Nature-Based Solutions as a Pragmatic Approach Towards Flood Resilient Cities

Madhuri Kumari, Pranjal Pandey, Akanksha, and R. K. Tomar

Abstract Flooding is one of the most common and severe disasters that afflicts several Indian states every year, and it is frequently followed by the spread of epidemics. The cities along the banks of river or seashore face great pressure in dealing with flood disaster management and such experience will mount up in the coming decades due to the rising intensity and frequency of natural hazards triggered by climate change. Therefore, there is a need to develop an environment-friendly pragmatic approach for making such vulnerable cities into a flood resilient city. In recent decades, flood risk reduction and management strategies are seen to be supplementing the traditional technical and engineering methods with nature-based solutions (NBS). NBS brings in multiple benefits to people and the social system by contributing towards improvement in quality of life, strengthening, and promoting ecological balance. This paper presents a conceptual framework for the integration of NBS into current Flood Risk Mitigation and Management (FRM) strategies. This framework is intended as a tool to be adopted by decision-makers to operationalize the NBS integrated pragmatic approach and work towards developing flood-resilient cities.

Keywords Flood resilience · Nature based solutions · Flood risk mitigation · Disaster risk reduction · Urban flooding · NBS framework

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1 Introduction

India experiences a variety of natural disasters and hazards, with flooding being the most significant. Flooding is defined as excessive surface runoff that inundates towns and farmland [1]. It is the most common natural catastrophe. The Intergovernmental Panel on Climate Change (IPCC) predicts that the region impacted by monsoon seasons will increase globally with rising precipitation levels, resulting in more flood events [2]. Flooding affects 14.6% of India's land area [3]. From 1978 to 2006, India had 2443 flood incidents causing 16 billion USD in damages [4]. During the monsoon season, which brings low to heavy rainfall, residents of Indian cities often experience flooded streets and waterlogged homes [5]. Monsoon season in India sees 80% of precipitation occur in a short time from June to September, leading to the highest number of flooding incidents (urban, rural, and coastal) in various regions of the country [6, 7]. Experts have long discussed the connection between climate-related disasters and their aftermath (socioeconomic losses and public health) [8]. Natural disasters such as flooding also pose a significant public health risk from water and air-borne infectious diseases, which have become increasingly prevalent over time [9]. Figure 1 shows that the states of Maharashtra, Tripura, West Bengal, and Bihar have had the highest number of flooding incidents in the last 15 years.

Flooding is classified into three types (ref. Table 1): rainfall-induced (pluvial), river flooding (fluvial), and tidal flooding (coastal) [10]. The preponderance of flood incidents during the monsoon season is triggered by prolonged rainfall and heavy downpours [11]. All river basins in India experience flood events; however, the Ganga and Brahmaputra River basins have the highest number and severity of flood events [12]. The Ganga River zone, the Brahmaputra River zone, the North-West River zone, and the Deccan (coastal) zone are the four principal flood zones in India [13].

Urban floods are common and have become serious issues around the world even in India as well [14]. Flooding happens most frequently in metropolitan areas due to substantial monsoon precipitation in a short period of time, causing significant damage to life and property. In India, 1561 urban local bodies out of 7935 are flood-prone [5, 15]. Figure 1 depicts the number of times flood occurred (flooding frequency) state-wise in India over the span of 15 years.

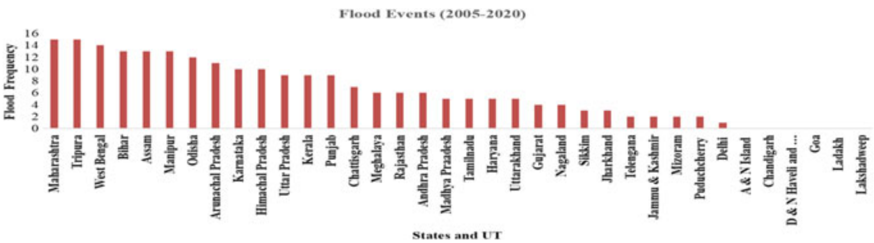

Fig. 1 Flood frequency in the last 15 years. (*Source* Annual disaster reports (2005–2020), Indian meteorological department (IMD))

