Organisation (WMO) declared in 2022 that there