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Article

Assessing Knowledge and Perceptions of Blue–Green Infrastructure among Local Government Officers in the Municipal Corporation of Greater Mumbai in India

Vedanti Kelkar [1,*], Anand Joshi [2] and Peter Krebs [1]

[1] Faculty of Environmental Sciences, Chair of Urban Water Management, TUD Dresden University of Technology, Dresden, Germany
[2] Independent Researcher, Tokyo, Japan
* Correspondence: vedanti.kelkar@mailbox.tu-dresden.de

Abstract

Urban flooding in rapidly urbanizing coastal megacities is increasingly intensified by climate variability, declining permeability, ecological degradation, and infrastructure pressures. In Mumbai, India, flood management continues to rely predominantly on conventional grey stormwater infrastructure despite growing international advocacy for Blue-Green Infrastructure (BGI). However, limited research has examined institutional readiness and governance conditions shaping BGI design, planning and implementation within Indian municipal systems. This study investigates institutional knowledge, perception, and implementation readiness regarding BGI within the Municipal Corporation of Greater Mumbai (MCGM) through a mixed-methods approach combining informal interviews with senior municipal officials and a structured survey administered across the Storm Water Drains (SWD), Planning, and Gardens departments. The findings indicate that Mumbai's stormwater governance framework remains largely engineering and drainage-capacity oriented, with flooding increasingly recognized as a multi-causal challenge associated with high-intensity rainfall, reduced permeability, drainage limitations, tidal interactions, and rapid urbanization. While institutional responses continue to prioritize grey infrastructure interventions, the interviews and survey findings reveal growing openness toward ecological and hybrid grey–green approaches within future flood-management planning. The survey findings demonstrate widespread institutional awareness regarding flooding occurrence and strong willingness toward BGI implementation across departments. However, technical understanding related to BGI multifunctionality, hydrological performance, implementation mechanisms, and limitations under extreme rainfall conditions remained comparatively uneven across institutional groups. The Planning Department demonstrated comparatively stronger conceptual understanding of BGI and ecological planning approaches, while the SWD and Gardens departments demonstrated comparatively stronger implementation willingness despite lower technical familiarity. The study identifies an important institutional gap between conceptual understanding and implementation readiness within the MCGM and highlights the need for integrated governance, technically grounded hydrological capacity building, and context-specific ecological planning approaches. The findings contribute empirical insights into governance transitions shaping hybrid grey–green stormwater management within dense tropical coastal megacities and support the development of integrated ecological and climate-resilient urban flood-management frameworks.

Keywords: blue-green infrastructure (BGI); stakeholder knowledge and perception; municipal stormwater governance; urban flood resilience; mumbai; climate-resilient urban planning

Introduction

Urban Flooding, Climate Change and Blue-Green Infrastructure

Rapid urbanization, climate change, and the expansion of impermeable surfaces have intensified urban flooding risks globally. Conventional grey stormwater infrastructure systems are increasingly challenged by high-intensity rainfall events, surface runoff accumulation, and pressures from urban densification (O'Donnell et al., 2017; Qiao et al., 2019). In response, Blue-Green Infrastructure (BGI), also referred to as Nature-Based Solutions (NbS), has emerged as an important approach for climate-resilient urban stormwater management. BGI integrates natural and engineered systems such as wetlands, bioswales, retention ponds, permeable pavements, urban vegetation, and water bodies to support infiltration, evapotranspiration, runoff reduction, biodiversity enhancement, ecosystem services, and urban cooling (Raymond et al., 2017; Lieberherr & Green, 2018).

Existing research demonstrates that BGI contributes not only to hydrological regulation but also to broader ecological and socio-environmental benefits including public health improvement, enhancement of urban liveability, and microclimate regulation (Lieberherr & Green, 2018). Previous studies have highlighted that rapid urbanization modifies natural hydrological systems by increasing built-up and compacted surfaces while reducing infiltration and groundwater recharge capacities, thereby increasing flood vulnerability in cities (Qiao et al., 2019). Climate change further exacerbates these challenges through increasing frequency and intensity of extreme rainfall events, generating substantial economic and infrastructural losses for cities globally (Flores et al., 2021).

Consequently, BGI has increasingly gained international attention as a multifunctional strategy capable of complementing conventional grey infrastructure systems. However, existing research has predominantly focused on hydrological performance and technical applications, while comparatively less attention has been directed toward institutional, governance, and stakeholder dimensions associated with implementation (Gupta & De, 2024).

Governance and Institutional Dimensions of BGI

The implementation of BGI requires institutional coordination across urban planning, stormwater management, environmental governance, and infrastructure development sectors. Local governments play a particularly important role because they oversee urban planning, infrastructure provision, maintenance, and environmental regulation at the city scale (Harrington & Hsu, 2018). Previous studies have shown that fragmented governance structures, lack of interdepartmental coordination, technical knowledge gaps, and limited institutional capacity often constrain the planning and implementation of integrated BGI systems (Sehrawat & Shekhar, 2023; de Rijke et al., 2025).

Research examining stakeholder perception and institutional knowledge has demonstrated that awareness and attitudes among professional stakeholders significantly influence the adoption of innovative stormwater management approaches. Piacentini et al. (2020) found that limited familiarity with Sustainable Urban Drainage Systems (SUDS) constrained implementation among municipal stakeholders despite general institutional interest. Similarly, O'Donnell et al. (2021) observed that positive stakeholder perceptions toward BGI can facilitate implementation processes and help overcome governance barriers. Studies have also shown that environmental attitudes and awareness positively influence support for green stormwater infrastructure investment and implementation (Pierce et al., 2021).

Despite growing international interest in governance dimensions of BGI, empirical studies investigating institutional readiness and municipal stakeholder perception remain comparatively limited within developing-country contexts. In rapidly urbanizing cities, where governance fragmentation and infrastructure pressures are particularly acute, understanding institutional knowledge and implementation readiness becomes essential for advancing climate-resilient urban infrastructure transitions.

Urban India and Mumbai Context

Indian cities are undergoing rapid urban expansion characterized by increasing built-up surfaces, infrastructure pressures, and climate vulnerability. Urban flooding has become a recurring challenge across major metropolitan regions due to drainage limitations, land-use transformation, reduction of natural drainage systems, and increasing extreme rainfall events. Simultaneously, rapid urbanization has significantly reduced urban green and blue spaces, increasing pressure on groundwater recharge and urban ecological systems (Gupta & De, 2024).

Mumbai represents one of India's most flood-prone metropolitan regions due to its high population density, coastal location, reclaimed low-lying land, and extensive impermeable surfaces. The city receives approximately 2300 mm of rainfall annually during the monsoon season and has experienced recurrent flooding events for decades. The 2005 Mumbai floods marked a major turning point in the city's stormwater management discourse following extreme rainfall events that severely disrupted urban infrastructure and caused extensive socio-economic damages. Continued urbanization, concretization, limited open spaces, and pressure on natural drainage systems have further intensified runoff generation and flood vulnerability across the city.

Mumbai's stormwater management system remains predominantly dependent on conventional grey infrastructure approaches including drains, nallas, pumping stations, and engineered flood mitigation systems. However, increasing rainfall variability, climate-related uncertainties, and infrastructure limitations continue to challenge the effectiveness of the prevailing stormwater management regime. At the same time, the city's high urban density and limited land availability constrain opportunities for large-scale infrastructural expansion.

Institutionally, stormwater management and urban development in Mumbai involve multiple agencies and overlapping governance responsibilities. The Municipal Corporation of Greater Mumbai (MCGM) functions as the primary urban local body responsible for stormwater drainage, planning, roads, and green spaces, alongside coordination with regional and state-level institutions. Such governance complexity presents challenges for integrated planning and implementation of multifunctional BGI systems (Sehrawat & Shekhar, 2023).

Research Gap and Study Contribution

Existing BGI research has predominantly focused on hydrological performance, ecological functions, and technical applications, while comparatively limited attention has been directed toward institutional knowledge, governance readiness, and stakeholder perception (Gupta & De, 2024). Within the Indian context, empirical research examining municipal stakeholder understanding and implementation readiness regarding BGI remains limited despite increasing urban flood risks and climate adaptation pressures (Rajan & Murali, 2022).

Previous studies in South Asia have highlighted the limited integration of BGI within prevailing urban infrastructure systems as well as the absence of comprehensive governance and planning frameworks to support implementation (Gupta & De, 2024). Research has additionally emphasized that fragmented institutional responsibilities, technical barriers, and limited interdepartmental coordination continue to constrain the adoption of integrated urban stormwater management approaches in Indian cities (Kumar & Gupta, 2022; Sehrawat & Shekhar, 2023).

Given Mumbai's recurring flooding challenges, governance complexity, and increasing climate vulnerability, understanding the knowledge, perception, and implementation readiness of municipal officers becomes particularly important for advancing climate-resilient urban infrastructure strategies. In this context, the present study investigates the knowledge and perception of BGI among officers of the MCGM through a cross-sectional survey and informal interviews with senior municipal officials. The study aims to assess institutional awareness, examine implementation willingness, and explore opportunities and barriers associated with integrating BGI within Mumbai's existing stormwater management framework.

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Aims of the Study

This study aims to:

1. Assess knowledge and perception of BGI among local government officers of the MCGM using a close-ended questionnaire survey
2. Undertake informal interviews of two high-ranking officers of the MCGM's Stormwater Drains department to discuss the challenges in the prevailing stormwater management and potential of integration of BGI in future municipal stormwater management regime of the MCGM.
3. Document the professional stakeholder agencies involved in city-wide stormwater management in Mumbai and the hierarchy of officers
4. Propose a professional stakeholder framework for integration of BGI with the existing SWM regime of the city

Methodology

Research Design

This study employs a quantitative cross-sectional survey design using close-ended questionnaires to investigate the knowledge and perception of BGI among professional stakeholders of the MCGM. In addition, informal interviews were conducted with the Additional Municipal Commissioner overseeing Stormwater Management and the Chief Engineer of the Stormwater Drains (SWD) department to attain institutional perspectives on prevailing stormwater management practices, flooding challenges, and opportunities for integrating BGI within the city's stormwater management framework. The study also undertakes stakeholder mapping of municipal agencies involved in city-wide stormwater management and documents the professional hierarchy of officers within the SWD department.