Table 1 Types of floods in India

Type of flooding	Descriptions
Rainfall induced flooding	Heavy amount of rain over minutes to hours inundates creeks and dry valleys
River flooding	The floodplain is inundated when water from a river or drainage channel cannot be contained within its stream channel or by built structure. It occurs often seasonally. This is the most common flooding
Tidal flooding	Increasing sea level caused by storm surges generated by tropical cyclones and tsunami

The increasing urbanization in India has resulted in Indian cities being constructed hastily and in a haphazard manner, which has contributed significantly to the increased risk of an urban flood [16]. 30–40% more rainfall is observed in Indian urban cities than in rural areas [15]. Figure 2 shows the major flood prone regions in India. Metropolitan cities such as Mumbai, Delhi, Bangalore, Assam, Chennai, and many others are key examples of cities that face frequent urban flooding events, demonstrating the current state of flood management in Indian cities. Most of these cities are unplanned, have poor drainage systems [17]. Because of high population density and inadequate infrastructure, the socioeconomic losses and public health risk due to flooding aftermath are significantly greater in urban regions than in rural ones, resulting in the rapid growth of flood occurrences in metropolitan areas [18].

Significant socioeconomic and environmental consequence are the results of flooding, including the loss of living beings' lives, infrastructure destruction, and damage to the natural environment [20]. There are examples of recent flood events: Jammu and Kashmir flooded in 2014 because of constant rain. Even after the Indian army evacuated 11,000 people, 138 people died. River Jhelum and its tributaries flew above the danger mark. Due to this, the Vaishno Devi Yatra has been suspended [21]. Chennai had suffered 3 billion losses and live losses of 138 people in the 2015 flood. In 2018, Kerala faced massive flooding due to unusual rainfall and the sudden discharge of water from reservoirs [22]. Assam Flood 2020 refers to a major flood event of the Brahmaputra River. 5 million people were affected with the loss of 123 people [23].

In Indian cities, measures have been taken to prevent floods. Due to the diverse weather patterns across different regions in India, flood mitigation measures are tailored to each location based on its climate and rainfall pattern. These locations can range from areas near dams to hilly, marshy, and coastal regions. The measures are mainly divided into structural and non-structural categories. Non-structural measures include using automatic weather stations to gather real-time information on rainfall and flood warnings [24] and conducting flood vulnerability mapping to identify high-risk areas. Structural measures include enhancing the urban drainage system with sustainable solutions like detention ponds or storage channels to make cities more resilient to floods [25].

