Lecture Notes in Civil Engineering

Yusuf A. Mehta · Iacopo Carnacina ·
D. Nagesh Kumar · K. Ramachandra Rao ·
Madhuri Kumari *Editors*

Advances in Water Resources and Transportation Engineering

Select Proceedings of TRACE 2020

Springer

Lecture Notes in Civil Engineering

Volume 149

Series Editors

Marco di Prisco, Politecnico di Milano, Milano, Italy

Sheng-Hong Chen, School of Water Resources and Hydropower Engineering, Wuhan University, Wuhan, China

Ioannis Vayas, Institute of Steel Structures, National Technical University of Athens, Athens, Greece

Sanjay Kumar Shukla, School of Engineering, Edith Cowan University, Joondalup, WA, Australia

Anuj Sharma, Iowa State University, Ames, IA, USA

Nagesh Kumar, Department of Civil Engineering, Indian Institute of Science Bangalore, Bengaluru, Karnataka, India

Chien Ming Wang, School of Civil Engineering, The University of Queensland, Brisbane, QLD, Australia

Lecture Notes in Civil Engineering (LNCE) publishes the latest developments in Civil Engineering - quickly, informally and in top quality. Though original research reported in proceedings and post-proceedings represents the core of LNCE, edited volumes of exceptionally high quality and interest may also be considered for publication. Volumes published in LNCE embrace all aspects and subfields of, as well as new challenges in, Civil Engineering. Topics in the series include:

- Construction and Structural Mechanics
- Building Materials
- Concrete, Steel and Timber Structures
- Geotechnical Engineering
- Earthquake Engineering
- Coastal Engineering
- Ocean and Offshore Engineering; Ships and Floating Structures
- Hydraulics, Hydrology and Water Resources Engineering
- Environmental Engineering and Sustainability
- Structural Health and Monitoring
- Surveying and Geographical Information Systems
- Indoor Environments
- Transportation and Traffic
- Risk Analysis
- Safety and Security

To submit a proposal or request further information, please contact the appropriate Springer Editor:

- Pierpaolo Riva at pierpaolo.riva@springer.com (Europe and Americas);
- Swati Meherishi at swati.meherishi@springer.com (Asia - except China, and Australia, New Zealand);
- Wayne Hu at wayne.hu@springer.com (China).

All books in the series now indexed by Scopus and EI Compendex database!

More information about this series at http://www.springer.com/series/15087

Yusuf A. Mehta · Iacopo Carnacina ·
D. Nagesh Kumar · K. Ramachandra Rao ·
Madhuri Kumari
Editors

Advances in Water Resources and Transportation Engineering

Select Proceedings of TRACE 2020

Springer

Editors
Yusuf A. Mehta
Department of Civil and Environmental Engineering
Henry M. Rowan College of Engineering
Rowan University
Glassboro, USA

D. Nagesh Kumar
Department of Civil Engineering
Indian Institute of Science Bangalore
Bengaluru, India

Madhuri Kumari
Department of Civil Engineering
Amity School of Engineering and Technology
Amity University Uttar Pradesh
Noida, India

Iacopo Carnacina
Department of Civil Engineering
Liverpool John Moores University
Liverpool, UK

K. Ramachandra Rao
Department of Civil Engineering
Indian Institute of Technology Delhi
Delhi, India

ISSN 2366-2557 ISSN 2366-2565 (electronic)
Lecture Notes in Civil Engineering
ISBN 978-981-16-1302-9 ISBN 978-981-16-1303-6 (eBook)
https://doi.org/10.1007/978-981-16-1303-6

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd. 2021
This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

Civil engineering primarily focuses on construction, operation, maintenance, and management of infrastructure including buildings and bridges; roads, railways, airports, ports, and harbors; dams and reservoirs; irrigation systems, river training, and flood mitigation works; water supplies and sewerage schemes. To keep the infrastructure future-ready, it is important that engineers work along with the UN Sustainable Development Goal (SDG) 11 which pertains to "Sustainable Cities and Communities" and SDG 9 which pertains to "Innovation and Infrastructure."

With an aim to learn and share the latest findings, trends, and advances in civil engineering, the third international conference on "Trends and Recent Advances in Civil Engineering" (TRACE 2020) was hosted by the Department of Civil Engineering on August 20 and 21, 2020, at Amity University, Uttar Pradesh, Noida, India. The conference witnessed the participation and presentation of research papers from academia, industry expert, and researchers from R&D centers from India and abroad. The selected research papers were compiled and published in the form of conference proceedings.

This book titled *Advances in Water Resources and Transportation Engineering* is a compilation of the latest research works carried out by esteemed experts in water resources and transportation engineering. Each chapter corresponds to the latest technological application for solving challenges and problems encountered by water resources or transportation engineers. It aims to cover a broad spectrum of audience by covering interdisciplinary innovative research and applications in these areas. The objective of this compilation is to provide up-to-date information to those who are striving to contribute to this domain by utilizing the latest technology. The topics include technological intervention and solution for water security, sustainability in water resources and transportation infrastructure, crop protection, resilience to disaster like flood, hurricane, and drought, microplastics in river, and traffic congestion. The chapters present the latest areas of research like the application of remote sensing and software for solving real-time issues. We are hopeful that it will prove to be of high value to graduate students, researchers, scientists, and practitioners working in water resources and transportation engineering domain.