Population and Sampling

The target population for the survey comprised local government officers from the Stormwater Drains, Planning, and Gardens departments of the MCGM. Purposive sampling was employed to select respondents involved in stormwater management, urban planning, and green open-space governance. The study included officers across multiple hierarchical levels ranging from senior management to field-level personnel, including Chief Engineers, Deputy Chief Engineers, Executive Engineers, Deputy Engineers, Engineers, Site Engineers, Senior Planners, and Planners.

Priority responses were sought from the SWD department due to its primary role in city-wide stormwater management, while responses from the Planning and Gardens departments were included because of their involvement in urban planning, implementation of the Development Plan 2030, and management of green open spaces. The final sample size was determined by the number of officers willing and available to participate during the data collection period. Constraints related to respondent availability, institutional access, and participation willingness influenced the final response count despite follow-up efforts to maximize participation.

Survey Instrument

The survey instrument was developed to assess the knowledge, perception, and implementation readiness of local government officers regarding BGI within the context of urban stormwater management and planning. Since BGI remains an emerging concept within Indian urban governance and planning practice, the questionnaire focused on attaining baseline understanding of institutional awareness, technical familiarity, perceived benefits, and implementation willingness among municipal officers.

The questionnaire instrument was developed originally by the authors based on the research objectives and thematic areas identified through the literature review. The survey comprised predominantly multiple-choice and Yes/No questions. Two questionnaire formats were prepared:

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one for officers of the SWD department and another for officers from the Planning and Gardens departments. Responses from Planning Department officials were obtained through both questionnaire formats.

The SWD questionnaire consisted of 31 questions divided into three sections: (i) demographic information, (ii) existing stormwater drainage and urban drainage approaches, and (iii) knowledge and perception of BGI. The questionnaire for the Planning and Gardens departments consisted of 37 questions, with the second section additionally including questions related to urban planning and green open spaces. The questionnaires were administered in English, which serves as one of the working languages of the MCGM. Table 1 outlines the thematic domains covered within the survey instrument.

Table 1.

Questionnaire sections for both the surveys	**Variables investigated in each of the sections**
Demographic Questions	Position and status as an officer at MCGM, when the degree was attained, educational qualifications, age, department of service at MCGM, gender, years of experience,
Existing Stormwater Drain/ Urban Drainage	Primary approach for SWM in Mumbai, flooding occurrences, causes of flooding
Existing stormwater drain/ urban drainage approaches, urban planning and green open spaces.	SWM and flooding, role of their department, urban planning, green open space provision, planning standards, function of green open spaces in SWM
Understand Knowledge of Blue-Green Infrastructure	Knowledge on SUDS concept, BGI, awareness of benefits and functions, knowledge on multifunctionality of BGI, effectiveness and outcomes of BGI implementation, technical understanding of BGI design parameters, cost-efficiency knowledge, challenges in introducing BGI in Mumbai, interest in capacity building programs on BGI and willingness to cooperate on experimental projects with scientists.

Data Collection

The survey was prepared in an online format and links were sent to key officials within the selected departments who further sent the online survey to other officials. Thus, the responses were all received through online format.

Informal Interviews, Professional Stakeholder Agencies and Hierarchy of Officers

Informal interviews were undertaken with two high-ranking officers at the MCGM. One was the Additional Municipal Commissioner (AMC) of MCGM and the other was the Chief Engineer (CE) of the Stormwater Drains department. Both are in-charge of the SWM while AMC overlooks other municipal governance portfolios in addition to SWM at the MCGM; CE solely leads the city-wide service delivery of SWM. A 26-minute interview was undertaken of the AMC while a 10-minute interview was undertaken of CE. The interviews have been recorded and transcribed. Both the persons were asked the same set of questions comprising 12 questions.

The objective of the informal interviews to attain comprehensive understanding from the high-ranking officers of the SWM department of the MCGM on their approach to city-wide stormwater

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drainage, their role in stormwater drains service delivery, drivers of flooding, its relation to urban planning and stormwater drain contamination with the view of introducing BGI alongside the prevailing SWM regime of the city.

The questionnaire comprised topics focused on prevailing stormwater management approaches, drivers of flooding, approaches towards flood mitigation, willingness of MCGM to plan and implement BGI, stormwater quality, sewage contamination concerns and future planned BGI projects. Table 1 provides an account of the themes of the main questions for the informal interviews and the answers with qualitative codes derived from the answers by the two interviewees. Supplementary materials contain Table 2 that provides the raw questions and answers of the informal interviews undertaken with Additional Municipal Commissioner and Chief Engineer Stormwater Drains of the Municipal Corporation of Greater Mumbai in India.

Table 1. Comparative Qualitative Analysis of Additional Municipal Commissioner of MCGM and Chief Engineer Stormwater Drains of MCGM.

Q. No.	Main themes of questions	Interviewee 1 – Key Points of answers & Codes derived by the authors	Interviewee 2 – Key Points of answers & Codes derived by the authors
1	City-wide stormwater management system?	**Key points:** System evolving over time; capacity increased from 25 mm to 55 mm; BRIMSTOWAD study with IIT Bombay; 90–95% augmentation completed; next phase due to changing rainfall patterns (>100 mm/4 hrs). **Codes:** Infrastructure capacity; Infrastructure limitations; Existing studies (BRIMSTOWAD); Infrastructure upgrading; High-intensity rainfall risk; Progress on infrastructure improvement; Climate change / rainfall pattern shift; Need for further infrastructure development	**Key points:** Classification of stormwater network into minor and major nallas; roadside drains (<1.5 m); four major rivers (Mithi, Poisar, Dahisar, Oshiwara). **Codes:** Roadside drains; Large-capacity drain channels; Key flow channels
2	Drivers of flooding / water clogging (last 5 years)?	**Key points:** 300+ flooding spots; dynamic nature (10–15% change annually); reclaimed land (Island City, BKC); low-lying areas; sharp gradients; silt and solid waste clogging drains. **Codes:** Large magnitude of flooding hotspots; Dynamic flooding numbers; Reclamation; Topographical factors; Drainage blockages	**Key points:** Systems designed as per BRIMSTOWAD I & II (50–55 mm/hr); erratic rainfall; short-duration heavy rain; increased runoff; climate change impacts. **Codes:** System design per master plans; Design rainfall specification; Climate-induced rainfall variability; Short-duration heavy rainfall; Waterlogging occurrences
3	Engineering approaches for	**Key points:** Hindmata holding pond, sump and pumping system; reduction of waterlogging from 4 hours to 30	**Key points:** Drain and river augmentation strictly as per BRIMSTOWAD II.

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	SWM & runoff reduction?	minutes; nalla diversion; underground tunnels suggested by BRIMSTOWAD. **Codes:** Prolonged flooding; Multiple interventions; Flood reduction post-intervention; Location-centric interventions; Augmentation of tunnels	**Codes:** System-wide master plan–based implementation
4	Role of MCGM & interviewee?	**Key points:** Dedicated SWD department; hierarchy from Chief Engineer; consultants and contractors; interviewee oversees stormwater department. **Codes:** Citywide stormwater operations; Multilayered hierarchy;	**Key points:** Civic responsibility of BMC; Chief Engineer oversees SWD across eastern, western suburbs and city. **Codes:** Institutional responsibility; Water management tasks; Role of Chief Engineer; Geographical division
5	Inclusion of natural elements / BGI?	**Key points:** City-wide flood mitigation plan under NDMA; IIT collaboration; central funding; bioswales, detention/retention tanks, permeable pavements; gardens as bioswales. **Codes:** Comprehensive city-wide planning; National flood programs; Institutional collaboration; Evidence-based planning; Green stormwater interventions; Runoff reduction outcomes	**Key points:** Agreement to include BGI and natural elements. **Codes:** Enabling towards BGI
6	Impact of roads & traffic on SWM?	**Key points:** Flooding slows traffic; socio-economic impacts; massive road concretization increases runoff; need for expert study. **Codes:** Flood–traffic correlation; Socio-economic impacts; Concretization increases flood risk; Need for impact assessment	**Key points:** Urbanization and paved surfaces reduce soil infiltration; concretization increases runoff. **Codes:** Urbanization impacts; Concrete paving; Reduced groundwater penetration; Increased runoff
7	Space constraints & urban planning deficiencies?	**Key points:** High land prices; underground/open interventions costly; holding ponds expensive; land scarcity affects feasibility. **Codes:** Space scarcity; High land prices; High capital costs; Underground infrastructure cost	**Key points:** Encroachments and slums restrict drain construction or augmentation. **Codes:** Space constraints; Encroachments; Inability to augment drains

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8	Contamination of stormwater drains?	**Key points:** Stormwater active mainly during monsoon; leakage impact minimal; sewage contamination is primary risk; systems are separate. **Codes:** Seasonal stormwater use; Low leakage impact; Sewage contamination risk; Separate systems	**Key points:** Separate sewer and SWD systems; contamination is exception, not norm. **Codes:** Separation of systems; Contamination as exception
9	Locations of contamination?	**Key points:** Can occur anywhere; unauthorized sewer connections; dry weather flow; aging pipelines; damage due to digging. **Codes:** Not stormwater-driven; Unauthorized sewer lines; Dry weather flow; Pipeline damage factors	**Key points:** Damaged sewer lines allow sewage to enter stormwater drains. **Codes:** Damaged sewer lines impact stormwater drains
10	What can be done?	**Key points:** Continuous pipeline upgrades; 2% replacement annually; preventive maintenance of trunk mains. **Codes:** Budgeted upgrades; Planned renewal; Aging infrastructure; Preventive maintenance	**Key points:** Repair sewer lines. **Codes:** Repairs
11	Treatment at outfalls?	**Key points:** No treatment needed if sewage not present in stormwater. **Codes:** No need for treatment without sewage	**Key points:** Stormwater is rainwater; no treatment required. **Codes:** No treatment for stormwater
12	Future of urban planning, SWM & BGI?	**Key points:** Climate variability; unseasonal rainfall; exceeded drain capacity; clogging by solid waste; need to revise desilting strategies and planning. **Codes:** Climate-resilient planning; Unseasonal rainfall; Capacity exceedance; Solid waste impacts; Revisiting desilting strategies	**Key points:** Future inclusion of nature-based, non-structural measures such as porous pavements, holding/detention/retention ponds, vegetation. **Codes:** Planned inclusion of BGI in SWM

The interviews collectively discuss the evolution, structure, and performance of Mumbai's city-wide stormwater management (SWM) system, including its historical design capacity, upgrades under the BRIMSTOWAD master plans, and ongoing augmentation in response to increasing rainfall intensity and climate variability. Key drivers of flooding identified include high-intensity short-duration rainfall, reclaimed and low-lying areas, sharp topography, siltation, solid waste clogging, rapid urbanization, high built-up density, increase in impermeable surfaces and large-scale road concretization that reduces infiltration and increases surface runoff. Engineering responses include location-specific interventions such as holding ponds, pumping stations, nalla diversion and widening, underground tunnels, and broader drain augmentation. Institutional responsibilities of

MCGM/BMC, departmental hierarchy, contractor-based implementation, and the role of technical collaboration (e.g., with IIT-Bombay) were also highlighted, alongside challenges posed by space constraints, high land prices, and existence of informal settlements on unauthorized land.

