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Review Article

Global insights, local realities: BGI challenges and opportunities in Indian urbanization

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ABSTRACT

This study provides a global perspective on the status of Blue-Green Infrastructure (BGI) and investigates the challenges and opportunities associated with its implementation in the urban landscape of India. The research delves into the multifaceted realm of BGI by first elucidating its current status worldwide. It explores how cities globally, amidst expanding urbanization and escalating environmental challenges, have recognized the importance of BGI as a pivotal strategy. The paper then narrows its focus to the specific challenges and opportunities confronting Indian cities in the adoption and integration of BGI. By conducting a comprehensive analysis of existing literature, global policy frameworks, and pertinent case studies, the study aims to unravel the complex interplay that governs BGI implementation in the Indian urban context. This dual approach ensures a nuanced understanding of both the global context and the specific challenges and opportunities faced by urban India in the realm of Blue-Green Infrastructure.

Keywords: Blue-Green Infrastructure (BGI); barriers; urban resilience; sustainable development; Indian cities

1. Introduction

The surge in urbanization in present-day India, marked by the rapid emergence of new towns along with the persistent migration from rural to urban areas, has intensified the burden on urban amenities and exacerbated environmental degradation[1]. The profound impact of urbanization in India has altered the natural landscape leading to increased surface runoff and decreased water retention[2]. As urbanization advances, alterations occur in the utilization of urban land, expanding the presence of impermeable surfaces. This, in turn, diminishes the capacity for water infiltration during storms and leads to a heightened volume of surface runoff. Ultimately, these changes disrupt the natural hydrological processes within urban areas[3,4]. The adverse impacts of climate change have further intensified the challenges faced by Indian cities, including floods, droughts, and storms[5,6]. As urbanization intensifies, numerous cities grapple with pressing challenges concerning urban sustainability and water management. Prevalent concerns in urban areas include an increased frequency of extreme weather events, water scarcity, degrading water quality, urban flooding, combined sewer overflow, and the outmoded water and drainage infrastructures[7,8]. In the face of rapid urban growth outpacing infrastructural development, cities necessitate an effective strategy to bridge the widening gap between expansion and demand, while simultaneously transforming the built environment to foster sustainability.

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Amidst these adversities, Blue-Green Infrastructure (BGI) represents a promising nature-based approach to promote sustainable urban development while addressing pressing challenges. The utilization of Blue-Green Infrastructure (BGI) is acknowledged as a more ecologically conscious strategy for managing urban flood risk, particularly in the context of pluvial events[9,10]. BGI can be characterized as an integrated system comprising both natural and human-designed landscape features, including water bodies, green spaces, and open areas. It is meticulously planned system of natural and partially natural landscapes incorporating green (i.e., parks, gardens, forests, and green corridors) and blue spaces (i.e., rivers, lakes, ponds, wetlands). Instances of BGI elements encompass green roofs, retention and detention ponds, re-naturalized and de-culverted rivers, swales, bioswales, and rain gardens rain gardens[11]. BGI provides various additional advantages, including enhancements in air and water quality, aesthetics, biodiversity, and overall amenity[12]. The integration of blue and green elements in cities can offer a novel and holistic solution, leveraging the power of nature-based approaches to tackle urban issues[13]. BGI is a vital planning tool for achieving viable, adaptable, diverse, and thriving urban areas, BGI has the potential to deliver diverse ecosystem services, encompassing climate regulation, augmentation of carbon sinks, protection of biodiversity, air purification, and provision of health, well-being, spiritual and recreational services such as regulating nutrient cycle and formation of soil[14–17]. India presents promising prospects for fostering both environmental and economic sustainability through the development of Blue-Green Infrastructure (BGI). As cities prepare to confront future challenges, the paper recognizes the considerable hurdles that demand attention to unleash BGI's potential in crafting resilient and vibrant urban environments. By comprehensively addressing challenges and opportunities, the paper introduces a three-tier solution framework encompassing micro, meso, and macro-level interventions, ultimately contributing to the advancement of sustainable urban planning and management in India.

2. Methodology

This study encompasses a comprehensive series of analyses, drawing from a thorough analysis of scientific literature and policy documents published by public institutions. India's prior water-management policies were examined by delving into past laws and legislations. This analysis involved studying a range of government reports to better understand the historical context. A timeline of the development of BGI as a concept in India was established. The study was designed to provide a comprehensive assessment of the challenges hindering the way of implementing BGIs in Indian cities. The study aim was to scrutinize the pivotal elements that played a role in the transformation leading to the acknowledgment and incorporation of BGI within urban development and planning. The study relied on a selection of peer-reviewed articles and official documents. In our exploration of the challenges and prospects associated with introducing BGI in Indian cities, we conducted a thorough literature review using the Google Scholar. It was chosen for its expansive coverage, guided our search strategy using terms like "green infrastructure" and "blue infrastructure," coupled with "barrier," "challenge," or "obstacle" in relevant fields. The inclusion of terms like "green infrastructure" (GI) and "blue infrastructure" (BI) aimed to encompass diverse expressions of BGI. Despite the distinct nature of BI and GI, their inclusion was imperative for a comprehensive overview. The search yielded 238 results, and after excluding conference papers, we scrutinized 191 abstracts. Rigorous criteria were applied to filter out literature reviews and articles lacking a clear focus on BGI barriers. Lastly 79 papers were identified for literature review. The research also includes five Indian cities: Chennai, Delhi, Udaipur, Kochi, and Kolkata to understand the current state of BGI implementation in these cities. This inquiry also assessed the viability of incorporating water management strategies into the urban environment across a diverse range of spatial scales. In terms of scale, their arrangement encompasses solutions applied at the regional level, including, parks and public spaces, urban wetlands, protected areas and retention and detention ponds. Additionally, it extends to private-scale components, such as blue and green roofs, private greens, and rainwater vessels.

Moreover, there are block-scale elements, including planters, permeable pavement, water squares, and subsurface storage[11,18].

Figure 1 depicts the methodology employed, beginning with a comprehensive analysis of the BGI concept. Subsequently, an examination of Indian water management policies and strategies, along with the scrutiny of master/development plans from various states/cities in India, was conducted. The assessment then extended to the status of BGI in India, incorporating a review of numerous peer-reviewed articles exploring the benefits and opportunities associated with BGIs worldwide. Lastly, an analysis of potential multi-scale BGI solutions was conducted, drawing insights from various countries to tailor strategies that align with the urban structure in India.