Glassboro, USA	Yusuf A. Mehta
Liverpool, UK	Iacopo Carnacina
Bengaluru, India	D. Nagesh Kumar
New Delhi, India	K. Ramachandra Rao
Noida, India	Madhuri Kumari

Acknowledgements

From the conceptualization of conference TRACE 2020 to its outcome in form of the compiled books, the journey was exciting and fulfilling. As I write this session, it gives me a great sense of achievement not because "I" was working for it day and night but because I was part of the great "team" who wrote the success story of this conference.

Though we were challenged by COVID-19, we kept going because of the positive push and motivation of our honorable Founder, Dr. Ashok K. Chauhan, respected Chancellor, Dr. Atul Chauhan, and esteemed Vice Chancellor, Dr. Balvinder Shukla. I wish to thank them all for believing in us and guiding us for hosting the first ever online international conference in civil engineering domain. I am extremely thankful to our dynamic leadership team including Joint Heads of Institution and Head of the Department for providing valuable suggestions and support whenever it was required.

I am very thankful to the advisory committee and the organizing committee of TRACE 2020 who provided continuous support for the successful execution of the online version of the conference. I express my sincere appreciation to all our sponsors for their support: Academic Partners: Liverpool John Moores University, UK, Tribhuvan University, Nepal, Rowan University, USA; Industry Partner: Defense Infrastructure Planning and Management (DIPM) Council of India; Knowledge Partners: Institution of Civil Engineers (ICE), India; Indian Association of Structural Engineers (IAStuctE); Women in Science and Engineering (WISE), India; Indian Geotechnical Society (IGS) and Indian Building Congress (IBC). I acknowledge the contribution of all the esteemed speakers from industry and academia for providing the insight on the latest trends and practices in civil engineering.

I wish to acknowledge and thank all the authors and co-authors of different chapters who cooperated with us at every stage of publication and helped us to sail through this mammoth task. Special thanks to all the national and international reviewers who helped us in selecting the best of the works as different chapters of the book.

I owe my sincere gratitude to my family members and faculty colleagues who helped me through the compilation of this book. Finally, I compliment the editing team of Springer who provided all guidance and support to us in the compilation of the book and shaped up the book into a marketable product.

Dr. Madhuri Kumari
General Co-chair, Trace 2020, Professor,
Department of Civil Engineering, Dy. Director,
Placement and Industry Relations, Amity School
of Engineering and Technology
Amity University Uttar Pradesh
Noida, India

Contents

About the Editors

Dr. Yusuf A. Mehta is professor in Department of Civil Engineering of Henry M. Rowan College of Engineering and has extensive experience in pavement systems and management. Dr. Mehta received his Ph.D. in Civil Engineering from The Pennsylvania State University in 1999 and and M.S. in Civil Engineering from The Oklahoma University in 1995. Dr. Mehta is a registered Professional Engineer in New Jersey. He has publications in refereed journals and international conferences. He has managed multiple projects of New Jersey Department of Transportation, Research and Innovative Technology Administration USDOT and New York State Department of Transportation. He received Aviation Research Award and New Jersey DOT Research Implementation Award in year 2012. He was recognized for his exemplary teaching by Mid-Atlantic American Society of Engineering Education in 2008. He received Louis J. Pignataro Memorial Transportation Engineering Education Award in 2013 for outstanding record of achievement in transportation engineering research, and undergraduate and graduate engineering education. He is Associate Editor of American Society of Civil Engineers Journal of Transportation Engineering. He is part of Editorial Board, Modern Traffic and Transportation Engineering Research (MTTER). He is member of American Society of Civil Engineers, Transportation Research Board, American Society for Engineering Education and Association of Asphalt Paving Technologist.

Dr. Iacopo Carnacina is Senior Lecturer in Civil Engineering at Liverpool John Moores University since year 2017. Prior to this he has been Lecturer and Researcher in River Engineering at UNESCO-IHE Institute for Water Education within the department of Water Science and Engineering. In 2006 he obtained his master degree in Hydraulic, Transportation and Territory Engineering from the University of Pisa, Italy. In 2010 he obtained his Ph.D. in Civil Engineering from the doctorate school of the University of Pisa “Leonardo da Vinci” Italy. Since 2007, he has also been a member of the professional body of Civil Engineers of the province of La Spezia, Italy. Previously, he was involved in the CARNOT/VITRE research project on sediment transportation of combined sewer networks using acoustic devices at the French Institute of science and technology for transport, development and networks

(IFSTTAR). After that, he worked for more than 5 years at AIR Worldwide, a catastrophe modeller firm, where he developed fluvial, pluvial and storm surge stochastic numerical models for the continental United States, Brazil, China, Central Europe, UK and Japan. There, he also worked as model manager and scientific lead for the new North Sea storm surge model in collaboration with Deltares, which resulted in development of new solutions using Delft3DFlexile Mesh. He is interested in local erosion in correspondence of hydraulic structures such as bridge, river training structures and dams, large scale numerical flood models and flood protection. He has also contributed to the study of sustainable river training structures, with focus on local erosion phenomena and morphology, design, energy dissipation and two phase flow development. His research focuses on the sustainable impact of hydraulic structures with focus micro-hydropower development in rural regions use of sustainable resource to optimize efficiency and minimize the environmental impact.