The discussions further address the integration of BGI and nature-based solutions such as bioswales, detention and retention ponds, porous pavements, and water-absorbing vegetation within a comprehensive, centrally funded urban flood mitigation plan. Concerns regarding sewer–stormwater contamination were noted, though contamination is described as an exception due to separate systems, with issues mainly arising from damaged or unauthorized sewer connections. Routine infrastructure renewal, including annual pipeline replacement and preventive maintenance, forms part of ongoing mitigation efforts. As next steps, both interviewees emphasize the need for climate-resilient planning, revised desilting strategies and localized climate studies to address changing rainfall patterns and future urban development pressures.

Originally designed to accommodate rainfall of merely 25 mm, the system has been progressively upgraded following the 2005 extreme flood event, with a target capacity of 55 mm, and further improvements are underway to address increased rainfall intensity due to climate change possibly upto a 100 mm capacity. The system includes a combination of minor and major drains, as well as four key rivers Poisar, Dahisar, Oshiwara, and Mithi that function as discharge channels. However, flooding remains a significant challenge, with over 300 hotspots that change dynamically each year. Reclaimed and low-lying areas, coupled with sharp gradients in certain parts of the city, make certain locations particularly vulnerable. Increased urbanization, concretization of roads, and the accumulation of silt and solid waste in drains exacerbate the problem. Additionally, the intensity and erratic nature of rainfall in recent years, linked to climate change, have put further strain on the stormwater system, often exceeding its design capacity.

To mitigate flooding and manage runoff, various engineering solutions are being implemented, such as location-specific interventions like the Hindmata holding pond, sump, and high-capacity pumps. Underground tunnels, nalla diversions, and widening are also being considered to enhance the drainage capacity and accommodate more rainfall. These interventions, while effective in reducing flooding durations, highlight the complexity of stormwater management in a dense, rapidly urbanizing city. The MCGM responsible for stormwater management, operates through a structured department led by the Chief Engineer, with contractors and consultants tasked with the execution of works. However, space constraints due to high land prices and unauthorized informal settlements land coverage limit the ability to expand or improve the stormwater infrastructure.

In the future, there is a push to integrate BGI into Mumbai's stormwater management plan. A comprehensive urban flood mitigation plan, supported by national funding and developed in collaboration with Indian Institute of Technology – Bombay (IIT Bombay), is under preparation. This plan proposes a mix of structural measures like holding ponds and retention tanks, alongside non-structural solutions such as bioswales, permeable pavements, and water-absorbing plants. The aim is to reduce runoff, improve flood resilience, and enhance the city's ability to absorb rainfall. Additionally, concerns over contamination due to leakage from sewers are noted, but these are seen as exceptions, particularly in areas where unauthorized connections or damaged pipes may compromise the stormwater system. The annual program for replacing 2% of Mumbai's water pipelines and preventive maintenance of key infrastructure are critical components of ensuring system reliability.

In terms of urban planning, the increasing concretization of roads and pavements is exacerbating runoff issues, as it reduces groundwater infiltration. This urbanization trend, coupled with the city's high population density, is causing surface runoff to increase, raising the risk of flooding. An expert study is being considered to assess the impact of road paving on flooding patterns. Moreover, the impact of climate change on rainfall patterns requires that the city's infrastructure planning be adaptable. As rainfall becomes increasingly erratic and intense, strategies like desilting and other maintenance procedures need to be reevaluated to ensure that Mumbai's stormwater management system can handle future challenges. With the potential for more unseasonal rainfall, integrating

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nature-based solutions, BGI and climate-resilient infrastructure is seen as essential for sustainable urban development in Mumbai.

Figure 1 illustrates the institutional and municipal government set up for stormwater management of 24 wards of Mumbai.

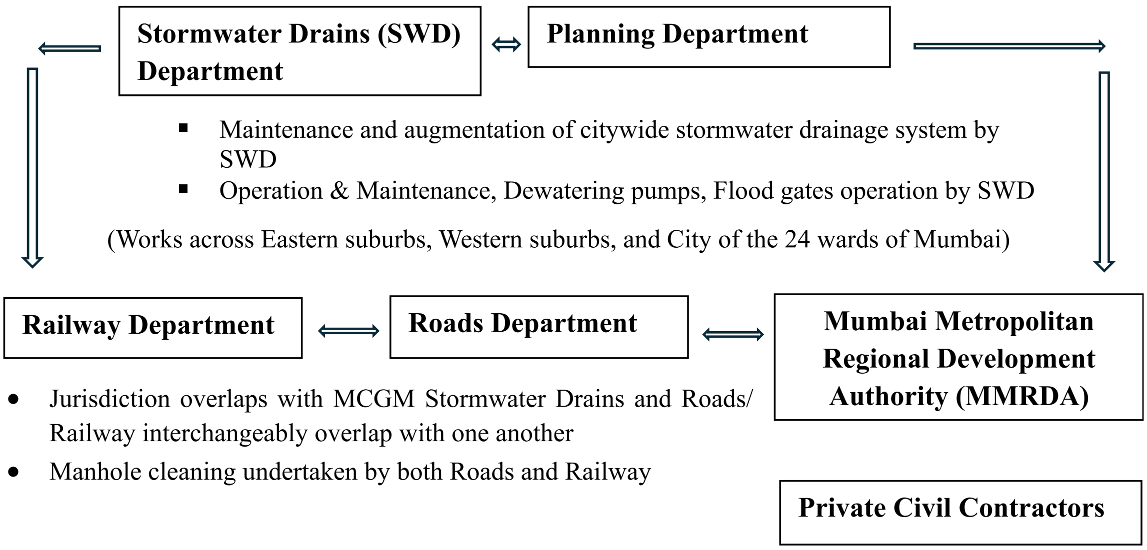

Figure 1. Framework showing the professional stakeholder agencies involved in stormwater management for the 24 wards of Mumbai.

Table 2. Professional hierarchy map of officers at the SWD department of MCGM.

Department wise professional hierarchy across the Stormwater Drains department of MCGM

Data Analysis of Survey Questionnaire

The survey questionnaire comprised three sections: (i) demographic and institutional profile, (ii) existing stormwater and urban drainage approaches, and (iii) knowledge, perception, and willingness to implement Blue-Green Infrastructure (BGI). Additional questions related to urban planning and green open spaces were included for respondents from the Planning and Gardens departments. The survey aimed to assess respondent characteristics, perceptions of existing stormwater management challenges, and institutional readiness for BGI adoption within the MCGM.

The first section captured respondent characteristics including professional rank, departmental affiliation, age group, gender, and experience. These variables enabled analysis of variations in BGI knowledge and perception across institutional hierarchies and functional roles within the municipal system.

The second section examined perceptions of existing stormwater management conditions, including flooding occurrence, drainage limitations, and drivers of urban flooding such as impermeable surfaces and climate-related impacts. This section established the infrastructural and environmental context within which BGI adoption was evaluated.

The third section assessed stakeholder awareness, conceptual understanding, perceived benefits, and implementation readiness regarding BGI. It examined familiarity with Sustainable Urban Drainage Systems (SUDS), understanding of BGI multifunctionality, perceived effectiveness, implementation willingness, and training needs.

Survey data were analysed using descriptive statistics and a weighted scoring approach with normalization. Responses were assigned weights based on correctness as, with fully correct answers receiving the highest scores. This was based on a expert-defined scoring criteria of the authors' subject-matter expertise. For questions with multiple correct responses, selected answers were normalized to ensure comparability across respondents. Normalized scores were then averaged across demographic categories including education, seniority, age group, and department. Figure 2 illustrates the weighted scoring, normalization, and averaging process used for the analysis.

Figure 2. Flowchart illustrating the survey data analysis workflow, including response weighting, score normalization, calculation of respondent-level topic scores, aggregation by demographic and departmental categories, and derivation of comparative average scores across the four survey themes

Demographic information including education, seniority, age and department of the surveyed employees was gathered. The survey covered four major topics, namely:

1. Knowledge of prevailing flooding
2.Urban planning integration with SWM
3. Knowledge of BGI
4. Willingness to implement BGI

In order to summarise results of the survey, all the answers were assigned weights depending on its correctness. A weight of 100% means that the answer is completely correct. Some of the questions were of a Yes/No type, where only one answer could be selected, "Yes" carried a weight of 100% and "No" had 0% weight. However, several other questions had more than one correct answer. For such questions, some of the answers carried a reduced weight, such as 80% or 50%, which was determined by the authors. Incorrect responses are given a weight of zero. Negative scoring was not used.

For a Yes/No question, the answer chosen by an employee simply becomes the final weight for that question. However, for questions with more than one correct answer, only if the officer selects all the correct answers will s/he be considered to have answered that question correctly. For such questions, the weights of each answer selected by an employee were added together. To ensure that the final correct answer should amount to 100%, the sum of weights of selected answers was divided by the sum of weights of all the correct answers. In other words, we normalise the weights of the answers.

Once answers for all the questions are normalised in this fashion, we undertake a category-wise average as shown in the all the analytical figures of this article on the following pages. The four demographic categories are divided as follows:

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Table 4. Demographic categories based on which the employees are grouped.