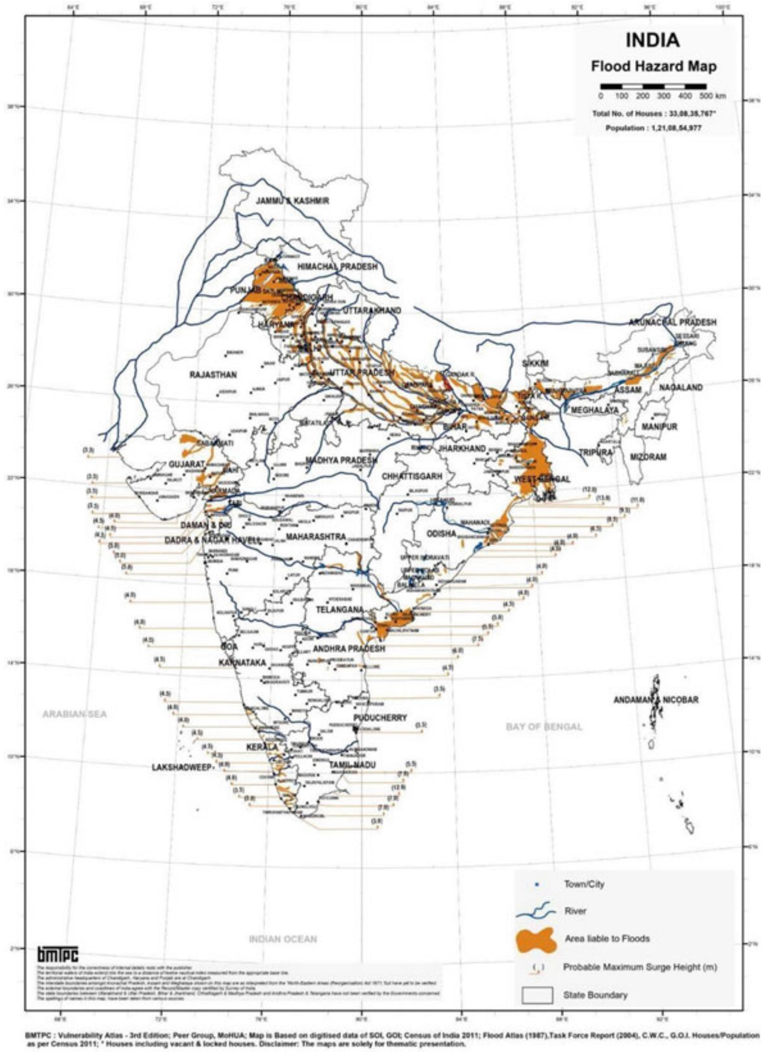

Fig. 2 Flood prone regions in India [19]

In addition to conventional strategies, nature-based solutions (NBS) are also being used for flood risk mitigation and prevention. NBS are strategies that address environmental challenges such as resource depletion, disaster risk reduction, and ecosystem degradation caused by urbanization and climate change [26]. This study focuses on the benefits of using NBS for socio-economic and public health purposes and proposes a framework for identifying and implementing nature-based projects in Indian cities to enhance flood resilience.

2 Nature-Based Solution for Flood Resilience Cities in India

According to the International Union for Conservation of Nature (IUCN), Nature-Based Solutions (NBS) are approaches to sustain, restore, and control natural or modified ecosystems in a sustainable manner, resulting in not only the elimination of environmental and social barriers but also the improvement of the physical and mental well-being of all living species through positive environmental externalities such as increased biodiversity [27]. The IUCN outlines eight principles that NBS activity should follow: embracing nature conservation, being integrated with other societal challenges, being determined by site-specific natural and cultural contexts, producing societal benefits fairly and equitably with transparency and broad participation, maintaining biological and cultural diversity and the ability of ecosystems to evolve over time, being applied at the landscape scale, recognizing trade-offs between immediate economic benefits and future ecosystem services, and being an integral part of overall design policies [28].

Traditional engineering solutions or structural ways of mitigating flood vulnerability have been used for centuries, such as building embankments, dams, levees, and canals [29]. These "hard" or "grey" infrastructure solutions have proven to be uneconomical and damaging to habitats and ecosystems, causing the loss of settlements, and forcing people to relocate without input or choice [30]. To address these drawbacks, there has been a growing interest in examining the role of nature-based projects as an alternative to traditional hard engineering solutions for flood risk mitigation in cities [31]. Concepts like "Nature-based solutions," "ecosystem-based adaptation," "eco-DRR," and "green infrastructure" have emerged as potential alternatives to traditional grey techniques, using natural processes and ecosystem services for purposes such as flood risk reduction and improved water quality [32].

In terms of flood management, NBS are divided into two categories: Natural Water Retention measures (NWRM) and Natural Flood Management (NFM) [33]. NWRM involves retaining water in and on plants, increasing plant transpiration, improving soil health, creating ponds and wetlands, and reconnecting floodplains. NFM uses landscape features to control flood risk by minimizing the maximum flow discharge and leveling it out [34]. These methods have the potential to remedy ecological hazards more effectively and NWRM can be used in various aspects of water management, such as water quality [31]. Floodplain restoration can also be considered an NBS that reduces the likelihood of flood-related disasters and can provide benefits for both ecosystem restoration and flood damage prevention [35, 36].