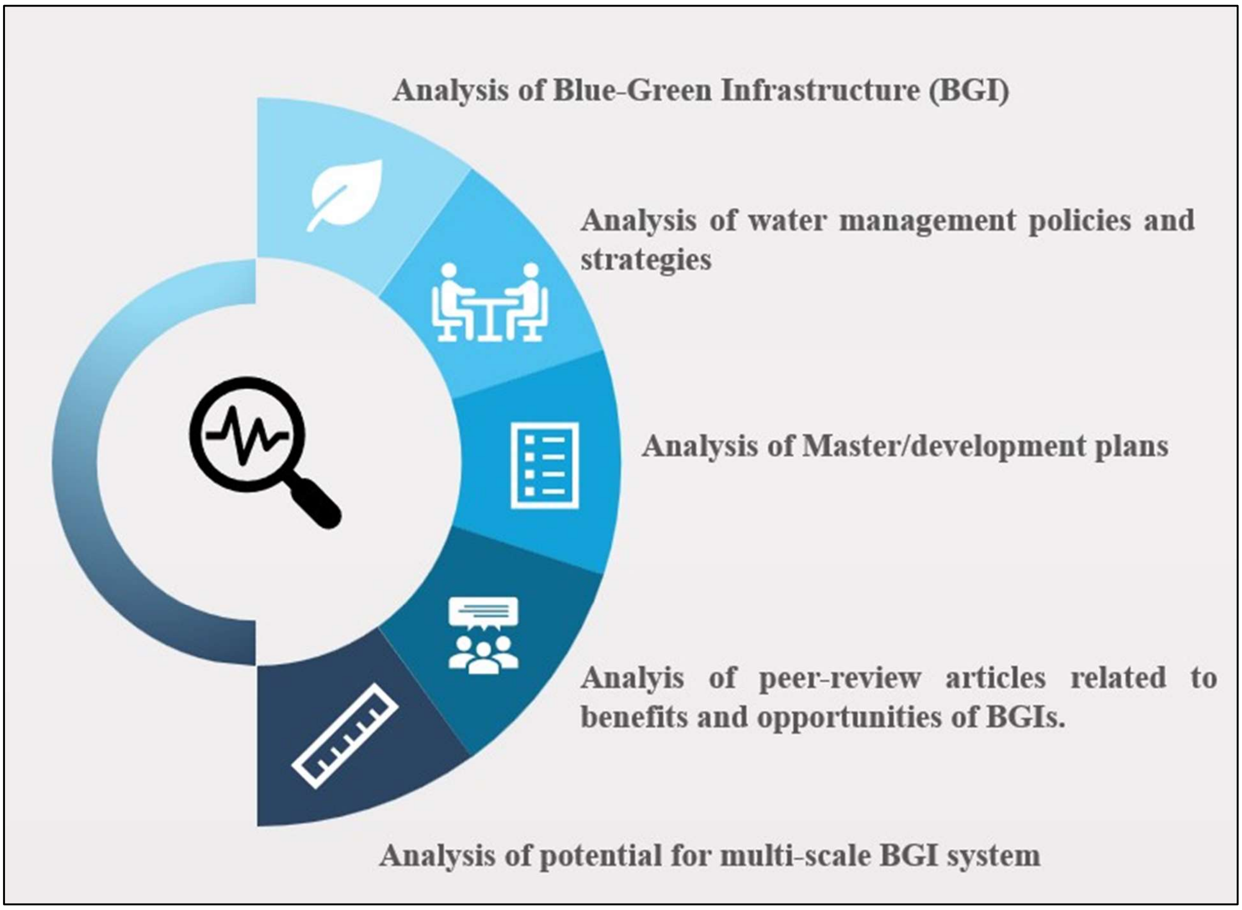


Figure 1. Research methodology (author's elaboration).

3. Multi-tiered solutions for effective blue green infrastructure implementation

Urban areas face a significant challenge due to limited green spaces, leading to water deficits. Addressing this issue requires a thoughtful analysis and the adoption of suitable solutions, especially centered around Blue-Green Infrastructure. Depending on the chosen approach, Blue-Green Infrastructure can stabilize the water management system to varying degrees. **Table 1** reveals the scale-based solution for various BGIs across the globe.

Table 1. Multi-tier implementation of BGI in urban fabric (author's elaboration).

Scale	Solution	Source
Micro	Rainwater harvesting system	[19,20]
	Rain garden	[21–23]
	Bioswales	[19,24,25]
	Green roofs	[26–28]
	Vertical garden	[29–31]
Meso	Constructed wetlands	[21,32]
	Green corridors	[33–35]
	Riparian zones	[36,37]
	Permeable Pavements	[38,39]
	Green streets	[40,41]
	Green roofs and walls	[28,42–44]
Macro	LID (Low impact development)	[45–47]
	SCP (Sponge city program)	[7,8,48,49]
	SUDS (Sustainable urban drainage system)	[50–52]
	ABC (Active, beautiful and clean city)	[53–55]

3.1. Micro-scale solutions

Micro-scale solutions refer to the implementation of smaller, localized measures within urban areas to address specific environmental challenges. These solutions (**Table 1**) are often applied at the individual property or street level and play a crucial role in achieving effective stormwater management and mitigating the urban heat island effect.

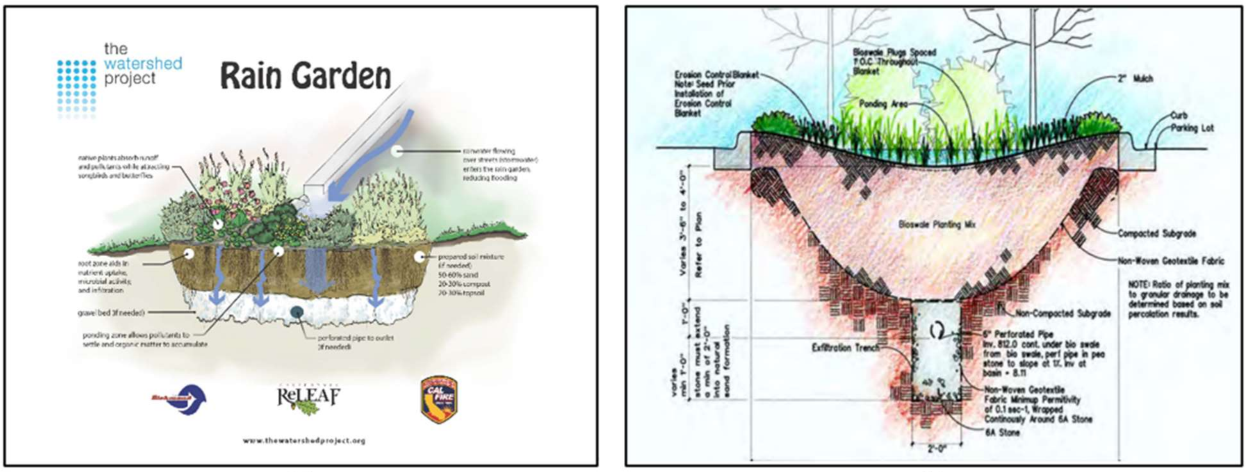
3.1.1. Rainwater collection systems

Rainwater collection systems can be installed to capture rainwater from multiple surfaces, such as rooftops, balconies, and paved areas. These systems include filters to remove debris and contaminants, ensuring that the collected rainwater is of good quality. Individuals can install rain barrels to collect rainwater from rooftops and use it for various non-potable purposes, such as watering plants and washing cars. Rainwater harvesting reduces the demand for freshwater and eases the burden on municipal water supply systems.

3.1.2. Rain gardens and bioswales

Rain gardens: Rain gardens are shallow, landscaped depressions planted with native vegetation and specifically designed to collect and absorb rainwater from impervious surfaces like rooftops and roads. The soil and plants in rain gardens act as natural filters, removing pollutants and sediments from the collected rainwater before it infiltrates into the ground (**Figure 2(a)**) This helps to reduce stormwater runoff, replenish groundwater, and prevent localized flooding. Property owners can create rain gardens in their yards or gardens to capture and manage rainwater runoff from rooftops and driveways. By selecting native plants and incorporating engineered soils, rain gardens not only enhance stormwater management but also add aesthetic value to the property. Also, installation of rain gardens in parking lots or streetscapes can help.

Bioswales: Bioswales are elongated, shallow channels or ditches with gentle slopes that redirect and manage stormwater flow. Lined with vegetation and engineered soils, bioswales allow rainwater to slowly infiltrate while removing contaminants (**Figure 2(b)**). They are effective in reducing the volume and velocity of stormwater runoff, thus minimizing erosion and flooding.



(a) (b)

Figure 2. Micro-scale solutions: Rain garden and bioswale[56,57]. **(a)** Rain garden; **(b)** Bioswale.

Example: Portland, Oregon, USA (known for its extensive use of rain gardens and bioswales to manage stormwater), Singapore has incorporated rain gardens and bioswales into its urban landscape as part of its ABC (active, beautiful and clean) waters program.

3.1.3. Green roofs and vertical gardens

Green roofs: Green roofs are vegetated surfaces installed on the top of buildings. They can be extensive, with a thin layer of soil supporting low-maintenance plants, or intensive, with deeper soil that accommodates a wider variety of vegetation (**Figure 3(a)**). Green roofs reduce the heat island effect by absorbing and evaporating solar radiation, providing a cooling effect on the building and the surrounding environment. They also offer additional benefits, such as improving air quality, reducing energy consumption for cooling, and extending the lifespan of roof membranes. Residents living in urban apartment buildings or houses with flat roofs can consider installing green roofs. For example, the residential buildings in Germany with green roofs have become popular for their energy-saving and environmental benefits.

Vertical gardens: Vertical gardens, also known as living walls or green walls, are structures covered with climbing plants or other vegetation (**Figure 3(b)**).

(a) (b)

Figure 3. Micro-scale solutions: green roof and vertical garden[58,59]. **(a)** Green roof; **(b)** Vertical garden.

For instance, Copenhagen, Denmark: The green lighthouse in Copenhagen is an iconic example of a green roof used for urban heat island mitigation. This modern building features a sloping green roof that helps regulate indoor temperatures and reduces energy consumption for cooling, Paris is home to the Musée du Quai Branly, which boasts a remarkable vertical garden covering its exterior walls.

3.2. Meso-scale solutions

Meso-scale solutions refer to larger, more centralized approaches to BGI implementation that operate at an intermediate level between micro-scale individual properties and macro-scale citywide systems. These solutions (**Table 1**) are typically applied within neighborhoods, districts, or specific areas within a city.