Education	Seniority	Age	Department
Bachelor	Field	25–34	Garden
Master	Junior	35–44	Planning
	Mid	45–54	Stormwater
	Senior	55–64	

Since among the responses there was only one female, thus the gender was not considered as a category. Year of graduation and seniority level are not entirely independent categories. MCGM's organizational structure is hierarchical and therefore, seniority as a category would reflect more meaningful distribution of scores across the hierarchies in comparison to the year of graduation and thus, the authors did not consider the year of graduation.

A total of 26 responses were obtained from officers across the Stormwater Drains (SWD), Planning, and Gardens departments of the MCGM. Figure 3 presents the overall results across four thematic areas: (i) prevailing flooding knowledge, (ii) urban planning integration with stormwater management (SWM), (iii) knowledge of Blue-Green Infrastructure (BGI), and (iv) willingness to implement BGI.

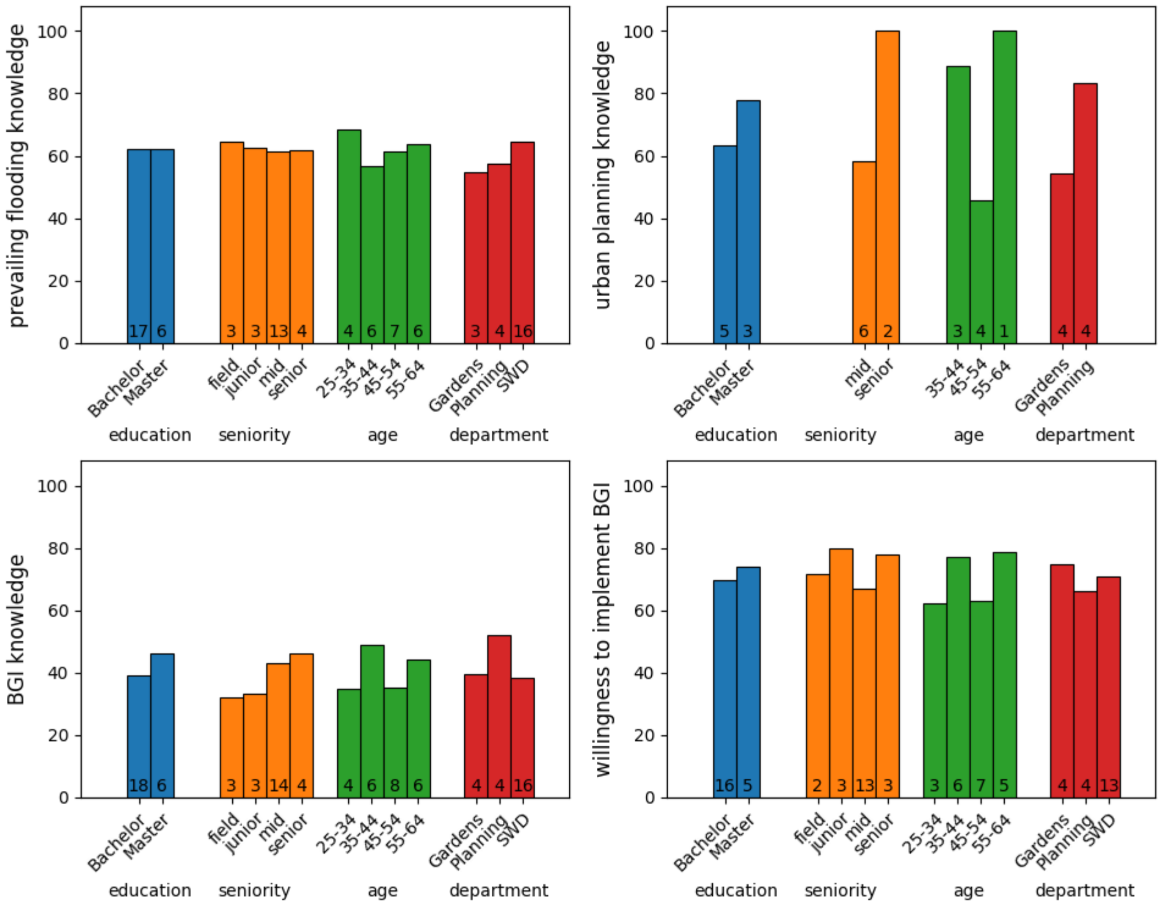

Figure 3. Division wise score for each category for each of the four topics selected in the survey.

The analysis quantified respondent understanding across these four thematic areas and four demographic categories: education, seniority, age group, and department. Category-wise normalized scores were averaged across all relevant questions within each thematic area to generate the results presented in Figure 3.

The Supplementary Materials contains Table 3 outlining the survey questionnaire and contains the weights assigned to responses for all relevant question.

(i)Prevailing Flooding Knowledge

Across all four respondent categories i.e. education, seniority, age, and department, the response rates for prevailing flooding knowledge were relatively consistent with an average of 62%, generally ranging between 54% and 68%. This indicates significantly above average and relatively uniform level of awareness regarding flooding issues among respondents. No major variation was observed across educational backgrounds, age groups, hierarchical levels, or departmental affiliations, suggesting that baseline knowledge about flooding risks is fairly widespread across the institutional landscape.

(ii) Urban Planning Integration with SWM

Knowledge related to the integration of urban planning and SWM was comparatively higher and more differentiated across respondent categories. Respondents with a Master's level education, those at the senior administrative level, and individuals in the 35–44 and 55–64 age groups demonstrated the highest knowledge levels.

It should be noted that this set of questions was only administered to respondents from the Planning and Gardens departments. Within these groups, response rates ranged from approximately 78% to 100%, with the Planning Department exhibiting particularly strong familiarity with planning-SWM integration concepts.

(iii) Knowledge of BGI

BGI knowledge levels were relatively consistent across all respondent categories, but overall lower than the other thematic areas, with response rates generally falling between 40% and 45%. However, some variation emerged across institutional roles. Mid-level and senior officers demonstrated comparatively higher BGI knowledge, suggesting that experience and exposure to policy or planning processes may contribute to greater familiarity with BGI concepts. Departmentally, respondents from the Planning Department showed higher BGI knowledge compared to those from the Gardens and SWD departments.

(iv) Willingness to Implement (WTI)

In contrast to the knowledge indicators, WTI of BGI measures was consistently high across all respondent categories, with response rates ranging between 76% and 80%. Notably, junior-level officers displayed the highest WTI, followed by senior officers, suggesting a strong institutional openness toward adopting BGI solutions across hierarchical levels. In terms of age groups, respondents in the 35–44 and 55–65 age brackets showed particularly high willingness. From a departmental perspective, Gardens and SWD departments demonstrated higher willingness to implement BGI compared to the Planning Department. This finding is particularly noteworthy because Planning respondents exhibited higher levels of BGI knowledge but comparatively lower WTI indicating a potential gap between conceptual understanding and practical adoption.

The responses to **Questions 11–14** in Figure 4 indicate generally strong awareness of flooding and stormwater management among respondents. For **Question 11**, which examined understanding of Mumbai's stormwater management system, the overall score of 60% suggests a good level of institutional knowledge, particularly among respondents from the SWD department, field and junior-level officers, and older age groups, reflecting stronger operational and institutional familiarity.

Question 12, assessing awareness of recurring annual flooding in Greater Mumbai, recorded consistently high response rates across most categories, with several groups scoring above 80% and junior and senior officers achieving 100% accuracy. Departmentally, the Gardens and SWD departments demonstrated particularly strong awareness, while the Planning Department showed comparatively lower recognition of recurring flooding events.

In contrast, **Question 13** revealed comparatively weaker understanding regarding the historical persistence of flooding in Mumbai, with generally low scores across departments and professional categories, indicating uneven institutional awareness of long-term flooding history.

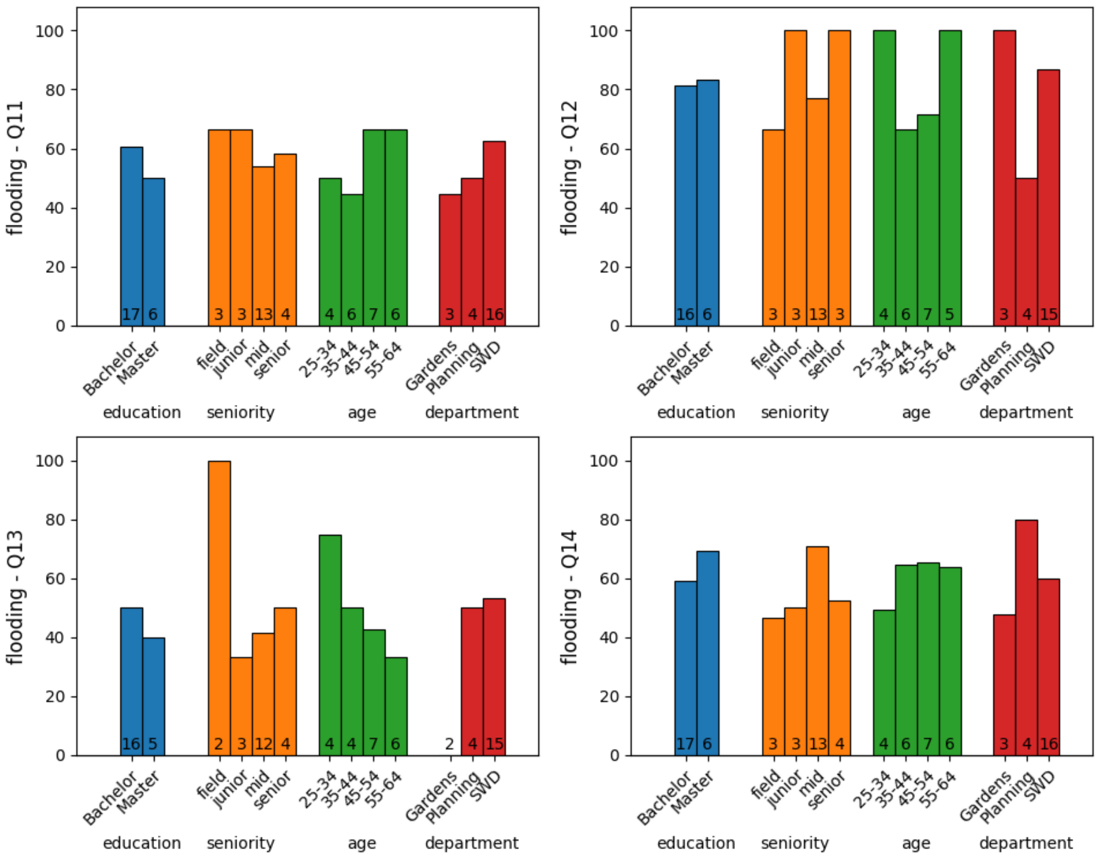

Figure 4. Question wise score towards responses for prevailing flooding knowledge integration across the four categories.