Prof. D. Nagesh Kumar is the Chairman, Centre for Earth Sciences, Indian Institute of Science, Bangalore. He has been working in the Department of Civil Engineering IISc since May 2002. Earlier he worked in IIT, Kharagpur (1994–2002) and NRSC, Hyderabad (1992–1994). He obtained Ph.D (Engg) from Indian Institute of Science, Bangalore, India in 1992. He visited Utah State University, USA in 1999 for 6 months on BOYSCAST fellowship. He worked as Visiting Professor in Ecole Nationale Supérieure des Mines, Saint-Etienne, France, in 2012. His research interests include Climate Hydrology, Water Resources Systems, Climate Change Impact on Water Resources, ANN, Evolutionary Algorithms, Fuzzy logic, MCDM and Remote Sensing & GIS applications in Water Resources Engineering. He has published more than 170 papers in leading international journals and conferences in his research fields. He has co-authored three text books viz., “Multicriterion Analysis in Engineering and Management” published by PHI, New Delhi and “Floods in a Changing Climate: Hydrologic Modeling” published by Cambridge University Press, U.K. and “Hydroclimatic Teleconnection: Indian Perspective” published by Scholars’ Press, Germany. He is Associate Editor for ASCE Journal of Hydrologic Engineering and ISH Journal of Hydraulic Engg. He received the best associate editor award for ASCE Journal of Hydrologic Engineering for the year 2014. He is in the Editorial Board of Open Hydrology Journal and Journal of Applied Computational Intelligence and Soft Computing. He has been reviewer for more than 65 international journals including Water Resources Research and Journal of Hydrology. He received IBM faculty award for the year 2012 for his outstanding research in the field of modeling hydrologic extremes using microwave remote sensing. He is a member, Working Group on Climate Change, International Association of Hydraulic Engineering and Research (IAHR), Spain. He is a Fellow of Institution of Engineers (India) and Indian Society for Hydraulics. He is a member of the AGU, IAHR, ASCE, IAHS (UK), IS-MCDM (USA) and Indian Society of Remote Sensing.

Dr. K. Ramachandra Rao is a professor in Department of Civil Engineering and Associate Faculty of Transportation Research and Injury Prevention Programme (TRIPP), Indian Institute of Technology, Delhi. He is a Transportation Engineering specialist. After completing PhD in Transportation Engineering at IIT Kharagpur in 1998, he started his teaching career in School of Engineering - University of KwaZulu Natal, Durban, South Africa (formerly University of Durban-Westville). Subsequently, he worked in IIT Guwahati in Civil Engineering Department as Assistant Professor. Since 2003, he is working in IIT Delhi. Besides teaching and research, he is involved in various projects at national and international levels. He has published research papers in leading international journals and conferences in his research fields. The main focus area of his work during the past 5 years has been on development of traffic models in heterogeneous and safe environments. Besides, he is also working on improvements of Bus transport systems, road safety and low carbon mobility.

Dr. Madhuri Kumari received her PhD from The Energy Resource Institute (TERI) for her work on geostatistical modeling for prediction of rainfall in Indian Himalayas. She completed her M.Tech in Hydraulics and Water Resources Engineering from Institute of Technology, Banaras Hindu University and B.E in Civil Engineering from Andhra University and was awarded Gold Medal. She is working as Professor in Department of Civil Engineering, Amity School of Engineering and Technology, Amity University Uttar Pradesh, Noida, U.P. She has vast industry experience of 11 years and academic experience of around 11 years. Her research works in area of rainfall modelling have been published in reputed journals. Her research interest is in application of geographical information system in solving problems related to water resources engineering.