3.2.1. Urban wetlands and ponds for flood control and water purification

Creating urban wetlands and ponds in designated areas can serve as natural stormwater retention basins. These features help reduce the risk of flooding by temporarily storing excess rainwater during heavy rainfall events (**Figure 4(a)**). Additionally, wetlands and ponds act as natural filters, improving water quality by removing pollutants and contaminants before the water is discharged into rivers or other water bodies. For example, Ballona Wetlands Ecological Reserve in Los Angeles, USA, London Wetland Centre, UK, and Central Park Reservoir, New York City, USA.

3.2.2. Green corridors and riparian zones for biodiversity enhancement

Establishing green corridors and riparian zones along water bodies or streams can create interconnected natural habitats and corridors for wildlife (**Figure 4(b)**). These green spaces help preserve biodiversity, enhance ecological resilience, and provide recreational areas for residents. Green corridors also contribute to natural stormwater management by absorbing and slowing down runoff. For example, Emerald Necklace in Boston, USA, Thames Barrier Park, London, UK and Copenhagen Green Finger, Denmark.

(a) **(b)**

Figure 4. Meso-scale solutions: Stormwater wetland and green corridor[60,61]. **(a)** Stormwater wetland; **(b)** Green corridor.

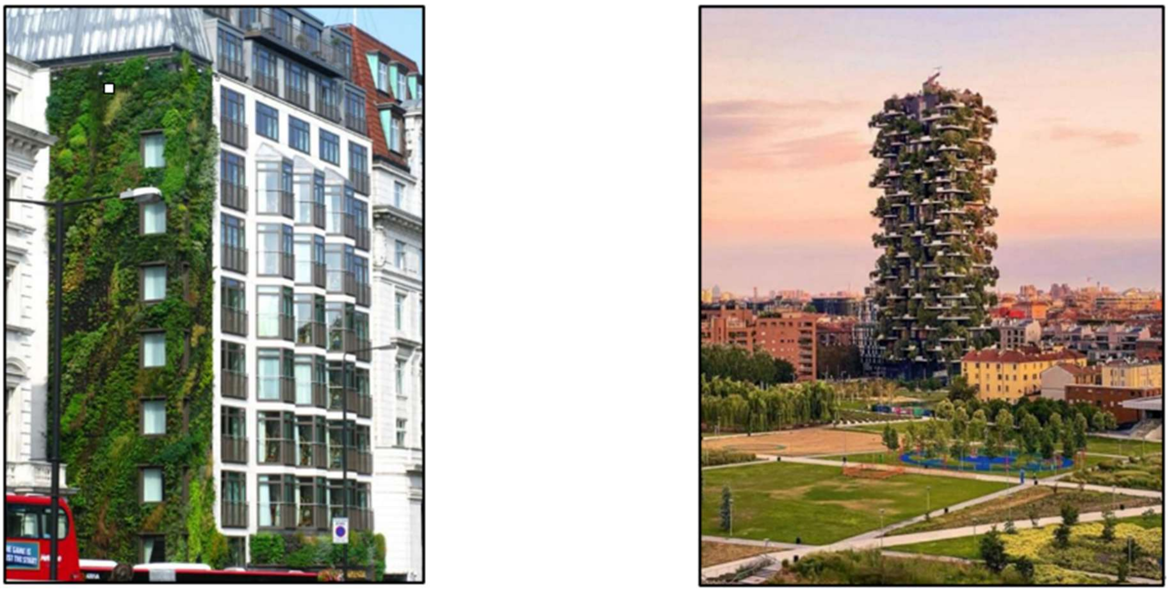
3.2.3. Permeable pavements and green streets

Implementing permeable pavements and green streets in specific urban areas can enhance stormwater infiltration and reduce surface runoff (**Figure 5**). Permeable pavements allow rainwater to pass through the surface and infiltrate into the ground, reducing the strain on traditional stormwater drainage systems. Green streets incorporate vegetation and permeable materials, contributing to improved water quality and urban aesthetics. Some examples are Freiburg's Vauban district, Germany, Borneo-Sporenburg District, Amsterdam, Netherlands and Jubilee Gardens, London, UK.

Figure 5. Types of permeable pavements[62].

3.2.4. Green roofs and green walls in commercial and institutional areas

Integrating green roofs and green walls in commercial buildings, schools, and other institutional areas can mitigate the urban heat island effect, enhance air quality, and provide additional green spaces within dense urban environments. Green roofs and walls contribute to energy efficiency and improve the overall microclimate. For example, the athenaeum hotel, London, UK (**Figure 6(a)**)[63], the Bosco Verticale, Milan, Italy[64] (**Figure 6(b)**), and one central park, Sydney, Australia[65].



(a) (b)

Figure 6. Meso-scale solutions: Green walls. **(a)** The athenaeum hotel, London, UK; **(b)** The Bosco Verticale, Milan, Italy.

3.3. Macro-scale solutions

Macro-scale solutions refer to large-scale and citywide approaches to Blue-Green Infrastructure (BGI) implementation that operate at the urban or regional level. These solutions (**Table 1**) encompass broader strategies that address citywide water management, urban planning, and environmental goals.

3.3.1. Sponge cities concept for comprehensive water management

The sponge city concept, originally developed in China, emphasizes the integration of BGI measures throughout the entire urban landscape to mimic natural water absorption and retention processes (**Figure 7**). Sponge cities incorporate various BGI elements such as permeable pavements, green spaces, rain gardens, and wetlands to effectively manage stormwater and reduce the risk of flooding.

Figure 7. Sponge city concept[66].

3.3.2. Floodplain restoration and river reclamation projects

Restoring natural floodplains and reclaiming urban riverfronts can provide additional space for water storage and flood control. These projects promote the natural hydrological functioning of water bodies, reduce the risk of urban flooding, and enhance the ecological value of urban river ecosystems. For example, Cheonggyecheon, South Korea, room for the River, Netherlands and Yamuna Biodiversity Park, India

3.3.3. Integrated urban water management plans

Developing comprehensive Integrated Urban Water Management (IUWM) plans that incorporate BGI elements can holistically address water-related challenges in cities. These plans integrate stormwater management, wastewater treatment, water reuse, and green infrastructure to optimize water resources and reduce the city's water footprint. For example, Melbourne's Water Integrated Cycle Management Plan, Portland's Integrated Water Management Plan and Barcelona's Sustainable Urban Drainage System (SUDS) Plan.

4. Challenges of implementing Blue-Green Infrastructure (BGI) in India

Despite the growing recognition of the importance of Blue-Green Infrastructure (BGI)[18,21,67,68] in addressing urban water management and ecological restoration, its widespread implementation in urban India is met with various challenges. As the country experiences unprecedented urbanization, rapid development, and the impacts of climate change, Indian cities face complex obstacles that hinder the effective adoption of BGI practices. This section explores the key challenges hindering the integration of BGI elements.

4.1. Spatial challenges

4.1.1. Intensive urban development and impervious surfaces

Rapid urban development in India has transformed natural landscapes into concrete jungles, causing increased impervious surfaces and disrupting the water cycle[69]**.** This results in amplified surface runoff and urban flooding during heavy rainfall.

Determining the ideal location for setting up the BGI is a cumbersome task keeping in mind the purpose and function of the same, and later surely the density and urbanization. Determining optimal locations for Blue-Green Infrastructure (BGI) involves a careful consideration of purpose and function. It's not just about geography but about aligning BGI elements with specific objectives. Flood mitigation elements like retention ponds or swales may be strategically placed in flood-prone areas, managing stormwater runoff effectively. Elements like green roofs and rain gardens focused on aesthetics and biodiversity can find their ideal spots in public spaces or urban corridors. The key is ensuring a harmonious match between the intended function of each BGI component and the environmental conditions of its location, maximizing benefits for both ecological and infrastructural needs in the urban context.

India is a densely- populated country. The land prices are higher, especially in the cities (developed urban areas). For the storm/rainwater that will be infiltrated into the ground, additional space is required for its restoration. Retrofitting the existing area is the idea that needs to be adopted. Here, retrofitting refers to the process of updating or modifying existing structures, infrastructure, or systems to meet contemporary standards or to enhance their performance, ensuring that existing elements are upgraded or adapted to accommodate evolving needs and standards. Also, keeping space entirely dedicated to BGI measures can result in conflicts with other developments. There are always space limitations issues as some of the measures require space along the roads (**Figure 8**).