Question 14 demonstrated above-average awareness of the major drivers of flooding, with stronger understanding observed among respondents with Master's level education, mid-level officers, and the Planning Department, likely reflecting greater engagement with urban planning and development processes influencing flood risk. Overall, the findings indicate that municipal officers possess strong awareness of recurring flooding and its drivers, although knowledge regarding the long-term historical context of flooding remains comparatively limited across institutional groups.Top of Form

The responses to **Questions 16, 18, and 20** in Figure 5 indicate strong institutional recognition of the relationship between urban planning, green open spaces, and stormwater management (SWM) across respondent categories.

Question 16, which examined whether integrated urban planning and SWM approaches form part of respondents' professional responsibilities, recorded strong agreement across all categories, particularly among respondents with Master's level education, senior officers, individuals aged 55–64, and the Planning Department. Overall, all respondents acknowledged the inclusion of integrated planning and SWM approaches within their professional duties.

Question 18 assessed perceptions regarding the role of green open spaces in stormwater management. Strong agreement was observed among Master's degree holders, senior professionals, respondents aged 35–44 and 55–64, and the Planning Department, many of whom recorded scores approaching 100%. Comparatively moderate scores were observed among Bachelor's degree holders, mid-level officers, respondents aged 45–54, and the Gardens Department.

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Question 20 examined perceptions regarding the adequacy of existing green open spaces across Mumbai's wards. Although some respondent categories, particularly senior professionals and respondents from the Planning and Gardens departments, reported relatively higher perceived adequacy, all respondents ultimately indicated that existing green open spaces in Mumbai are inadequate, highlighting a widespread institutional recognition of insufficient green-space provision within the city.

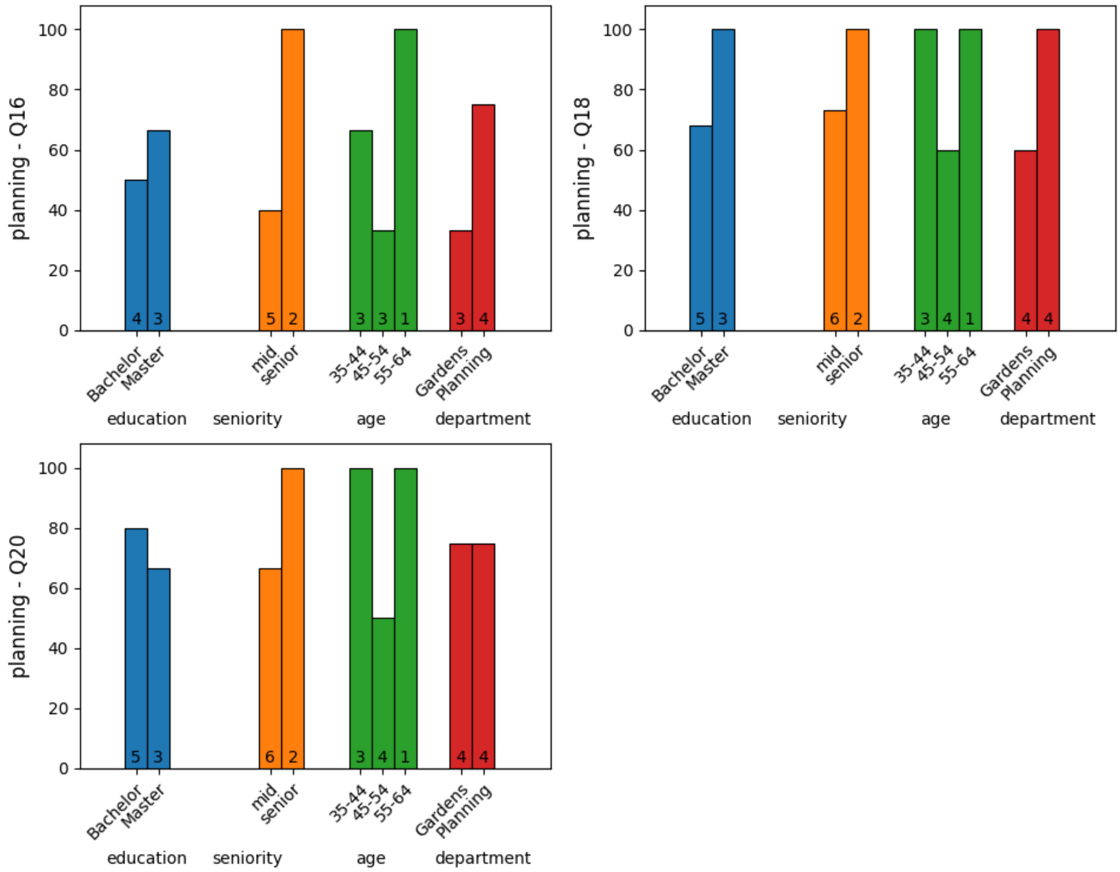

Figure 5. Question wise score towards responses for prevailing urban planning integration with SWM across the four categories.

The responses to **Questions 21–24** in Figure 6 reveal varying levels of awareness and understanding of Sustainable Urban Drainage Systems (SUDS) and Blue-Green Infrastructure (BGI) across respondent categories.

Question 21, which assessed awareness of SUDS, recorded the highest scores among respondents from the Planning Department, senior officers, Master's degree holders, and individuals within the 35–44 and 55–64 age groups. In contrast, the Gardens and SWD departments demonstrated comparatively lower awareness, indicating uneven familiarity across departments.

Question 22, which examined general familiarity with BGI, revealed comparatively low awareness across all respondent categories, with most scores remaining at or below 50%. Respondents aged 35–44 demonstrated relatively stronger familiarity, although overall understanding of the concept remained limited.

Question 23, which assessed respondents' ability to correctly identify the description of BGI, similarly recorded low scores across most categories. Only respondents with Master's level education demonstrated comparatively higher understanding, while the remaining categories reflected below-average conceptual familiarity with BGI and its defining characteristics.

Question 24 examined awareness regarding the multifunctional benefits and functions of BGI. Comparatively stronger awareness was observed among Master's degree holders, respondents aged

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35–44, field officers, and mid-level officers, while most other categories recorded lower levels of understanding.

Overall, the findings indicate that although respondents reported general awareness of SUDS and BGI concepts, detailed conceptual and functional understanding remained moderate to limited across most institutional groups. Respondents demonstrated stronger recognition of BGI as an interconnected green and water-based system supporting ecosystem services, while comparatively fewer respondents associated BGI with stormwater management, green-space planning, and multifunctional urban infrastructure benefits.

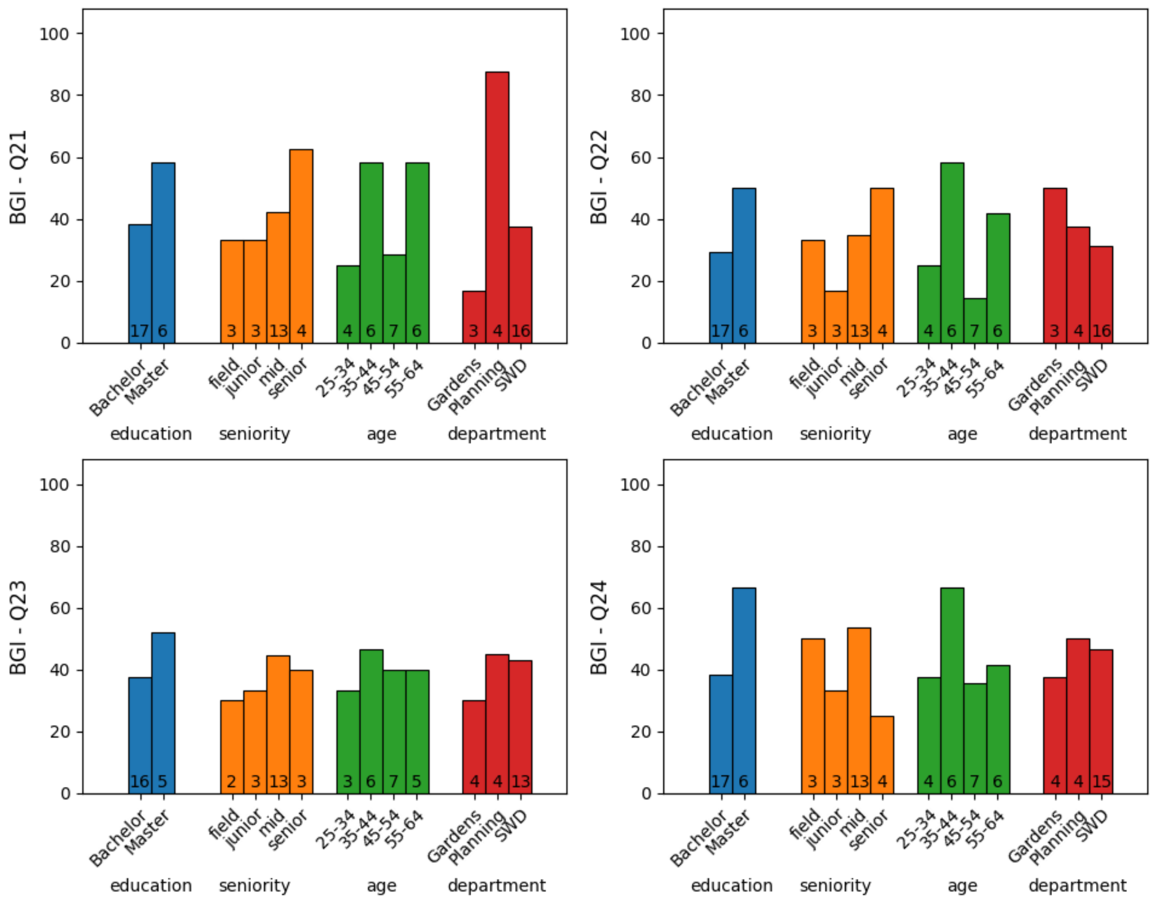

Figure 6. Question wise score towards responses for prevailing BGI knowledge and perception across the four categories (Q21 to Q24).