Nature-Oriented Paradigms for Urban Water Security: Perspective on Framework, Scale, and Sector

Negin Balaghi-Ficzkowski, Nidhi Nagabhatla, and Tariq A. Deen

Abstract Water security in urban areas is threatened by a multitude of direct and indirect drivers. On the one hand, the demand for water is increasing on a daily basis as the urban population and lifestyle needs increase; on the other hand, events such as floods, tropical cyclones, and other natural hazards result in disruption of water provisioning systems and processes. Additionally, climate change impacts such as heat waves and sea-level rise affect the sustainability of water supplies in urban areas. Conventionally, hard engineering structures and strategies have been implemented around the world to address water needs in urban areas and solutions that are often costly and intrusive to the natural environment. Nature-based solutions (NBS) in the past years emerged as a framework for exploring the potential of soft engineering solutions—as an alternative for managing urban planning, building climate resilience, and sustaining water needs of the urban communities. In this chapter, the following points are explained: (a) review of selected nature-oriented conceptual framings and practical options that apply to urban water systems, (b) illustration of existing NBS practices such as permeable pavements, green roofs, and bioretention ponds in urban landscape architecture planning, and (c) future of urban landscapes with comparative context of traditional versus nature-based water management practices. The conclusion draws attention to the UN Decade on Ecosystem Restoration (2021–2030) that is aiming to prevent, halt, and reverse the degradation of ecosystems globally. The aim is to present a synthesis that can steer integrated development planning while addressing basic water needs, climate resilience, and ecosystems protection in all settings and particularly in urban landscapes.

N. Balaghi-Ficzkowski (✉) · N. Nagabhatla · T. A. Deen
McMaster University, Hamilton, ON, Canada
e-mail: negin.balaghi@gmail.com

N. Balaghi-Ficzkowski
United Nations University Institute for Water, Environment, and Health, Hamilton, ON, Canada

N. Nagabhatla
The United Nations University Institute on Comparative Regional Integration Studies
(UNU-CRIS), Brugge, Belgium

© The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd. 2021

Y. A. Mehta et al. (eds.), *Advances in Water Resources and Transportation Engineering*,
Lecture Notes in Civil Engineering 149,
https://doi.org/10.1007/978-981-16-1303-6_1

Keywords Urban water security · Nature-based solutions (NBS) · Climate change · Natural hazards · Water resilience

1 Introduction

Driven by the prospect of social spaces and economic opportunities, more and more people have been moving into cities over the past century, resulting in urban population increase at a rate faster than ever before. In 1950, urban population accounted for 30% of the world's population; by 2014, this number increased to 54% [37]. As the urban population continues to grow, the urban landscapes become crowded, and the existing civil/municipal infrastructure deteriorates at a faster rate; social and public services are rendered insufficient, and the pressure for quick development rises. In the working group document to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Revi et al. [26] illustrate how expanding urban centers is characterized by dense infrastructure which directly impacts inhabitants' vulnerability to weather disturbances and climate change impacts.

Data projections by the World Health Organization (WHO) indicate a continuous increase in urban population over the next few decades, projecting 2.5 billion people flow by 2050 [37]. This could be inferred as around 6.4 billion people living in cities in the next 30 years resulting in increased demand for food, energy, and water supply. The World Bank anticipates about 50% increase in urban water demands within the next 30 years [31]. Some trends are shown in Fig. 1.

According to a recent estimate, by 2030 (Sustainable Development Goals tenure) close to one billion additional people will live in cities in the Latin America and the Caribbean region which is currently considered the most urbanized developing region globally [35]. The already scarce freshwater supplies and the simultaneous impacts

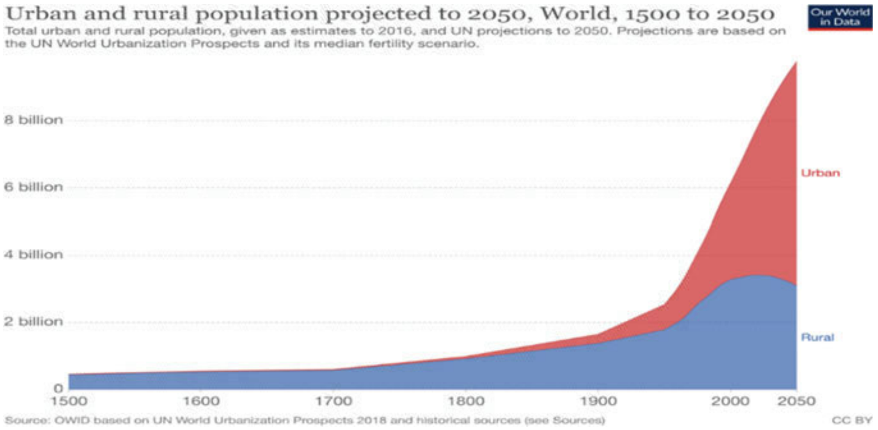

Fig. 1 Projected Urban Population by 2050 based on UN World Urbanization Prospects 2018 and others. *Source* ourworldindata.org [27]

of the water crisis, such as pollution and contamination, call for a paradigm shift to sustainable urban planning, more so in developing cities. This means infrastructure designs of cities must emphasize on community spaces, green zones, and water use–reuse–recycle systems. Moreover, climate change condition exacerbates water insecurity and adds additional need for developing (or adopting) efficient and effective water policies globally. The sustainability issue with the existing (mostly gray) infrastructure and the economic benefits of long-term planning require investigation of nature and resource-efficient solutions that offer multiple benefits to environmental and human health [39].