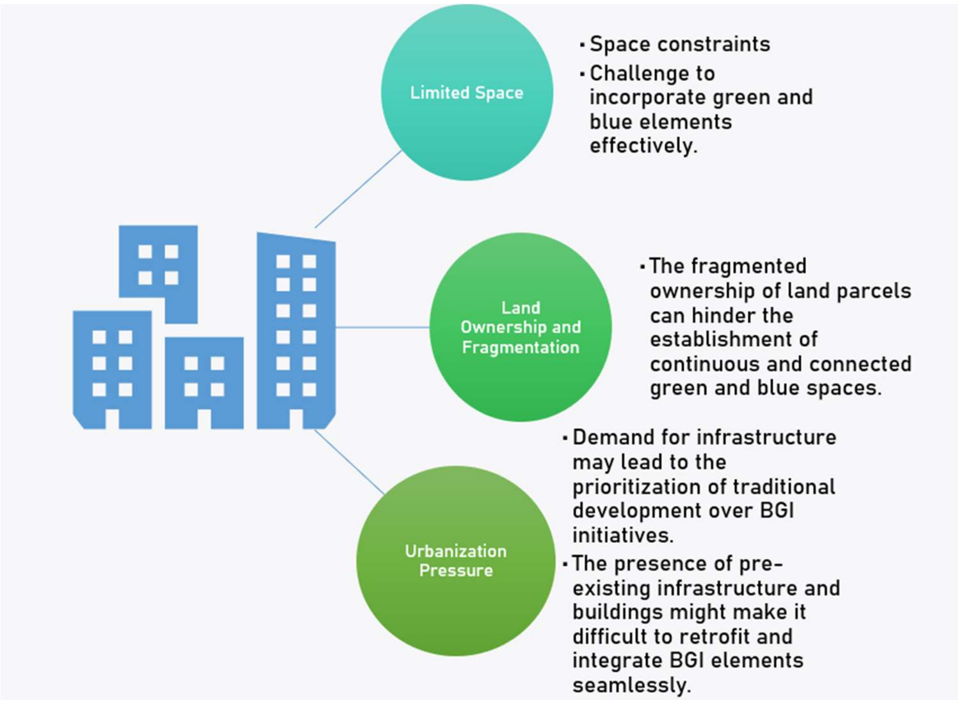


Figure 8. Spatial challenges in BGI (author's elaboration).

Each urban area is unique in terms of its hydrology, planning, soil, and climate characteristics, and understanding the local conditions in implementing the BGI is the key to success (implementation). It should be kept in my mind that not all BGIs perform in the same way when set up in different locations. Therefore, to select the proper installation for a location, it is crucial to understand how well a certain BGI performs on a particular site. For instance, for small parking spaces, vegetation-covered filter strips could be appropriate[70]; but, may not be an ideal solution for a huge drainage area. Most studies revealed that porous pavement is quite good at reducing flood damage, however, not everybody around the globe may find it to be economically viable[39,66,71]. Thus, along with space, economic aspects are also important. If a city aims to manage stormwater in a dense urban area prone to flooding, the performance of rain gardens as a BGI element should be assessed. Factors such as soil composition, drainage patterns, and existing infrastructure will influence how effectively the rain gardens mitigate flooding and enhance water infiltration[21]. Similarly, suppose a suburban neighborhood is interested in sustainable water management and reducing dependence on external water sources. Then evaluating the performance of rainwater harvesting systems involves considering the average annual rainfall, roof area for collection, and community water demands. This assessment ensures the effectiveness of the BGI in meeting the water needs of residents while considering regional climate patterns[72]. Another instance is, if an industrial area seeks to address water quality issues and provide ecological balance. Then determining how well urban wetlands perform in this context requires assessing the pollutants in the industrial runoff, the wetland's water purification capabilities, and its resilience to industrial activities. The success of the wetland as a BGI hinges on its ability to improve water quality and support local biodiversity[3,70].

4.1.2. Climate and soil conditions

Climatic and soil challenges pose significant obstacles to the successful implementation of BGI (Blue-Green Infrastructure). In areas with high rainfall intensity, managing large stormwater volumes becomes a daunting task, requiring more robust BGI features to handle the deluge effectively. Erratic rainfall patterns present a design challenge, demanding BGI solutions that can adapt to both dry and wet periods. On the other hand, regions experiencing droughts may struggle to maintain BGI elements that rely on consistent water availability. In hot and arid climates with high evaporation rates, the efficacy of BGI elements, such as rain gardens or retention ponds, may be compromised[8]. Flood-prone areas necessitate careful planning to ensure that BGI features do not exacerbate flooding or compromise safety during heavy rain events.

Soil conditions also play a crucial role in hindering BGI implementation. Soil with high salinity levels can limit water infiltration and affect the performance of BGI elements, particularly in coastal regions[73]. Compact or impermeable soil hampers the effectiveness of BGI features such as rain gardens or permeable pavements, as they rely on efficient water infiltration—steep slopes present challenges in managing stormwater flow, necessitating specialized BGI designs to prevent erosion and flooding. Erosion-prone soils require additional stabilization measures to protect BGI installations from damage.

4.2. Technological challenges

Significant technological gaps exist between developed and developing nations, with the latter having inadequate experience or abilities in implementing new management strategies. BGI technologies are limited to the hands of significant stakeholders and government organizations that are dealing with flood control and mitigation. Most of India's municipalities do not emphasize BGI adoption enough, mainly because they are unaware of available technology options.

4.2.1. Lack of sound research and uniqueness

BGI is a broad concept and relies on evidence-based practices and reliable data. Still, the lack of sound research on the effectiveness of BGI elements in specific urban contexts can hinder their adoption and create uncertainties about their impact[48]. Each city has distinct geographical, climatic, and socio-economic characteristics, which influence the suitability of BGI elements. Identifying and tailoring BGI solutions to meet the unique needs of each city demands in-depth understanding and thorough research. Implementing BGI requires adaptation to local conditions, and the absence of adequate research can lead to poorly designed features that do not effectively address local water management challenges[74].

Furthermore, incorporating BGI into existing urban infrastructure necessitates a comprehensive understanding of the city's layout, utilities, and planning, and the lack of research may hinder seamless integration and create conflicts with pre-existing systems. Robust research is essential to develop scalable and adaptable strategies that can be applied effectively in different cities. Sound research can inform decision-makers, ensuring that BGI solutions are well-suited to each city's unique characteristics and contribute to sustainable and resilient urban development.

4.2.2. Human resource capacity

The level of general human capability within the urban water sector's institutions may be determined by the presence of critical technical proficiency. The availability of specialized water engineers with degrees from reputable universities is essential in planning and implementing any water management strategy. On the other hand, high vacancy rates in top technical jobs point to a limited capability for change. In addition to formal education, training, and exposure are different ways that skills are created (**Figure 9**). The presence of on-the-job skills training is another factor to consider when evaluating the capacity of urban water organizations. In India, there exists a general gap in the experience of integrating a conventional method for water management[75], No proper training and education of the staff, and limited resource person with expertise. No sync between designing, planning, and maintaining infrastructure[73,76,77]. The development and consulting sectors lack a significant understanding of BGI concepts and practices, in addition to local practicing staff and management professionals. As a result, the industry culture is either dubious of the BGI approach or results in bad planning and design. Also, integrating BGI elements involves intricate design processes and long-term maintenance planning. The lack of skilled human resources to handle these complex tasks can lead to suboptimal BGI implementation and reduced effectiveness over time.

Figure 9. Human resource capacity in BGI (author's elaboration).

4.2.3. Poor database

For accurate and reliable decision-making water-related information across various urban water sectors is essential. It is the precision and accuracy of the data that decide the ambition of planning. For the successful implementation of BGIs, a wide category of a database is required including land use and land cover maps, soil characteristics, water sources, water supply and demand, drainage network, distribution of water bodies and green spaces, etc. But unfortunately, this requirement is a challenge in the Indian context; as such performance data are not available for the entire country. Only the database of major metro cities is maintained but not for all other cities. There aren't any centralized databases in the majority of Indian cities also. The data is collected according to the needs of individual agencies. A method for data exchange amongst the agencies is essential in these circumstances because it may compensate for the absence of a centralized database.

4.3. Monetary challenges

4.3.1. Initial investment

Developing and integrating BGI elements often requires significant upfront costs. For example, constructing green spaces like rain gardens or bioswales, installing permeable pavements, or building retention ponds may involve substantial expenses in material and labor (**Figure 10**). These initial investments can deter cities from adopting BGI, especially if their budgets are already strained with other infrastructure priorities.