The responses to **Questions 25–28** in Figure 7 indicate varying levels of conceptual understanding regarding the benefits, components, and multifunctionality of Blue-Green Infrastructure (BGI).

Question 25, which assessed respondents' overall understanding of BGI benefits, recorded the strongest performance within the Planning Department, with scores approaching 80%, indicating comparatively high conceptual familiarity. The SWD department demonstrated moderate understanding, while the Gardens Department recorded comparatively lower scores, highlighting knowledge gaps across departments. Across educational qualifications, professional roles, and most age groups, awareness levels remained relatively consistent at around 60%.

Question 26 examined respondents' ability to correctly identify the features and components of BGI. Overall response rates remained comparatively low across most categories, generally at or below 50%, indicating limited technical understanding of BGI components. Slightly stronger comprehension was observed among younger respondents, senior officers, and Planning Department officials.

Question 27, which assessed understanding of multifunctionality in BGI, revealed moderate awareness across respondent groups. Field officers and respondents within the 25–34 age group demonstrated comparatively stronger understanding, although overall familiarity with multifunctionality concepts remained moderate rather than strong.

Question 28 investigated respondents' ability to identify interventions supporting multifunctional BGI planning and implementation. The findings indicate mixed levels of understanding across categories. While comparatively lower scores were observed within the Gardens and SWD departments, stronger awareness was recorded among senior officers, respondents with Bachelor's and Master's qualifications, and younger to middle-aged groups, reflecting relatively better familiarity with multifunctional BGI interventions among these segments.

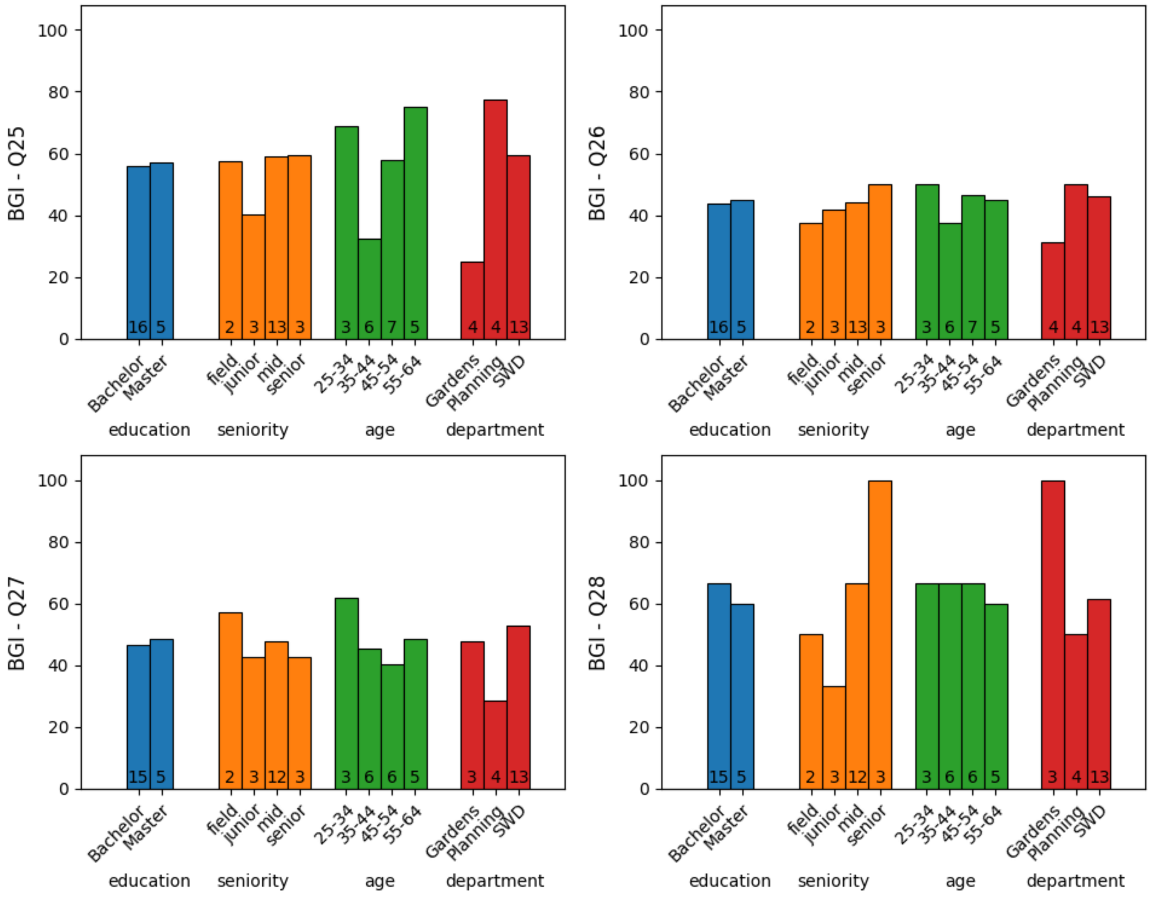

Figure 7. Question wise score towards responses for prevailing BGI knowledge and perception across the four categories (Q25 to Q 28).

The responses to **Questions 29–31** in Figure 8 indicate moderate to limited understanding of specific technical aspects related to BGI performance and implementation.

Questions 29 and 31 recorded response rates generally below 50% across most categories, indicating comparatively lower technical familiarity. In **Question 29**, relatively stronger understanding was observed among senior officers and respondents from the Planning and Gardens departments. Similarly, in **Question 31**, field-level and senior officers demonstrated comparatively higher response rates approaching 50%.

Question 30 assessed perceptions regarding the effectiveness of BGI in mitigating high runoff volumes and flooding during high-intensity rainfall events. Since BGI performance varies depending on local conditions, rainfall intensity, and the type of intervention implemented, responses were analysed separately using a histogram to capture the distribution of "Yes" and "No" responses across categories. The findings indicate that most respondents perceived BGI as effective in mitigating

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flooding during intense rainfall events, with particularly strong agreement among Bachelor's degree holders, mid-level officers, and respondents from the SWD department.

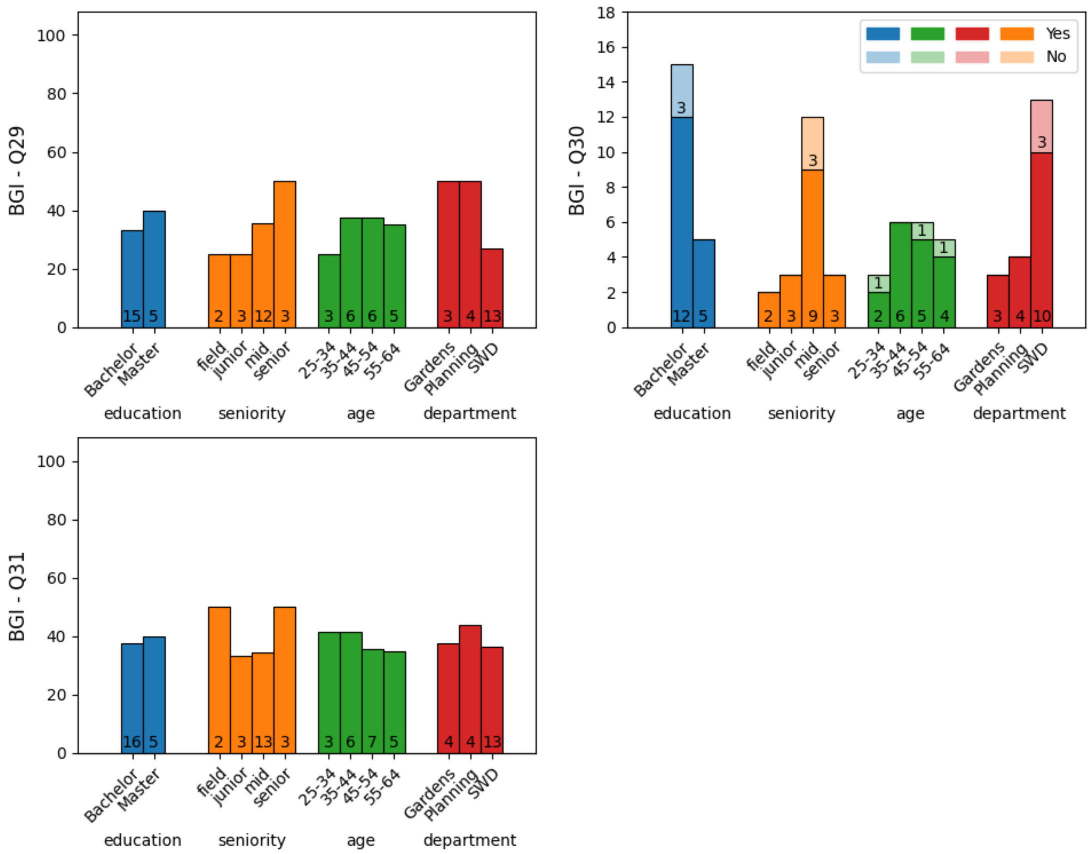

Figure 8. Question wise score towards responses for prevailing BGI knowledge and perception across the four categories (Q29 to Q31).

The responses to **Questions 32, 34, 35, and 37** in Figure 9 indicate strong institutional interest, implementation willingness, and demand for capacity building related to BGI.

Question 32 assessed respondents' interest in learning about BGI design parameters and features such as bioswales, infiltration trenches, and retention ponds. All respondents expressed interest in further learning, with particularly strong engagement among senior and junior officers, Master's degree holders, respondents aged 35–44 and 55–64, and the Planning Department. Comparatively lower, though still positive, response rates were observed among the Gardens and SWD departments, field and mid-level officers, and younger to middle-aged respondents.

Question 34 examined awareness of related terminology and approaches such as Nature-Based Solutions (NbS) and Low-Impact Development (LID). Response rates remained relatively consistent across categories, with all respondents recognizing NbS, while familiarity with LID remained comparatively lower, indicating partial gaps in technical terminology despite overall awareness of BGI-related approaches.