In this chapter, an overview of the nature-based solutions (NBS) framework is provided within the context of water security and with focus on urban landscapes. Furthermore, gaps and needs are analyzed by quoting examples of best practices worldwide to demonstrate integration of the nature-based solutions in urban planning. We discuss effective and appropriate implementation of NBS toward reducing exposure and vulnerability to urban water insecurity with respect to the Sustainable Development Goals (SDGs) and the New Urban Agenda which together present a foundation for climate and water resilient city planning.

2 Overview of Frameworks, Scale, and Sector: NBS and Water Security

A key reference to set the design of this chapter is the water security definition by UN-Water: "*the capacity of a population to safeguard sustainable access to adequate quantities of and acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability*" [36]. For the first time, this narrative presents water as an interlinked challenge within environmental, social, and political domains. Water security and climate resilience are inseparable, deeply and naturally interconnected [29]. The broad scope of water security framework of UN-Water [36] allows for developing the water security nexus, highlighting the interdependencies between achieving water, energy, and food security with the relational aspects of climate change adaptation (CCA), disaster risk reduction (DRR), and the objectives of human development, national security, and sustainable economic development (Fig. 2).

The integrated water resource management (IWRM) framework introduces three key aspects of *ecological sustainability*, *economic efficiency*, and *social equity* in water management and planning [9]. This framework bears flexibility in context of the larger water security nexus planning and implementation in all settings for urban, agricultural, industrial, and other economic sectors of computing water use; therefore, it has been adopted by many development agencies (including the World Banks and UNDP). IWRM as a water management framework compliments the

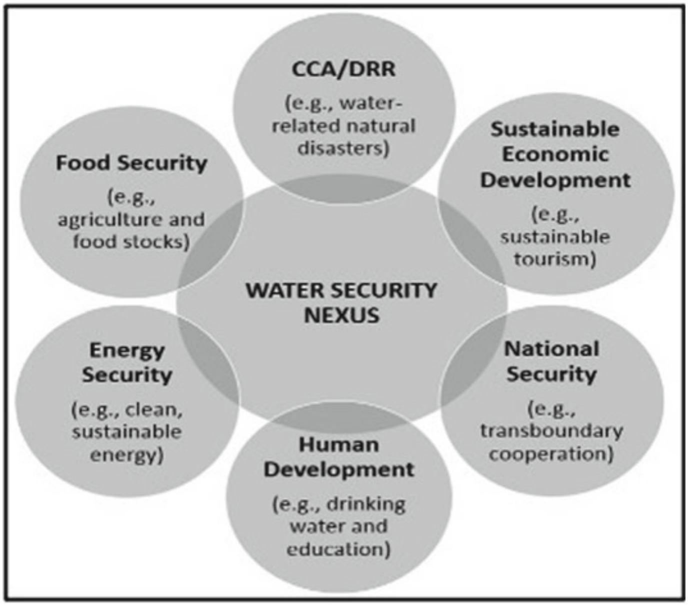

Fig. 2 Multiple challenges with relational aspects to the water security nexus (Figure by Tariq Deen)

water security perspective. As such, knowledge and experience between these two conceptual framings can be applied to urban water security agenda setting.

The water security challenges in the urban regions (city, township, or a municipality) are influenced by various drivers such as population density, lifestyle choices, and informal settlements. Climate change impacts on cities manifest in various ways, for instance, increasing heat island effect, dry conditions impacting water availability and recharge, sea-level rise (if that applies in geographical context), coastal or river flooding and erosion, storm surges and stormwater management, flooding, and health outcomes for these impacts noted as heat stress and respiratory disorders [26]. While all urban social groups are either directly or indirectly affected by climate change and environmental stresses, certain groups are more vulnerable; these include the elderly, children, pregnant women, the homeless, people living with disabilities, and people living with low levels of income [39]. Therefore, it is crucial to organize basic water provisioning needs and climate resilience programs for the benefit of all citizens [12].

The urban water security concept finds background in addressing water-related impacts of climate change that threatens cities. Post 2010, some cities have begun to implement strategies to protect their communities, infrastructure, and environmental resources from natural hazards and future impacts of climate change; for example, a public square built in Copenhagen that stores stormwater [20] or the “Sponge City” project constructed in Shenzhen that bears capacity to capture 60% of annual rainfall [5]. Shenzhen aims to minimize the impact of rapid urbanization on the environment and water pollution to build a sustainable and healthy water circulation system in the future [5]. Nevertheless, implementing such projects often requires an understanding and awareness of ecosystem-based low-impact development (LID) solutions, justification of social and economic co-benefits, governance approach, engagement with multiple actors, and even new financing models [4].

Nature-based solutions (NBS) are initiatives that take advantage of the various mechanisms that nature provides at protecting communities from the destructive forces of natural hazards and other environmental changes. The International Union for Conservation of Nature (IUCN) explains NBS as "*actions to protect, sustainably manage and restore natural or modified ecosystem that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits*" [6]. The framework has gained recognition due to the potential it carries to address the emerging challenges of water security and disaster risk management, climate change adaptation, environmental protection, water and human security, and projecting itself as a cost-effective measure compared to traditional hard engineering strategies (see various chapters in Multifunctional Wetlands [21]).