2.1 Ecosystem-Based Adaptation for Flood Impact Mitigation

Ecosystem-based adaptation initiatives generally focus on long-term adaptation to chronic and irreversible stressors, such as gradually warming temperatures, sea level rise, and glacial melting. Employing a range of biodiversity and ecosystem conservation approaches, such initiatives help people adapt to the adverse effects of climate change and mitigate climate-related hazards.

Ecosystem-based disaster risk reduction aims to reduce hazard events and/or communities' exposure and vulnerability to them. Disaster risk reduction is typically focused on near-future risk, such as landslides or floods. Such initiatives may involve, for example, the installation of early warning systems. But we can also reduce disaster risk through the planting of trees to stabilize slopes. Ecosystem-based disaster risk reduction addresses both non-climate-related events, such as earthquakes and tsunamis and climate-related events like hurricanes and heat waves, as well as other kinds of hazards. While different, these approaches share an emphasis on ecosystem management, restoration, and conservation and can be thought of as interventions that are implemented on a hazard continuum that ranges from near-term, often sudden events such as landslides, to longer term, generally gradual events such as sea level rise.

At the project or operational level, they are often indistinguishable. Environmental management is central to both approaches and can be combined with measures that explicitly reduce disasters and climate impacts. Such interventions have been around for decades, but it's only recently that we have started to emphasize disaster risk reduction and climate change adaptation.

3 Proposed Framework for Integrating NBS in Flood Resilience

Eco-engineering can have an impact on the structural components that support the ecosystem's functioning [37]. One notable example is the Azamenose Riverine Wetland Restoration Project in Saga, Japan, led by the Ministry of Land, Infrastructure, Transport, and Tourism in partnership with various stakeholders including local communities, NGOs, local governments, and academics, particularly Kyushu University [38]. In this project, a wing-shaped flood control basin was built along the curved part of the Matsura River to absorb overflow downstream [39].

These flood control basins not only reduce the risk of flooding but also provide habitats for biodiversity, as seen in wetland creation, which is a common approach in urban areas for flood control, improved drainage, and ecosystem restoration [40]. Wetlands, like those developed as part of an eco-neighborhood initiative in Geneva, Switzerland, serve to collect excess rainwater and provide a habitat for birds [41]. Ecological engineering plays a crucial role in incorporating modern technology, such as early warning systems for landslide movements and river height monitoring, or climate-smart agriculture, into these established and successful methods for promoting community resilience [42]. The concept of "building with nature" is often used to describe this process, but it should be used cautiously as many procedures, like using deep-rooted grasses to stabilize slopes, may be more accurately described as "weaving or knitting with nature" [43].

Ecological engineering is often described as "building with nature and people" due to its emphasis on involving local communities in its implementation [44]. It involves impacting the living tissue of ecosystems and the organisms that make them up, as well as the underlying structures such as mountains and valleys [45]. Efforts are underway to further the implementation of Nature-Based Solutions (NBS) for flood risk reduction through publications such as the World Bank's Implementing Nature-based Flood Protection (2017) and WWF's Guidelines on Natural and Nature-Based Flood Management: A Green Guide (2017).

The study suggests a framework for integrating NBS into current Flood Risk Mitigation and Management (FRM) methods in Indian urban cities. The framework begins by identifying flood hazards, categorizing them into three types: extreme weather events, riverine flooding, and tidal flooding. The next step involves determining the types of flood risk mitigation solutions, which are divided into non-structural and structural. Non-structural solutions involve policy development, public awareness, early-stage flood warning, and monitoring. Structural solutions include hard engineering solutions, soft solutions (i.e., nature-based solutions), and hybrid solutions combining both hard and soft approaches. To effectively reduce flood risk, it is recommended first to apply non-structural solutions and then consider structural solutions by prioritizing NBS whenever possible as part of an integrated approach. In the case of no other options, then gray solutions can be selected. With NBS in focus, the framework further focuses on the guiding principles describing key considerations [46] that are taken into consideration when planning Nature-based projects for flood risk mitigation. These majorly five principles to guide nature-based flood development in cities are as follows:

1. **System scale perspective**: Figure 3 depicts a system-wide review on the basis of spatial extent, time scale, local socio-economic, environmental, and institutional factors should be the first step in addressing nature-based solutions for climate change adaptation and disaster risk reduction.
2. **Risk and benefit assessment of a full range of solutions**: A complete assessment of the risks and benefits of the whole spectrum of possible measures, including risk reduction benefits as well as social and environmental consequences should be carried out.