Question 35 assessed willingness to implement BGI within projects and development works. The findings demonstrate a highly positive outlook toward implementation, with all respondents expressing willingness to adopt BGI measures. Particularly strong support was observed among field and senior-level officers, younger respondents, and the Planning Department, while moderately lower but still positive response rates were recorded among junior and mid-level officers and respondents from the Gardens and SWD departments.

Question 37 examined perceptions regarding the need for training, capacity building, and knowledge dissemination related to BGI. All respondents acknowledged the importance of

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institutional training and capacity-building initiatives. Strong agreement was observed across most professional and age categories, although moderate variation in response intensity was observed among mid-level officers and respondents from the Planning and SWD departments.

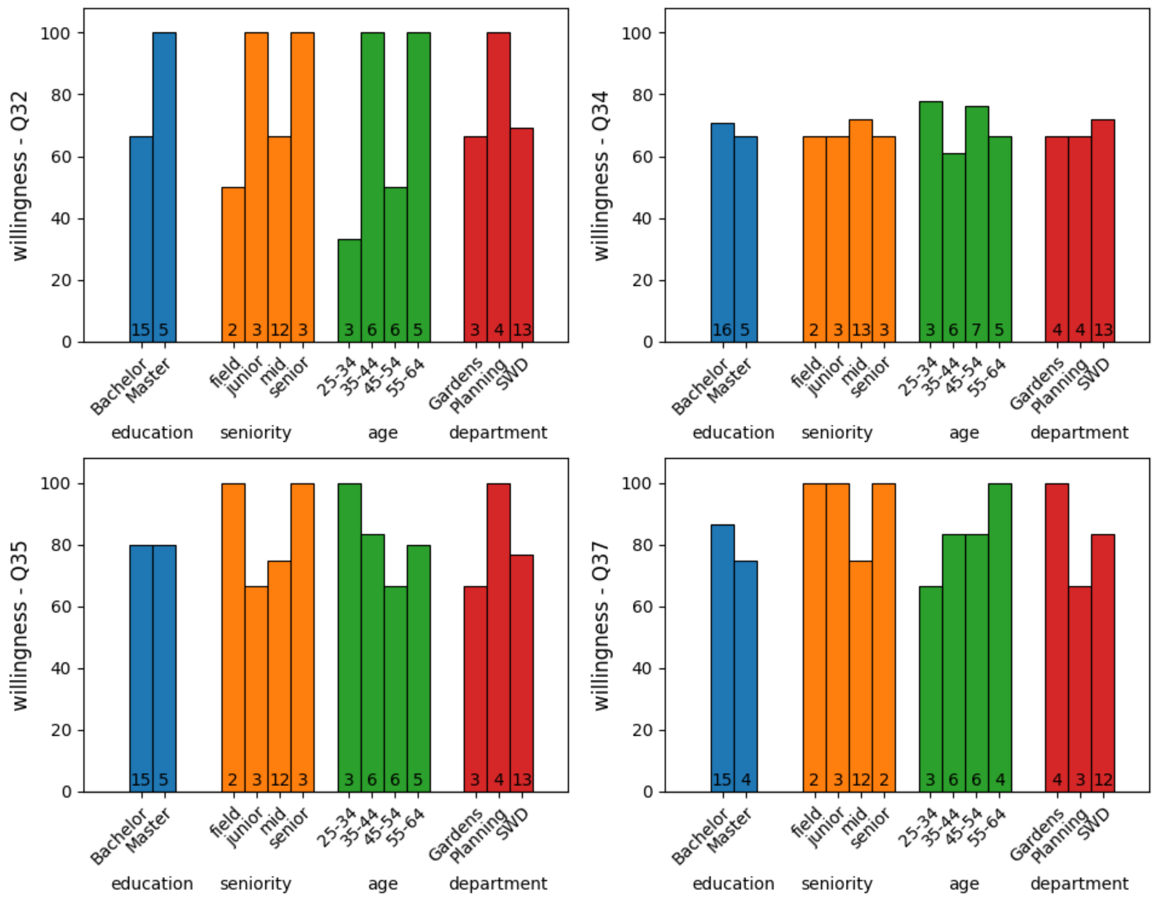

Figure 9. Question wise score towards responses for Willingness to Implement BGI across the four categories (Q32 to Q 37).

Overall, the findings indicate strong institutional openness toward BGI implementation alongside a widespread recognition of the need for technical training and knowledge development within the MCGM.

Question 38 assessed respondents' willingness to cooperate with researchers on experimental BGI pilot projects. The findings indicate a generally strong openness toward collaborative and research-oriented BGI initiatives, with "Yes" responses representing positive willingness to participate.

Senior officers and respondents from the Gardens Department demonstrated the highest levels of engagement, recording response rates approaching 100%, while Master's degree holders also showed comparatively strong participation. In contrast, field-level and junior officers, respondents within the 25–34 and 45–54 age groups, and officers from the Planning and SWD departments recorded comparatively lower response rates, indicating uneven engagement across institutional categories.

From an educational perspective, respondents with Bachelor's and Master's qualifications demonstrated above-average willingness to participate in collaborative pilot initiatives, suggesting that higher educational exposure may contribute to stronger engagement with research and experimental implementation processes.

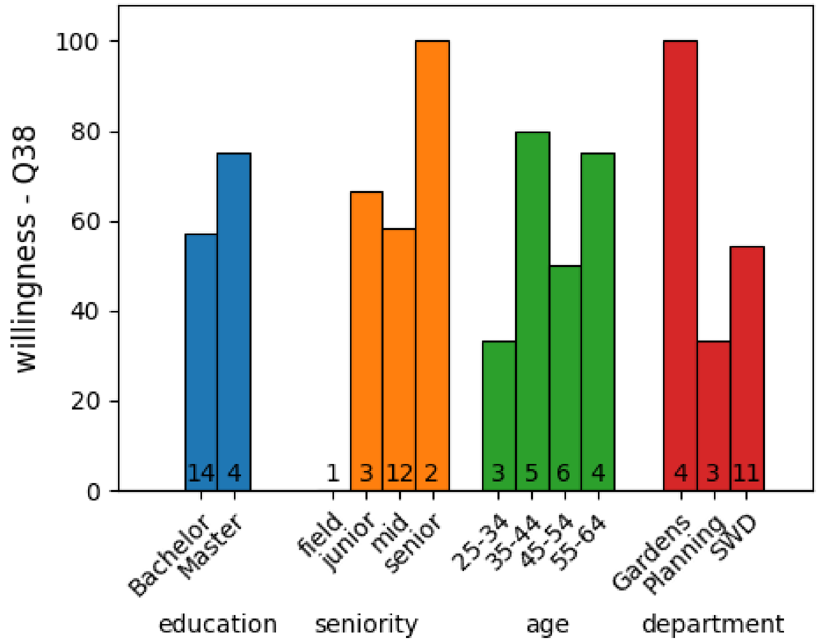

Figure 10. Question wise score towards responses for Willingness to Implement BGI across the four categories (Q 38).

Results

This section presents the findings from: (i) informal interviews conducted with two senior MCGM officers involved in stormwater management, and (ii) the BGI knowledge and perception survey administered to officers from the Storm Water Drains (SWD), Planning, and Gardens departments of the MCGM.

Informal Interview Findings

The informal interviews explored institutional perspectives on stormwater management, flooding drivers, infrastructure constraints, and opportunities for integrating BGI within Mumbai's stormwater management framework.

City-wide Stormwater Management and Flooding Drivers

The interviews revealed that Mumbai's stormwater management system remains predominantly grey-infrastructure based and was originally designed for rainfall intensities of 25 mm/hr before being upgraded under the BRIMSTOWAD I and II master plans to capacities of approximately 50–55 mm/hr. Although most augmentation works have been completed, recent high-intensity rainfall events continue to exceed design thresholds.

Both interviewees identified climate variability, rapid urbanization, concretization, silt accumulation, solid waste blockages, and low-lying reclaimed areas as major contributors to flooding across the city. More than 300 flooding locations were identified during 2024, with flood-prone locations varying annually.

Engineering Approaches and Institutional Role

Current flood mitigation approaches remain largely structural and capacity-enhancement oriented, including pumping stations, holding ponds, drain widening, underground tunnels, and marine outfalls. The interviews highlighted the example of the Hindmata flooding hotspot, where holding ponds, pumping infrastructure, and sump systems substantially reduced flood duration.

The MCGM operates through a dedicated Storm Water Department responsible for augmentation, maintenance, and flood mitigation works through centralized technical oversight and decentralized implementation mechanisms.

Integration of BGI and Nature-Based Approaches

Both interviewees expressed institutional support toward integrating BGI within future stormwater management strategies. Proposed interventions included bioswales, permeable pavements, detention and retention systems, and conversion of gardens and open spaces into multifunctional BGI elements. However, current institutional emphasis remains primarily focused on grey infrastructure expansion rather than ecosystem-based flood management.

The interviews further indicated that a broader urban flood mitigation framework involving the National Disaster Management Authority and IIT Bombay is considering BGI integration within future planning initiatives.

Infrastructure Constraints and Future Directions

Spatial limitations, high land values, dense urban development, informal settlements, and large-scale road concretization were identified as major constraints affecting stormwater management expansion and infiltration potential across Mumbai. While underground drainage solutions were viewed as spatially efficient, they were also considered highly cost intensive.

The interviews highlighted increasing institutional recognition of the need for climate-resilient and hybrid grey-green infrastructure approaches. Future strategies discussed included porous pavements, holding ponds, water-absorbing vegetation, and broader integration of BGI within Mumbai's stormwater management framework, although grey infrastructure upgrades continue to remain the dominant policy focus.

Survey Results

A total of 26 responses were collected from officers across the SWD, Planning, and Gardens departments of the MCGM. The survey assessed four thematic domains: (i) prevailing flooding knowledge, (ii) urban planning integration with stormwater management (SWM), (iii) knowledge and perception of BGI, and (iv) willingness to implement (WTI) BGI measures.

Responses were analysed across four institutional and demographic categories: education, seniority, age group, and department. Weighted and normalized scores were aggregated across thematic domains to generate both topic-wise and question-wise assessments of institutional awareness, technical understanding, and implementation readiness.