The 2018 UN World Water Development Report highlights the NBS framework as a solution to water crisis, stating that NBS can use or mimic natural processes to enhance water availability (e.g., soil moisture retention, groundwater recharge), improve water quality (e.g., natural and constructed wetlands, riparian buffer strips), and reduce risks associated with water-related disasters and climate change (e.g., floodplain restoration, green roofs). Two significant impacts of climate change on urban areas are reduced water availability (or water scarcity due to dry conditions or water pollution) and rise in unwanted water (flooding). Currently, the solutions to combat these challenges within the urban water management remain heavily dominated by traditional, human-built ('gray') infrastructure. The potential for NBS as a means to move beyond existing systems remains underutilized in addressing many of the water challenges, including in the urban settings [39]. The geographical location of an urban population provides some initial considerations for exploring applicable nature-based solutions for urban infrastructure developers. The potential solutions can address three main types of settings representing water security needs in an urban landscape: (a) land-locked urban areas, (b) coastal cities, and (c) watersheds, reservoirs, and other sources of water storage and protection. Some examples are listed in Annexure 1.

NBS systems could be implemented naturally through creation, protection, or restoration of only ecosystem elements. In a joint report, the World Bank Group and World Resources Institute (WRI) propose structural strategies aimed to advance the integration of green and gray infrastructure solutions to substitute, augment, or work in parallel with existing gray infrastructure in a cost-effective manner [4]. Strategizing the NBS approach in urban infrastructure planning aims to find a balance of the green and gray combination that maximizes the benefits and system efficiency of the solutions and minimizes the trade-offs between the costs and the environmental impacts.

A case study example illustrating NBS noted in the Mekong Delta in Vietnam reflects integration of green and gray integration project, wherein mangrove ecosystems were rooted into the project design to restore the existing sea dikes. The rapid aquaculture expansion in late 1980s along the northern coast of Vietnam caused significant loss of mangrove forests that were acting as the area's natural defenses against coastal floods and erosion. To mitigate the impacts of the natural disasters and protect the ever-growing population, restoration of the mangrove forests was agreed as necessary and in 1994, Mangrove Plantation and Disaster Risk Reduction Project was launched to enhance the existing gray infrastructure by investing $9 million in restoring 9000 hectares (ha) of mangroves area and as 100 km of dike lines by 2010. Noted was significant reduction of maintenance cost of dikes by $80,000 and $15 million saved as damage to private property and other public infrastructure also lowered considerably [14]. The coastal cities worldwide are hub of economic activity and therefore to maintain ecological and development balance remain pertinent to ensure sustainable development. It can be argued that often the cost of investment in NBS bears merit in medium to long terms planning, in comparison with short and quick gray infrastructure solutions [24]. In addition, strategies that can combine gray approach and NBS are also investigated by experts and agencies.

NBS is leveraging from existing concepts like the ecosystem-based adaptation (EBA) that propagates well-managed ecosystem as an adaptive tool to climate change and ecosystem-based disaster risk reduction (Eco-DRR) that considers well-managed ecosystem with an objective to reduce the effects of natural hazards that do not necessarily have to be linked to climate change [6]. These two approaches can be used in tandem with NBS to enhance ecological and social resilience, especially in the urban areas with high population density. For instance, mangrove ecosystems have traditionally functioned as a natural strategy for coastal protection because of its complex root structure and dense branch system. Global case studies illustrate how mangroves have helped maintain coastal soil structure and reduce wave energy during storm surges. If planned systematically, mangroves can significantly reduce exposure to coastal hazards like tsunamis and tropical cyclones [11].

Nature-based solutions are widely explored for coastal flooding. Most NBS (or hybrid-NBS) projects reported by the World Bank in 2017 are to combat ongoing river flooding challenges [4]. A good example is river reconnection in China [42]. The construction of dam and dike in the Yangtze River Basin in China from the 1950s to 1970s caused significant undesirable impacts on the existing river–lake wetlands systems. As a result, major flooding events were noted in 1990s that caused loss of life for thousands and direct economic losses in billions of dollars. In a partnership with World Wildlife Fund (WWF), the Chinese Government reconnected the Yangtze River with the disconnected lakes and rehabilitated the natural functions of the wetland system as an attempt to reverse the damages and mitigate the flooding risk. Noted was restoration of nearly 500 km^2 wetlands with floodwater retention capacity up to 300 cubic meter;amid other economic co-benefits of this project and was more than 17% increase in lake districts fisheries production [42].

NBS approach offers variety of co-benefits in tackling challenges related to urban water security and DRR. For example, for tropical regions coastal resilience strategy, mangrove ecosystems can provide ecological co-benefits in terms of pollution control for aquatic and marine life. Kathiresan and Rajendra [18] show how Indian hamlets with mangroves were significantly less damaged after the 2004 Indian Ocean Tsunami, compared to those without a dense mangrove zone. Das and Vincent [7] observed that mangroves were able to buffer the 1999 super cyclone in Orissa, India. In other parts of the world, the European Union (EU) projects, focusing on efficient and effective design of NBS for restoration of degraded marine environments, demonstrate examples to scale and to support policy negotiations [13].