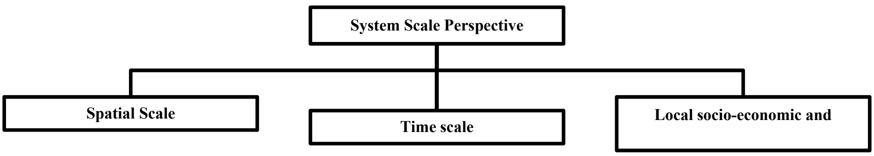

Fig. 3 Types of system scale perspective [47]

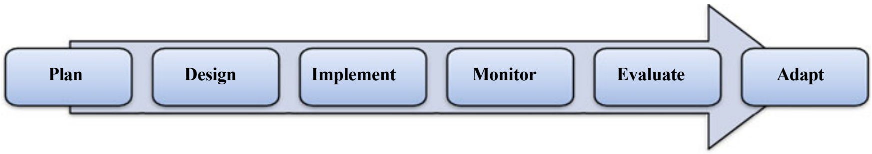

Fig. 4 Adaptive management process (CEDA, 2015)

3. **Standardized performance evaluation**: Nature-based solutions for flood risk management need to be tested, designed, and evaluated using quantitative criteria.
4. **Integration with ecosystem conservation and restoration**: Nature-based solutions for flood risk management should make use of existing ecosystems, native species, and comply with basic principles of ecological restoration and conservation.
5. **Adaptive management**: Nature-based solutions for flood risk management need adaptive management based on long-term monitoring. Figure 4 shows the process flow of adaptive management process, which contributes to ensuring NBS's sustainable performance.

The adaptive management cycle is based on an objective or outcome that may be predicted. Implementation, monitoring, data evaluation, decision-making, and adjustment of possible management measures are all parts of this process. This cycle should be performed at regular intervals throughout the measure's lifespan. The adaptive management cycle not only ensures constant management after the project is completed but also serves as a foundation for developing lessons learned for future projects. In addition to the principles, the World Bank (2017) [33] report outlines the processes for implementing a potential nature-based flood resilience project in the city. These eight implementation processes combine to form the framework's final step, resulting in a full and effective nature-based flood management project in both non-coastal and coastal communities. Figure 5 provides a summarised view of the proposed framework for integrating NBS as flood risk management tools in cities. The eight steps to successfully implementing any nature-based initiative are as follows (Fig. 6).

4 Discussion and Conclusion

Nature presents various answers to the multiple challenges humanity faces today, and there is still time to put these into practice. As the global climate crisis intensifies, natural disasters are becoming more frequent. These are partly due to climate change and partly due to poor land and resource management. The implementation of nature-based solutions for climate and disaster resilience is already taking place worldwide, and many have the potential to have a global impact. These solutions are sustainable, cost-effective, and bring multiple benefits. They can be used to tackle a variety of