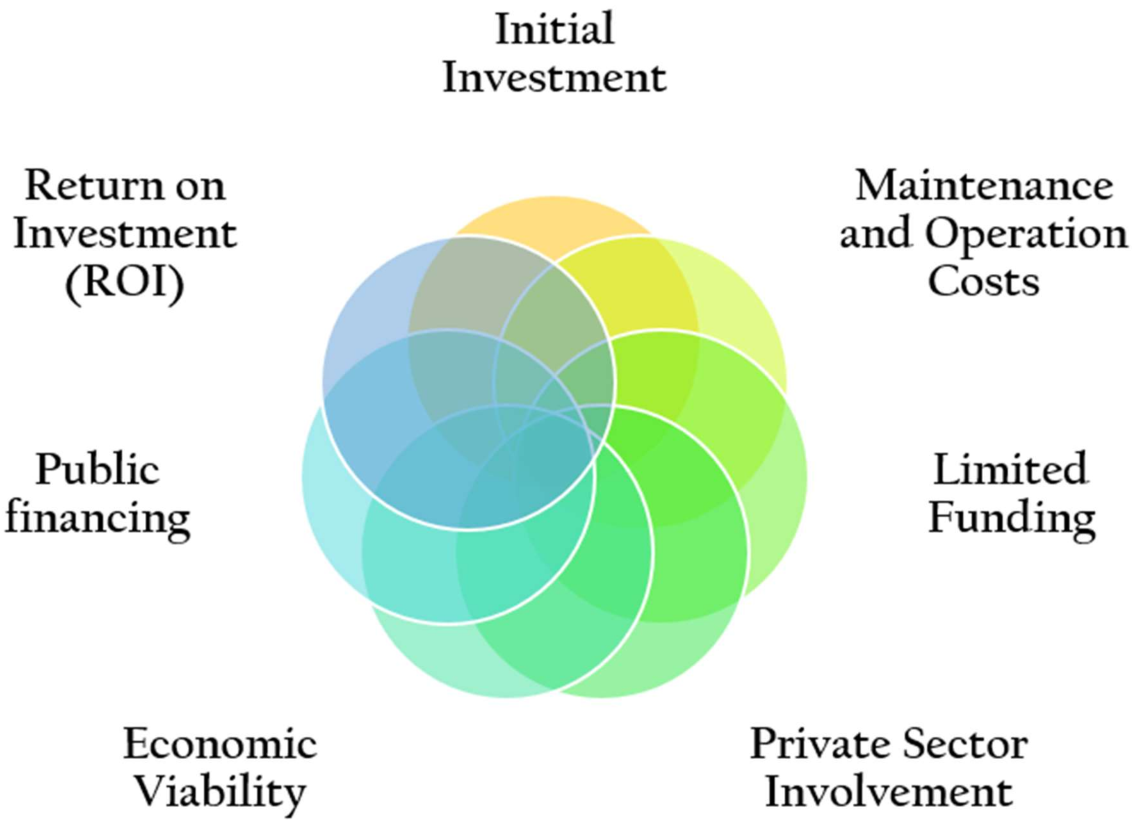


Figure 10. Monetary challenges in BGI (author's elaboration).

4.3.2. Maintenance and operation costs

BGI features need regular upkeep and management to ensure their continued effectiveness. For instance, maintaining green spaces requires periodic landscaping, pruning, and pest control. Similarly, ensuring permeable pavements remain unclogged and functional demands regular inspection and cleaning. These ongoing maintenance costs can be an ongoing burden for cities if not properly planned and budgeted.

Various agencies can show their participation at different span of BGI implementation, for instance, Municipalities can shoulder the responsibility of integrating BGI into urban planning and development frameworks, overseeing ongoing maintenance tasks like routine inspections and repairs. Local Environmental and Water Management Agencies are pivotal in the initial planning and design phases, ensuring BGI adherence to environmental regulations and subsequently monitoring water quality and ecological health. Public Works Departments are often responsible for the physical maintenance of BGI components, handling tasks such as repairs, cleaning, and ensuring proper functionality. Their involvement spans from the construction phase through ongoing maintenance, addressing both routine and unexpected tasks. Public-Private Partnerships can be established in the planning and implementation stages, delineating clear agreements on ongoing maintenance responsibilities.

4.3.3. Limited funding

Many cities face limited funding options for infrastructure projects, including BGI. With numerous demands on their budgets, it may be challenging for cities to allocate sufficient funds for large-scale BGI initiatives. As a result, BGI projects may be smaller in scale or postponed due to insufficient funding.

4.3.4. Private sector involvement

Engaging the private sector in funding and partnering for BGI projects can be advantageous but may face challenges. For instance, businesses and developers might be interested in investing in BGI elements on their properties if they see potential cost savings or enhanced property values (**Figure 10**). However, ensuring that private sector involvement aligns with public goals and that there are clear incentives for participation can be complex. Public-private partnerships must be carefully structured to ensure mutual benefits and long-term success.

4.3.5. Economic viability

Assessing the economic viability of BGI measures is essential to justify the investment[78,79]. Cities need to evaluate the cost-benefit ratio of BGI projects, considering their long-term benefits, such as reduced flooding, improved water quality, and enhanced urban aesthetics[32]. If the projected benefits do not outweigh the costs, cities may be reluctant to proceed with BGI initiatives. The assessment of multiple benefits is gaining momentum in both academic and industrial sectors, facilitated by the introduction of innovative tools like the CIRIA Benefits of Sustainable Drainage Systems (SuDS) Tool (BeST). This tool enables a structured cost-benefit analysis, aiding in the quantification and monetization of each benefit[78]. Another valuable resource, the Blue-Green Cities Multiple Benefit GIS Toolbox, can generate benefit maps and profiles. These tools offer context-specific evaluations, revealing the spatial extent and intensity of benefits and providing insights into beneficiaries[80]. It is advisable to leverage such tools in the design of BGI projects and engage with institutional and industry stakeholders to explore potential benefits and establish collaborative funding partnerships.

4.3.6. Public financing

Securing public financing for BGI projects can be challenging, especially if there is limited public awareness or support for nature-based solutions. Convincing taxpayers and policymakers of the importance and benefits of BGI may require public education campaigns and transparent communication about the long-term advantages.

4.3.7. Return on investment (ROI)

Cities and stakeholders need assurance that BGI investments will yield meaningful returns over time (**Figure 10**). For example, if a BGI project reduces stormwater management costs, avoids flood damage expenses, and enhances property values, it contributes positively to the ROI. Demonstrating these tangible and intangible benefits is crucial to gaining support for BGI projects. The quantification of the various benefits provided by Blue-Green Infrastructure (BGI) can be assessed through tools like B£ST (Benefit Evaluation of SuDS Tool) or TEEB (The Economics of Ecosystems and Biodiversity). These tools are designed to assign economic values to the diverse advantages associated with BGI implementation, such as improved air and water quality, enhanced biodiversity, and aesthetic improvements. B£ST specifically focuses on evaluating the economic performance of green roofs and walls, while TEEB offers a broader framework for assessing the economic value of ecosystems and biodiversity. Utilizing these tools helps in the comprehensive monetization of BGI benefits, enabling decision-makers to make informed choices based on economic considerations in addition to environmental and social factors[78,80,81].

4.4. Administrative challenges

4.4.1. Complex governance structure

India's urban governance often involves multiple layers of administration, with responsibilities spread across various government departments and agencies. This complexity can lead to coordination challenges in integrating BGI measures across different sectors. Implementing BGI in a city might require collaboration between the urban planning department, water resources department, environmental agency, and municipal corporation, National Highways Authority of India, Municipal Corporation Parks and Gardens Departments and various state development organizations such as Delhi Development Authority (DDA), Haryana Urban Development Authority (HUDA), Ahmedabad Urban Development Authority (AUDA). Lack of effective coordination among these entities can slow down the decision-making process and delay BGI implementation[82]. For instance, one agency may construct the wastewater and water supply infrastructure while another organization may monitor it. Stormwater management is the responsibility of a third organization. Maintaining the city's lakes and other water features is the responsibility of a fourth. To break down the silo across the sectors and achieve common knowledge grounds stakeholder engagement is required. This can be achieved through implementing proactive stakeholder engagement strategies. Form cross-sectoral working groups, initiate joint planning processes, and organize regular inter-sectoral meetings to encourage collaboration. Leverage technology with collaborative platforms for real-time communication. Incentivize cross-sectoral research, promote leadership commitment, and create a culture of cooperation. These solutions aim to bridge gaps, facilitate information exchange, and cultivate a collaborative environment among stakeholders from diverse sectors, ensuring a shared understanding and collective progress.