A common planning challenge for densely populated cities is spatial footage and a lack of available real estate to adopt or implement NBS [24]. Use of integration strategies in existing infrastructure is one of the common strategies in such situations. For instance, roof gardens (also known as living roofs, vegetated roofs, or eco-roofs) address space limitation in densely developed metropolitans. The roofs of buildings can host gardens comprising live vegetation, with innovative structures, built to application; however, the foundation of a layer of soil/growing material and a vapor seal to protect the building from water and vegetation roots are key design aspects, plus additional layers to transport water to a storage tank. These systems are adopted for stormwater management system in some instances, wherein collection of filtered water helps to reduce municipal water demand during dry periods. Around this foundation, construction of hybrid natural solutions plus hard engineering structures to relocate rainwater to storage tanks is an alternative. The stored water can be utilized for provisioning needs such as drinking water during conditions of water shortage. In addition, benefits such as regulation of temperature for the building are noted as the soil layers act as insulators [24]. So, the energy efficiency dimension applies, especially during summer months in buildings and establishments integrating NBS systems as measures for urban planning.

Ho Chi Minh City in Vietnam has a growing population of 8 million. Much of the city's natural landscape is converted to urban expansion and green spaces are limited to 0.25%. The natural drainage system is filled, encroached, or blocked by waste which results in flooding. Upstream development of the Saigon-Dong Nai River results in water shortages for the city during the dry season. The city is exploring options for sustainable urban planning, wherein houses are designed as "pots" with roof gardens to store stormwater and mitigate flooding impacts. A design includes placing a thick layer of soil on roofs to retain stormwater and planting banyan trees to make use of their aerial root system. The ground is made of permeable bricks to increase infiltration during rainfall events. This intervention was tested for the President Place that serves as office and commercial space. Leading to a successful experiment, the building received a Leadership in Energy and Environmental design (LEED) Gold certification in energy and water efficiency category. It used 50% less water than other non-LEED buildings quoted Asian Development Bank [2].

The final case study highlights the importance of policy implication in NBS implementation and developing integrated strategies for NBS deployment [30]. Peru has dealt with water crises related to El Niño for many years; a trend that has been intensified by the climate change effects during last decades. In 2016, the Peruvian lawmakers called the Sanitation Sector Reform Law aiming to remediate the increasing water-related risks. This policy requires water utilities to earmark revenue from water tariffs for watershed conservation and climate change adaptation and to consider these strategies in the official budgeting and planning processes. The policy was implemented and for 4 years generated \$30 million for NBS via payments for ecosystem services and an additional \$86 million for climate change mitigation and disaster risk management [16].

3 Global Governance Tools for Sustainability and the Urban Water Security Context

Sustainable Development Goals (SDGs) are a set of 17 global goals that aim to end poverty, protect the planet, and ensure prosperity for all [41]. The SDGs are the successor to the Millennium Development Goals (2000–2015) and include 169 targets many of which are interlinked. With respect to urban water security, goals 6 (Clean Water and Sanitation), 11 (Sustainable Cities and Communities), 13 (Climate Action), and 15 (Life on Land) contain relative targets for addressing the issue. Some selected examples of SDG targets that apply to urban water security include SDG 6.6 calling for protection and restoration of water-related ecosystems, including mountains, forests, wetland, rivers, aquifers, and lakes; SDG 11.6 emphasizing reduction in the adverse per capita environmental impact of cities, including paying special attention to air quality and waste management. SDG 13.1 on strengthening resilience and adaptive capacity to climate-related hazards and natural disasters in all countries and SDG 15.1 ensuring the conservation, restoration, and sustainable use of terrestrial and inland fresh ecosystems and their services, in particular forests, wetlands, mountains, and drylands, in line with obligations under international agreements.

Water insecurity is an issue that is interconnected with other environmental and socioeconomic challenges, and SDGs provide a guiding framework for cities and communities to identify development priorities with a balanced approach (i.e., human and ecological development agendas addressed in tandem). For instance, SDG targets 6.6, SDG13, and SDG 15.1 all relate to the protection and restoration of aquatic ecosystems, noting that healthy ecosystems are better able to protect communities from climate change impacts and natural hazards and can better serve provisioning needs for people and populations such as drinking water. The concept of resilience is often associated with the defined frameworks, including NBS, steering the notion of creating systems that are better prepared to cope with and recover from natural disasters, environmental changes, and climate change, through the preserving and restoring of basic infrastructure and services. The SDG agenda can only be achieved when its implementation strategies are risk-informed, and water climate and disaster risks are tackled through integrated frameworks. Note that SDG 13.1 calls that countries must plan long-term development tools, rather than responding with short-term emergency measures.