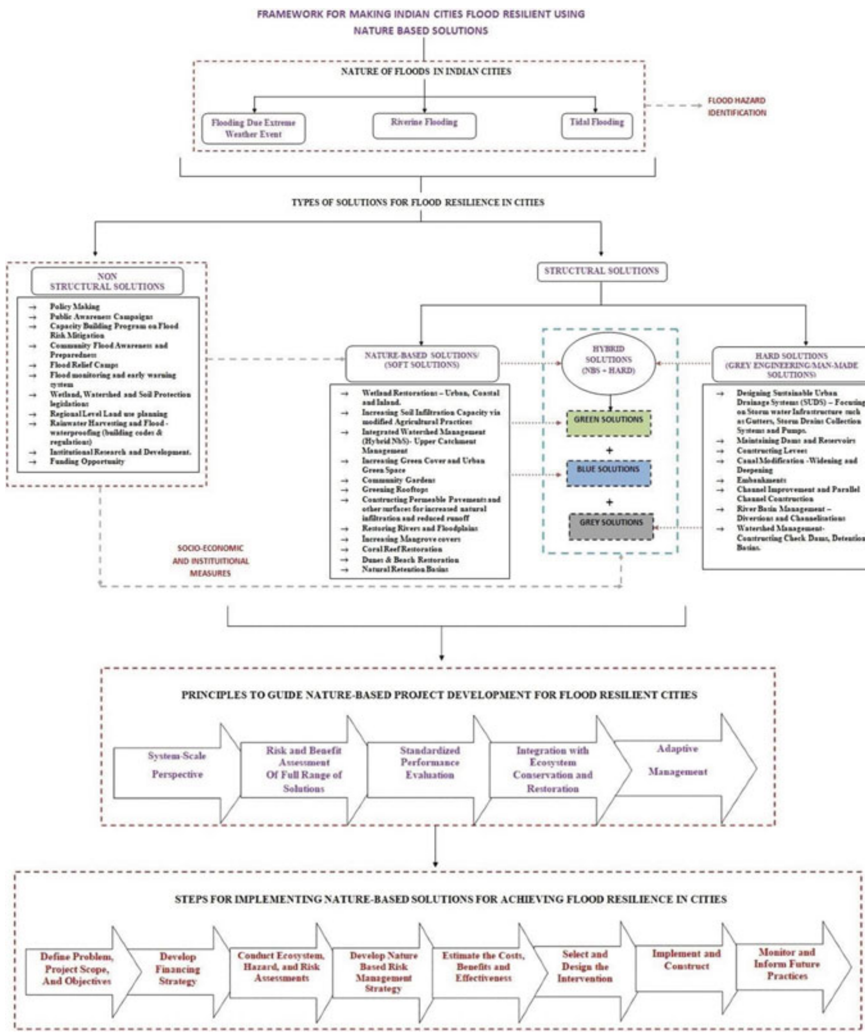

Fig. 5 Proposed framework for integrating NBS as flood risk management tools in cities

issues, from reducing carbon emissions to solving societal problems such as income inequality, food security, and other inequalities.

One main goal of nature-based solutions is to address problems caused by natural hazards such as earthquakes, floods, and landslides. People's decisions often contribute to hazards becoming disasters. For example, building in a floodplain increases a town's risk of flooding. Efforts such as planting trees on steep slopes to prevent landslides or relying on traditional flood management techniques such as water harvesting and conservation ponds can be made to reduce urban flooding [48].