4.4.2. Regulatory framework

Unclear or inconsistent regulatory frameworks related to land use, zoning, and environmental protection can create obstacles for BGI projects. For instance, if the existing regulations do not explicitly allow or support the integration of BGI features like permeable pavements or green roofs, obtaining the necessary permits and approvals can become a bureaucratic challenge. Obtaining the necessary permits and approvals for BGI projects requires navigating through various administrative procedures, which can be time-consuming and cumbersome. This lack of clarity in the regulatory framework can discourage developers and investors from incorporating BGI elements in their projects, even if they recognize the potential benefits. Effective management BGI practices involves addressing the responsibility for overseeing these practices post-construction, which may encompass various stakeholders such as homeowners, local authorities, and relevant parties. To ensure the successful integration of BGI techniques that yield multiple advantages, it becomes imperative to establish a framework of management laws and regulations. This framework serves as a crucial foundation, supporting the optimal functionality and long-term benefits of BGI practices while upholding environmental integrity.

4.5. Community challenges

The attitudes, perceptions, and engagement of the local community can also create challenges.

4.5.1. Lack of awareness and understanding

Many community members may have limited awareness or understanding of BGI concepts and their benefits. This lack of awareness can lead to misconceptions or resistance to BGI initiatives. Since public perception is important, the government should conduct outreach programs for residents where the plan will be executed and educational activities & training to the municipal staff to shift their perceptions. Education in both forms i.e., formal and informal should be provided to make the community understand the concept of a BGI. For instance, Green Alleys Project, Chicago; USA, Cheonggyecheon Restoration, Seoul, South Korea; Mill River Park, Stamford; Connecticut, USA; and Malmo Green Roofs, Sweden are some of the case studies where public workshops, guided tours, and informational campaigns were organized to educate residents about the benefits of the initiative.

4.5.2. Engagement and participation

For the successful development of any project, citizen engagement is the most important as everything that is being executed is for the benefit of the citizens. Planning should be inclusive as well as participatory, to give citizens a sense of ownership. A good plan can increase engagement, especially among the underprivileged, women, and other disadvantaged groups to participate in decisions and can have a significant impact on their lives.

5. Harnessing the potential of Blue-Green Infrastructure in Indian urban landscapes

A comprehensive and thoughtfully designed Blue-Green Infrastructure strategy holds the key to mitigating climate emergencies, enhancing the environment, fostering sustainable urban renewal, and unlocking economic growth. By embracing this approach, India can seize the opportunities and position itself as a global leader in the realm of sustainable development.

5.1. Incorporating nature into India's urban fabric

To facilitate the effective implementation of blue-green projects in Indian cities, it is imperative to establish a comprehensive framework that operates at both local and national levels. This framework ensures consistency and coherence across cities and regions, providing a common set of guidelines, standards, and best practices for efficient execution. It aligns the efforts of stakeholders, including local authorities, communities, and government agencies, towards a shared vision.

Key to the framework is the integration of Blue-Green Infrastructure into urban planning. For example, Portland, Oregon, USA - Integrated Stormwater Management, the city's approach includes green streets with bioswales and permeable pavements, widespread adoption of green roofs (Eco roofs), and strategic urban greening to effectively manage stormwater. Likewise, Rotterdam's Water Sensitive Urban Design integrates water plazas, floating parks, and green streets to manage stormwater, enhance water quality, and create a climate-resilient urban environment. By harmonizing urban planning documents and incorporating environmental considerations early on, the framework ensures seamless integration and avoids fragmentation. It empowers cities to incorporate blue-green elements into their urban fabric, promoting sustainable and holistic urban development.

The framework addresses challenges through mechanisms that tackle technical, financial, and regulatory hurdles through a multifaceted approach. It includes technical mechanisms such as site assessments and performance standards, financial mechanisms like diverse funding models and cost-benefit analyses, regulatory mechanisms integrating BGI into zoning regulations, capacity building through training programs and public awareness, and collaborative platforms for stakeholder engagement and information sharing. This adaptable framework emphasizes continuous monitoring and adaptive management, recognizing the complexity of BGI implementation hurdles. These mechanisms enable quick and informed decision-making at the local level, allowing stakeholders to navigate uncertainties effectively[82].

Transparency and accountability are integral to the framework. This can be achieved by establishing public reporting systems, engaging communities in decision-making, defining clear performance metrics, conducting independent audits, ensuring regulatory compliance, and implementing mechanisms for stakeholder feedback. Through budget transparency, conflict of interest policies, and documentation of decision-making processes, the framework aims to enhance openness and trust. Periodic public forums further facilitate direct communication, fostering a culture of accountability in BGI implementation. It promotes transparent decision-making processes, clarifies roles and responsibilities, and establishes robust monitoring and evaluation mechanisms. By upholding transparency, the framework fosters trust and enhances the integrity of blue-green projects. It ensures accountability by tracking progress and learning from successes and challenges.

5.2. Transforming environmental status reports into annual audits for sustainable city policies

To harness the full potential of annual environmental status reports in Indian cities, there is a need to convert them into annual blue-green audits. These audits will serve as a valuable tool for creating realistic policies and bridging existing gaps in sustainability. By incorporating demographic data, such as population density and poverty indicators, alongside the environmental findings, a more comprehensive understanding of the social challenges can be obtained. The transformation of these reports into blue-green audits offers a holistic approach that integrates environmental considerations with urban planning. It enables cities to assess their progress, identify areas for improvement, and make well-informed decisions to prioritize the development of resilient, livable, and sustainable urban environments[82].

Moreover, by including demographic data in the audits, cities can gain insights into the specific needs and dynamics of their communities. This knowledge facilitates the implementation of targeted interventions and policies that address the social challenges in a more equitable and inclusive manner.

By utilizing the annual blue-green audit approach, Indian cities can maximize the benefits of their environmental status reports, moving beyond mere documentation to actionable insights. This integration of environmental and social factors ensures a more comprehensive and effective approach to urban development, paving the way for sustainable and inclusive cities in the future.

5.3. Public private partnership (PPPs)

Public-private partnerships (PPPs) offer a promising avenue for successful implementation of BGI in India's urban development. By fostering collaboration between government entities and private sector organizations, PPPs can leverage resources, expertise, and innovation to accelerate the adoption of nature-based solutions in cities.

For instance, a city planning to implement a BGI project, such as a green park with rain gardens and permeable pavements to manage stormwater, can benefit from a PPP. The public sector can provide the necessary land and initial funding, while a private company specializing in green infrastructure design and construction can bring in technical expertise and innovative approaches to create an effective and aesthetically pleasing green space.

Moreover, PPPs can help address funding challenges. Suppose a city aims to retrofit existing urban areas with BGI features to reduce flooding and improve water quality. The private sector's involvement can introduce innovative funding mechanisms, such as impact investments or green bonds, which attract private funding for these initiatives. This collaboration ensures a more substantial financial pool to implement the BGI project successfully[8,82,83]. While private sector involvement in BGI brings innovative funding, it's crucial to address concerns about benefit distribution. Ensuring equitable sharing of benefits, aligning private interests with community welfare, and implementing mechanisms like community benefit agreements can prevent potential disincentives for private investment. Striking this balance is essential for a successful and socially equitable BGI implementation.

PPPs can also expedite the implementation process. For instance, in a partnership between a municipality and a construction company, the private sector's efficiency and project management practices can complement the public sector's bureaucratic processes. This streamlined approach can lead to quicker execution and tangible benefits for the community.

The partnership between Rotterdam's municipality and EcoScape Innovations exemplifies the effectiveness of public-private collaboration in BGI. By combining the municipality's regulatory processes with EcoScape's construction efficiency, a large-scale sustainable drainage project incorporating green roofs and rain gardens was swiftly implemented[84].

Furthermore, long-term commitment is vital for the effectiveness of BGI projects. By engaging in PPPs with private sector entities responsible for maintenance and management, cities can ensure the continued functionality of BGI features over extended periods.