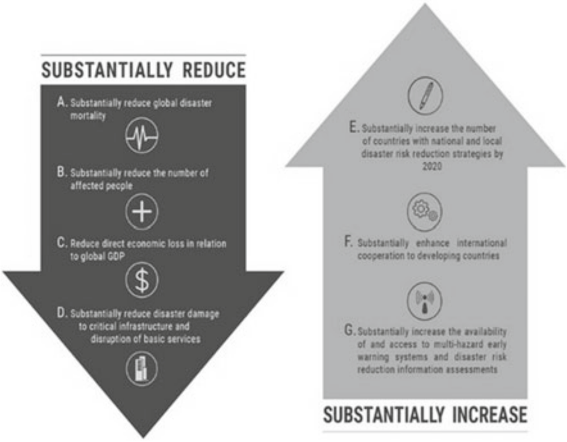

Fig. 3 Seven goals of the Sendai framework figure. *Source* United Nations Office for Disaster Risk Reduction [38]

The Sendai Framework is the successor to the 2005–2015 Hyogo Framework for Action and was adopted at the Third UN World Conference on Disaster Risk Reduction in Sendai, Japan, in March 2015. This non-binding disaster risk reduction (DRR) agreement asserts that it is the responsibility of the state, local governments, the private sector, and other stakeholders to protect communities against natural hazards. The outcome of the framework states that the substantial reduction of disaster risk and losses in lives, livelihoods, and health in the economic, physical, social, cultural, and environmental assets of persons, businesses, communities, and countries covers a period from 2015 to 2030 [40]. The seven goals as summarized in Fig. 3 also link with SDGs to a fair extent.

Other international agreements, like the Paris Agreement, include high-level commitments to promote ecosystem-based solutions such as NBS. The New Urban Agenda [41] describes a vision, with principles and commitments, a call for action, and an implementation plan. It sets the pathway for Sustainable Cities and Human Settlements and is targeted toward the key stakeholders involved in urban governance and planning, including nation states, cities, UN agencies civil societies, and NGOs. The New Urban Agenda also highlights the human right principle and criteria in relation to drinking water and sanitation. Water is embedded within the vision, commitments, and call for action for this agenda offering incentives to design sustainable solutions for urban water management. The frameworks and principles provided assist urban leaders to develop and implement their vision for managing urban water needs and climate resilient cities. Commitments outlined in the New Urban Agenda is provided in Annexure 2. The goal to encourage collaborative action and vision is central to most global governance frameworks so that local governments, urban professionals, and individuals actively engage in addressing and finding solutions on urban water management challenges driven by paradigm shifts [15].

4 Key Discussion Points

NBS as a strategy is not to prevent weather disturbances, natural hazards, or environmental processes from occurring but rather to reduce the impact these disturbances have on infrastructure, human lives, and economic activity. Therefore, NBS can and will contribute to the SDG targets and the goals of the Sendai framework in the urban water security context and serve as a strategy to create a frame for policy changes at local government level while allowing focus on resilience in urban planning and infrastructure development.

While there is a growing appetite for investment globally to support nature-based initiatives, there are certain considerations and barriers to implementing NBS projects. NBS planning is often a long-term investment which requires commitments of states and communities through co-creation and consultative processes. In the current system, development priorities do not necessary align with ecological benefits or inter-agency and regulatory approval processes, lack clarity, or are long and cost intensive. In addition, lack of awareness or shared knowledge about the success stories and best practices sever to limit scalability NBS options [17]. To overcome these underlined challenges, key considerations include careful evaluation, smart planning, minimization of trade-offs in infrastructure planning and participatory approach to project/program design. Some NBS projects are exceedingly context specific and needing customization, as such, technical expertise and systematic analysis on design, planning, and implementation are pertinent. For instance, drought management in urban environments can be challenging since droughts have wide-reaching spatial and temporal impacts including the effect on water availability. Hence, integrated design of a household/residential building to capture rainwater, store access water or recycle–reuse wastewater are options that can be implemented within the NBS framework. Some examples of such interventions are documented in the monograph, Multifunctional Wetlands-Pollution Abatement and Other Ecological Services from Natural and Constructed Wetlands [21].

Other important considerations in implementation of NBS are enabling conditions. Existing practices, programs, and policies need to be modified to allow unlocking NBS opportunities. During past few years, considerable effort toward establishing NBS frameworks is observed. For instance, in 2017 the World Bank outlined eight distinctive steps for planning and strategizing NBS implementation. Building on the work of the EKLIPSE project in the European Union, Raymond et al. [25] developed and proposed a seven-stage process for co-benefit assessment within policy and project implementation for NBS in urban areas. The importance of frequent engagement with stakeholders, continuous monitoring and evaluation post implementation, sharing best practices, and evaluating scaling potential are key dimensions that apply.

International Water Association (IWA) distributed 17 principles for water wise cities toward water sensitive urban infrastructure encouraging policy development at the local scale [15]. The initiative was reassuring for urban developers and decision-makers to share their experience with NBS and encourage mutual partnerships. Such