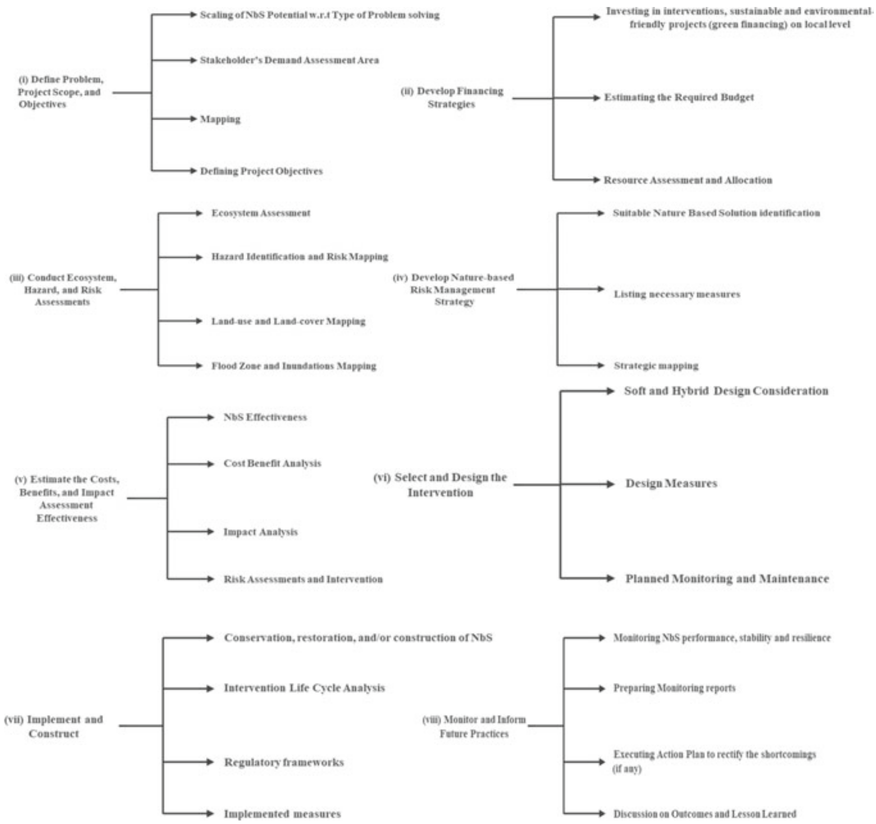

Fig. 6 The eight major steps to successfully implementing NBS for flood resilient cities

Nature-based solution is a term that encompasses a variety of ecosystem-based methods to tackle various social and economic issues. The concept is based on the ecosystem approach, which aims to manage land, water, and living resources in an integrated manner, promoting conservation, restoration, and sustainable use in an equitable way. Figure 7 summarizes the stages for successfully implementing the framework, which, when followed correctly, provides a comprehensive solution that addresses all critical categories: social and economic, institutional, and environmental, resulting in the development of an integrated Flood Risk Management tool.

It is crucial to consider both biophysical and socio-economic factors in a comprehensive manner in order to effectively implement Nature-Based Solutions (NBS) using the framework outlined in this study. To achieve this, a multi-disciplinary approach involving experts in fields such as water resources, environmental engineering and science, economics, and social studies must be taken. A participatory approach that involves all relevant stakeholders is also essential for designing

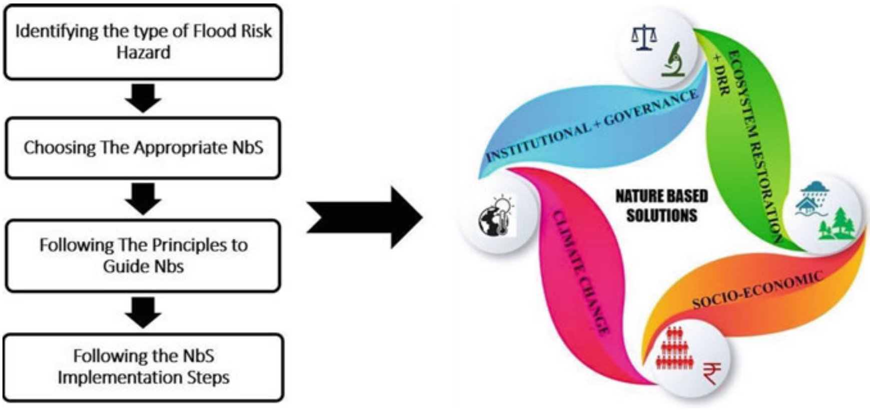

Fig. 7 Nature-based solution—an integrated approach for making cities flood resilient

and implementing effective nature-based programs for flood risk assessment and management.

Incorporating the socio-economic and institutional elements of non-structural flood risk reduction methods is vital to the success of any NBS project. NBS not only provides an environmental friendly approach to improving flood resilience in cities but also addresses flood risks while promoting conservation, development, and poverty reduction. The socioeconomic component of NBS can help to establish new partnerships and collaborations between government officials, local stakeholders, civil groups, and relevant private sector representatives. The concept of working with nature rather than against it is at the core of NBS, which seeks to address climate change through both adaptation and mitigation techniques. This approach prioritizes long-term environmental management and climate change mitigation.

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