5.4. Cooperative synergy

Interagency cooperation plays a pivotal role in the successful implementation of BGI in urban development. By fostering collaboration among various government agencies and departments, it ensures comprehensive planning, efficient resource utilization, and streamlined decision-making for BGI initiatives. For instance, in a city's efforts to combat urban flooding and improve water quality through BGI, interagency cooperation between urban planning, water resources, and environmental protection agencies can lead to the seamless integration of green spaces, retention ponds, and permeable pavements. This collaboration enables data sharing, shared responsibilities, and a unified communication strategy, facilitating adaptive management and community engagement. Through a coordinated effort, interagency cooperation strengthens the effectiveness of BGI projects, promoting more sustainable and resilient urban landscapes for the community's benefit. The principle of adopting pathways in BGI emphasizes flexibility and adaptability. Cities, like Copenhagen, exemplify this by implementing BGI schemes with adaptable green spaces and modular stormwater management. Copenhagen's Cloudburst Management Plan, integrating green roofs, permeable pavements, and innovative storage, serves as a prime example[85]. This approach allows for adjustments in response to uncertainties, climate changes, and evolving urban dynamics, ensuring enduring resilience in the face of environmental shifts.

5.5. Digital advancement and research

Digital platforms and research play pivotal roles in facilitating the successful implementation of BGI (Blue-Green Infrastructure) goals in India's urban development. For instance, data-driven decision-making using advanced analytics can identify ideal locations for BGI features like rain gardens and permeable pavements, addressing specific environmental challenges effectively. Geographic Information Systems (GIS) and mapping tools aid in visualizing flood-prone areas[86–88] and heat islands[89–91], enabling targeted BGI interventions. Through websites, social media, and mobile apps, public engagement and communication efforts inform residents about BGI benefits, encouraging community participation and support[48]. Remote sensing technologies, such as satellite imagery, monitor changes in green spaces and vegetation, assessing BGI's impact on urban ecosystems[92–95]. Research-driven modeling and simulations predict BGI outcomes, guiding policymakers in effective resource allocation[32,83,96]. Continuous research efforts ensure evidence-based approaches, leading to policy improvements and advancing BGI knowledge. By combining digital advancements with ongoing research, India can achieve its BGI implementation objectives, ensuring sustainable and resilient urban landscapes for the future. India's attainment of BGI goals can be significantly advanced by strategically combining digital advancements with ongoing research efforts. Drawing inspiration from the success of Singapore[53,97], where the integration of real-time monitoring and data analytics has bolstered BGI efficiency, India can leverage similar technologies. For instance, implementing smart sensors in green spaces to monitor biodiversity or employing predictive modeling for stormwater management allows for adaptive, data-driven decision-making[98,99]. This approach ensures that India's urban landscape becomes not only sustainable but also resilient, responding effectively to evolving environmental challenges.

6. Unlocking India's water resilience: Harmonizing blue-green interventions

India, with a resolute commitment to the preservation of nature ingrained in its cultural fabric, finds constitutional support for the protection and enhancement of the environment through provisions such as Article 48A and Article 51A(g) (Environment Protection under Constitutional Framework of India, n.d.). These constitutional provisions reflect the country's commitment to safeguarding its ecological resources, including forests, wildlife, and the natural heritage, in line with its profound reverence for nature. In 1985, a significant achievement was marked with the formation of the Ministry of Environment and Forest (now known as MoEFCC- Ministry of Environment, Forest and Climate Change) as the leading authority devoted to safeguarding the rich biodiversity, encompassing flora, fauna, forests, and wildlife. This institution spearheaded the introduction of extensive and all-encompassing environmental legislation, paving the way for a multitude of initiatives and schemes implemented by various levels of government. These endeavours aim to conserve and manage our invaluable blue-green resources in a manner that is environmentally sustainable and ethically responsible.

The effective execution of these missions encounters significant challenges rooted in institutional, systemic, and procedural impediments (**Figure 11**). These barriers encompass restrictions in financial resources, the imperative for inter-ministerial collaboration, a dearth of technical proficiency, and protracted project clearance procedures. These factors pose substantial obstacles that hinder the proficient implementation of the missions. Furthermore, there exists a lack of cohesion among the missions, as they are still perceived as distinct portfolios within different ministries, impeding the unified application of policies.

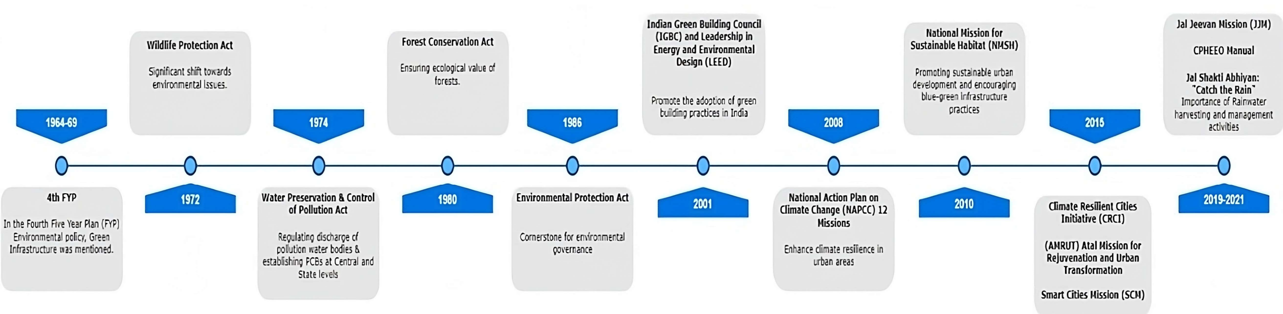


Figure 11. Timeline of Indian's blue-green concept (compiled by authors).

The achievements of these missions are intricately intertwined with the accomplishments of grassroots governing bodies such as panchayats, councils, and municipal corporations. The triumph of these initiatives relies heavily on effective decentralization and functional segregation. Unfortunately, the prevailing hierarchical approach falls short in providing sufficient capacity-building endeavors and comprehensive guidelines, particularly concerning financial provisions, training opportunities, and technological expertise. This insufficiency curtails the ability of state governments to adequately support local bodies in the effective implementation of the missions.

The urgent need for Indian cities to implement Blue-Green Infrastructure (BGI) stems from the necessity to address environmental degradation, climate change impacts, and the well-being of urban residents. Rapid urbanization, population growth, and climate change have significantly impacted the sustainability and livability of cities. BGI offers a holistic approach that integrates natural elements such as green spaces, wetlands, and water bodies with built infrastructure to create resilient and sustainable urban environments. By integrating nature-based solutions into urban planning and design, cities can achieve a balance between growth and environmental conservation.

One major aspect needs to be considered while incorporating the BGIs are its negative impacts. The integration of BGI in urban settings may inadvertently support the presence and persistence of vector or host organisms, potentially contributing to the spread of many infectious diseases. Moreover, encouraging green connectivity within urban areas could amplify the involvement of rats and ticks in the transmission of such diseases. Although water bodies and wetlands play a pivotal role in urban climate adaptation and mitigation, but poorly designed or inadequately maintained BGI elements may lead to water stagnation, creating breeding grounds for mosquitoes and other pests, and contribute to the emergence of harmful algal blooms. Also, the augmentation of urban green spaces might have negative implications for individuals prone to pollen allergies[100–102].

Furthermore, if BGI projects are not inclusive and inadvertently contribute to gentrification, they may result in the displacement of existing communities. After the implementation of greening projects, the subsequent gentrification processes tend to exacerbate inequality by forcing lower-income residents out of recently revitalized neighborhoods[103]. As these greening initiatives improve the visual appeal and overall quality of life in the communities, the surge in property values leads to the displacement of economically disadvantaged families, reminiscent of a contemporary manifestation of the well-known “rent gap” predicament[104]. Adopting an inclusive design approach can mitigate the risk of displacement by considering the needs of all community members. Robust community engagement and public awareness campaigns are crucial to build understanding and garner support. Regulatory oversight and an adaptive management approach can ensure that BGI projects meet standards and adapt to evolving conditions. By implementing these solutions, BGI projects can effectively mitigate negative impacts and contribute positively to both the environment and communities.

BGI contributes to sustainable urban development by promoting resource efficiency and reducing the ecological footprint of cities. It also encourages the use of renewable energy, promotes sustainable transportation options, and supports efficient waste management practices. Through features like green roofs and permeable pavements, BGI efficiently manages stormwater, reducing reliance on traditional drainage systems. Additionally, the inclusion of green spaces and trees contributes to natural climate regulation, lessening the need for energy-intensive cooling. BGI enhances biodiversity, aiding in pest control and reducing reliance on chemical interventions. Moreover, BGI mitigates water pollution by managing stormwater runoff and contributes to carbon sequestration, improving air quality.

Despite being a relatively recent concept, some Indian cities, including Chennai, Delhi, Udaipur, Kochi, and Kolkata, are incorporating blue-green elements into their master or action plans (**Table 2**). The objective is to improve existing natural blue systems within the urban areas and surrounding public spaces through intentional and strategic planning. The summary of the Indian BGI initiatives in these cities are shown in **Table 2**.

Table 2. Initiatives by Indian cities to transform them into blue-green cities[105–110].

City	Initiative	Scale	Responsible agency	Objectives	Challenges
Chennai	Sponge city transformation	Metropolis	Greater Chennai Corporation	Prevent floods and replenish groundwater reserves.	• Implementation of measures such as establishment of sponge parks and restoration of the Pallikaranai marshland. • Incorporation of permeable pavements and ground level elevation practices. • Mitigating the impact of monsoon-related flooding.
Delhi	Master Plan for Delhi 2041	Citywide	Delhi Development Authority (DDA)	Development of Blue-Green Infrastructure, cycling infrastructure, walking circuits. Transformation of unauthorized colonies.	• Addressing various aspects including population density reduction. • Integration of natural elements into urban development. • Conservation and sustainable management of water bodies, wetlands, and green spaces.
Udaipur	Blue-Green Infrastructure (BGI) initiatives	Citywide	Udaipur Development Authority (UDA)	Lake conservation and restoration. Rainwater harvesting techniques. Integration of green spaces, parks, and gardens. Wetland conservation.	• Preserving ecological balance of lakes. • Addressing water scarcity. • Promoting biodiversity and improving urban microclimate. • Protection and restoration of wetlands.
Kochi	Wetland restoration and climate change adaptation	Citywide	Collaborative efforts of various stakeholders	Restoration of wetlands. Buffer zones and no-development zones. Integration of green spaces and urban farming.	• Incorporating guidelines into master plans. • Collaborative efforts and community involvement. • Balancing economic viability with environmental and agricultural elements.
Kolkata	Roadmap for Low Carbon and Climate Resilient Kolkata	Citywide	Kolkata Municipal Corporation (KMC)	Incorporation of solar power and rainwater harvesting systems. Green building guidelines and use of native plants. Climate-smart built environment. Conservation of natural resources and mitigation of climate change impacts.	• Loss of open spaces and increased GHG emissions. • Threats to traditional water bodies and urban heat islands. • Implementation of green building guidelines and capacity building programs. • Establishing monitoring mechanism and Green Building Fund. • Addressing provisions for slums and ensuring the well-being of residents.

Source: Compiled by authors using data and information[105–110].

Chennai (**Table 2**) has pinpointed more than 52 water bodies, encompassing rivers, canals, marshlands, tanks, and lakes, for the purpose of restoration and rejuvenation as per their 2019 plan. The anticipated outcomes of this restoration initiative include mitigating floods, ensuring a sustainable water supply for the city, and facilitating the replenishment of groundwater resources. Delhi's master plan (**Table 2**) states that the revitalized zones bordering the drains will be officially designated as buffer areas and green corridors, accompanied by the introduction of walking and cycling pathways amid lush gardens. Within these spaces, there will be the implementation of eco-friendly amenities, such as exercise zones, yoga gardens, open-air theaters, museums, boating facilities, greenhouses, and community vegetable gardens.

Udaipur (**Table 2**) places significant emphasis on the revitalization of lakes, encompassing initiatives to curb sewage discharge, remove aquatic plants, and prohibit idol immersions. Given the city's reliance on tourism, especially centered around its lakes, the primary focus of the program lies in purifying the water bodies and enhancing the appeal of waterfronts and surrounding spaces. Kochi (**Table 2**) urban planners acknowledge the increasing risk of urban flooding. Amendments are made in the Kerala State Action Plan on Climate Change. In alignment with the Government of India, the National Lake Conservation Plan and National Wetlands Conservation Program were established to facilitate the restoration of wetlands. These initiatives have implemented regulations, including the creation of buffer zones and the designation of no-development zones, aimed at safeguarding BGI. Kolkata (**Table 2**) has made initiatives along the Hooghly River, like beautification projects and riverfront development.

The benefits of BGI solutions, as outlined in **Table 3**, exhibit nuanced manifestations across diverse urban contexts. In flood-prone areas, rainwater management can effectively mitigate flooding and erosion, while in water-stressed regions, the emphasis may shift towards strategies like green roofs. Biodiversity enhancement through BGI flourishes in urban settings aspiring to augment green spaces, with tailored approaches ranging from wetlands creation to tree canopy expansion based on local ecosystems. Pollution reduction strategies adapt to the unique pollutants and their sources, addressing heavy metal filtration in industrial zones and nutrient removal in residential areas. Air quality improvements are crucial in urban zones with elevated emissions, guiding the selection of specific green infrastructure interventions such as street trees or green barriers. Climate resilience interventions are tailored to local challenges, increasing green cover in heat-affected areas or implementing water-sensitive designs in flood-prone regions. Groundwater recharge initiatives hold particular significance in water-scarce regions, aligning BGI practices with local hydrogeological conditions. Noise reduction strategies find optimal application in densely populated urban areas with high noise levels, guiding the implementation of green buffers or sound-absorbing green walls. Carbon sequestration, a critical element for climate change mitigation, is strategically implemented based on local vegetation and climate conditions. Sustainable urban growth through BGI is tailored to each city's unique development pressures, with controlled urban expansion strategies adapting to the specific challenges and goals of individual urban environments. Employment opportunities generated through BGI align with local employment needs and skills, fostering a sense of community pride and identity. In essence, the effectiveness of BGI benefits hinges on their strategic adaptation to the specific characteristics and challenges of each urban environment, underscoring the importance of context-dependent approaches.

Table 3. Benefits of BGI (author's elaboration).

Benefits	Environmental	Social	Economic
Rainwater Management	Mitigates flooding and reduces erosion	Enhances community well-being	Reduces costs of flood damage
Biodiversity Enhancement	Creates habitats for wildlife	Promotes recreational spaces	Boosts ecotourism and property values
Pollution Reduction	Filters pollutants from runoff	Improves public health	Decreases healthcare costs
Air Quality Improvement	Absorbs pollutants and improves air quality	Provides green spaces for exercise	Reduces costs of air pollution-related illnesses
Climate Resilience	Mitigates heat island effects	Reduces heat stress	Lowers energy consumption for cooling
Groundwater Recharge	Replenishes groundwater resources	Provides spaces for social interactions	Reduces water supply costs
Noise Reduction	Absorbs and buffers urban noise	Creates peaceful and tranquil spaces	Increases property values and desirability
Carbon Sequestration	Captures carbon dioxide from the atmosphere	Enhances mental well-being	Supports carbon trading and offset programs
Sustainable Urban Growth	Supports controlled urban expansion	Fosters a sense of community	Reduces infrastructure maintenance costs
Employment Opportunities	Generates jobs in design, construction, and maintenance	Enhances local pride and identity	Boosts local economy through green jobs

7. Conclusion

Blue-Green Infrastructure (BGI) is gaining global recognition as a valuable tool for addressing climate change and related challenges. Despite its potential, BGI remains underutilized compared to traditional grey infrastructure, encountering numerous barriers. This paper introduces a framework to identify and overcome these barriers, emphasizing the need for strategic approaches spanning diverse spheres. The challenges identified underscore the interdependence of barriers, necessitating collaborative efforts from decision-makers, practitioners, professionals, and communities. The recommendation to position BGI as a versatile concept aligning with diverse policy objectives highlights its broader contributions beyond flood risk management. This encompasses climate change adaptation, urban regeneration, and health and wellbeing, emphasizing the need for strong business cases supported by evidence and collaborative funding mechanisms. Long-term strategic thinking and active community engagement are deemed essential for successful BGI implementation. Moreover, the paper emphasizes the importance of reducing biophysical uncertainties through improved data and scientific understanding to construct scientifically sound and widely supported BGI infrastructure.

In the context of India, BGI practices are gaining traction, driven by a growing awareness of the benefits of natural hydrology emulation. The paper illuminates significant challenges specific to the Indian context, showcasing localized water policy adaptations for safer and more sustainable cities. It identifies opportunities to create urban environments that prioritize safety and integration, emphasizing the need for comprehensive, multi-level strategies in modern urban planning. The exacerbation of flooding concerns due to urban expansion, reduced permeable surfaces, and alterations to natural ecosystems underscores the urgency of embracing BGI. In conclusion, the paper advocates for a holistic approach to sustainable urban progress, recognizing the intrinsic connection between environmental stability and social and economic well-being. It emphasizes the imperative for India to formulate a comprehensive plan acknowledging the symbiotic relationship between its cities' stability and the environment for a sustainable future.

Conflict of interest

The authors declare no conflict of interest.

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