Overall Thematic Assessment

Prevailing Flooding Knowledge

Prevailing flooding knowledge demonstrated relatively consistent and above-average response rates across all respondent categories, indicating widespread institutional awareness regarding flooding occurrence and flood-related challenges within the MCGM.

Respondents demonstrated particularly strong awareness of annual flooding occurrence and major flooding drivers, including urbanization, reduced permeable surfaces, inadequate drainage capacity, and tidal interactions during intense rainfall events. However, awareness regarding the long-term historical persistence of flooding in Mumbai remained comparatively limited across several institutional groups.

Operational and system-level understanding was strongest among SWD personnel, field officers, and older respondents, suggesting that institutional experience and operational exposure significantly influence flood-related understanding.

Urban Planning Integration with SWM

Urban planning integration with SWM recorded the highest thematic scores among all survey domains. Respondents from the Planning and Gardens departments demonstrated strong recognition of the relationship between urban planning, green open spaces, and stormwater management.

All respondents acknowledged that integrated planning and SWM approaches form part of their professional responsibilities. Similarly, respondents widely recognized the role of green open spaces in flood mitigation and stormwater management. Despite this, all respondents indicated that existing green open spaces across Mumbai remain inadequate.

Knowledge and Perception of BGI

Compared to flooding and planning-related themes, BGI knowledge levels remained comparatively moderate and uneven across respondent categories. Although general awareness of BGI and SUDS was widespread, detailed conceptual and technical understanding remained limited across several institutional groups.

The Planning Department, senior officers, and respondents with Master's qualifications generally demonstrated comparatively stronger BGI knowledge. Respondents showed stronger familiarity with broad BGI benefits such as stormwater management, flood mitigation, urban cooling, and ecosystem services, while technical understanding related to multifunctionality, intervention types, and implementation approaches remained comparatively weaker.

Most respondents perceived BGI as effective in mitigating runoff and flooding during high-intensity rainfall events, indicating broad institutional confidence in the applicability of BGI approaches within Mumbai's flood-management context.

Willingness to Implement BGI

In contrast to the comparatively moderate technical knowledge scores, willingness to implement BGI measures remained consistently high across all respondent categories.

All respondents expressed willingness to adopt BGI within future projects and development works and demonstrated strong interest in learning about BGI design parameters, implementation approaches, and performance characteristics. Similarly, all respondents acknowledged the need for technical training, capacity building, and institutional guidance related to BGI implementation.

Willingness to participate in collaborative pilot projects was also generally positive, particularly among senior officers and respondents from the Gardens Department, although engagement levels varied across some institutional categories.

Overall, the findings demonstrate that institutional willingness to implement BGI substantially exceeds current levels of technical and conceptual understanding across the MCGM.

Discussion of the Results

Informal interview results

Research examining knowledge and perceptions of BGI increasingly aims to generate insights applicable to both developed and developing regions. However, the institutional contexts within which such knowledge is situated vary significantly. In many developed cities, local governments operate within mature environmental governance frameworks where BGI and nature-based solutions have already been incorporated into urban planning and infrastructure delivery. In contrast, cities in many developing countries are only beginning to engage with these concepts. In India terms such as BGI and nature-based solutions have only recently entered planning and infrastructure discourse. While municipal practitioners may demonstrate familiarity with these terms, technical knowledge regarding their practical implementation remains relatively nascent.

To examine these dynamics in the context of Mumbai, we conducted informal interviews with municipal officials involved in stormwater management within the MCGM. The interviews explored the functioning and evolution of the city's stormwater management system, the drivers of flooding, engineering responses to waterlogging, institutional roles in stormwater governance, integration of natural elements and BGI, infrastructure constraints, stormwater contamination issues, and future directions for urban development and stormwater management.

Interviewees described Mumbai's drainage system as a hierarchical network of roadside drains, minor and major *nallas*, and four primary river systems Poisar, Dahisar, Oshiwara, and Mithi which convey stormwater toward coastal outfalls. They highlighted the historical evolution of the system, including upgrades following the 2005 floods through the BRIMSTOWAD program, which increased drainage design capacity. Interviewees also emphasized the multi-causal nature of flooding in Mumbai, identifying factors such as high-intensity rainfall events, drainage capacity limitations, siltation, and solid waste blockages. Institutional responsibility for stormwater management rests with the Storm Water Drainage Department within MCGM, which oversees infrastructure augmentation, maintenance, and waterlogging mitigation across the city.

The interviews further highlighted that engineering responses to flooding continue to rely primarily on location-specific grey infrastructure solutions such as pumping stations, drainage widening, and channel diversion. While nature-based measures and BGI approaches are beginning to enter planning discussions particularly within broader urban flood mitigation initiatives supported by national agencies these approaches remain at an early stage of institutional consideration. Interviewees also highlighted challenges associated with urban surface concretization, spatial constraints for infrastructure expansion, and localized contamination of stormwater drains due to unauthorized sewer connections, aging pipelines, and infrastructure damage.

Beyond these interview findings, several broader implications emerge for the implementation of blue–green infrastructure and long-term stormwater governance in Mumbai. First, the hydrological and spatial conditions of the city require careful consideration when implementing BGI interventions. Mumbai experiences high-intensity rainfall, shallow groundwater levels, and extremely limited open space availability, which together create complex boundary conditions for infiltration-based solutions. Certain interventions such as modifications to existing gardens or open spaces may therefore require careful design to ensure that adequate overflow capacity and drainage integration are maintained.

Second, safeguarding and restoring Mumbai's natural ecological systems including mangroves, creeks, rivers, and coastal wetlands should form an integral component of the city's stormwater resilience strategy. These ecosystems play a crucial role in regulating hydrological flows, buffering storm surges, and enhancing the ecological functioning of urban drainage networks. Strengthening their protection and restoration can therefore contribute significantly to the long-term performance of integrated grey–green stormwater systems.

Third, the increasing concretization of urban surfaces highlights the need for a more integrated infrastructure strategy that combines conventional drainage upgrades with permeable surfaces, vegetated systems, and other BGI components capable of moderating runoff volumes.

Fourth, the frequently cited narrative of land scarcity must be critically examined within the broader political economy of urban land development in Mumbai. Over the past several decades, strong real estate pressures and development-oriented planning have significantly reduced urban green cover across the Mumbai Metropolitan Region. The prioritization of land as a high-value commodity has often overshadowed environmental and infrastructural considerations necessary for long-term urban resilience. A shift in planning priorities is therefore required, emphasizing pro-environmental and pro-infrastructure approaches that prioritize liveability, ecological integrity, and the infrastructural needs of the city's residents. As one of the wealthiest municipal corporations in India, the MCGM has substantial financial capacity to invest proactively in sustainable and resilient stormwater infrastructure.

Finally, contamination risks within the stormwater system also raise important considerations for the design of BGI interventions such as bioswales and infiltration trenches. If runoff entering such systems is contaminated by sewage leakage or illegal connections, the ecological and water-quality benefits of BGI may be compromised. Addressing these challenges therefore requires strengthening the separation and maintenance of sewer and stormwater networks.

More broadly, achieving effective stormwater management in Mumbai will also require addressing the structural fragmentation of the city's urban landscape, particularly the divide between formal and informal settlements. Informal urbanization frequently emerges in areas lacking adequate infrastructure and drainage systems, increasing vulnerability to flooding and complicating the maintenance of stormwater networks. Transitioning toward a more formalized urban settlement framework would improve the systematic provision of municipal infrastructure, including grey–green stormwater systems, while also enabling more effective urban planning and service delivery across the city.

Survey Results

The findings reveal important institutional patterns regarding flood awareness, urban planning integration, ecological understanding, and implementation readiness toward Blue-Green

Infrastructure (BGI) within the Municipal Corporation of Greater Mumbai (MCGM). While awareness regarding flooding occurrence and willingness to implement BGI measures were consistently high across most respondent categories, technical understanding related to BGI performance, multifunctionality, hydrological limitations, and implementation mechanisms remained comparatively uneven across departments and institutional roles. The findings therefore indicate both significant institutional opportunity and substantial technical and governance gaps in transitioning Mumbai toward an integrated hybrid grey-blue-green urban flood management framework.

The consistently high prevailing flooding knowledge across departments demonstrates that flood risk has become deeply embedded within the operational understanding of the MCGM. Respondents demonstrated strong recognition of key flood drivers including urbanization, reduction in permeable surfaces, inadequate drainage capacity, tidal interactions, and climate-related rainfall variability. These findings reinforce the understanding that flooding in Mumbai is increasingly recognized not solely as a drainage issue, but as a combined outcome of hydrological alteration, ecological degradation, urban densification, and infrastructure limitations.

However, the comparatively limited understanding regarding the historical persistence of flooding suggests that institutional knowledge remains largely operational and event-based rather than historically and ecologically grounded. This is significant because long-term flood vulnerability in Mumbai is strongly associated with decades of wetland reclamation, floodplain encroachment, mangrove loss, creek modification, coastal infrastructure expansion, and increasing impervious urban development. The comparatively stronger performance of field-level officers and SWD personnel further indicates that experiential and operational exposure contributes substantially to flood-related understanding, particularly regarding drainage behaviour and flooding patterns.

The strong understanding of urban planning integration with SWM among Planning and Gardens Department respondents' highlights increasing institutional recognition regarding the relationship between land-use planning, permeability, green-open-space systems, and flood mitigation. Importantly, all respondents acknowledged that existing green open spaces across Mumbai's wards are inadequate. This reflects growing institutional awareness that highly dense urban development patterns and severe permeability deficits have significantly reduced the hydrological buffering capacity of the city.

The findings therefore suggest that future flood mitigation strategies in Mumbai cannot rely solely on conventional drainage expansion, but must incorporate broader ecological restructuring and landscape-based planning approaches. This requires a transition from isolated engineering-based flood management toward integrated ecological urbanism approaches that simultaneously address drainage, permeability, land use, biodiversity, heat mitigation, and hydrological restoration.

An important institutional pattern emerging from the study relates to the uneven but generally positive ecological and pro-environmental understanding across the three departments. The Planning Department consistently demonstrated the strongest conceptual understanding of BGI, SUDS, multifunctionality, ecosystem services, and planning-oriented integration approaches. This likely reflects greater exposure to planning concepts, spatial systems thinking, and policy-oriented frameworks. However, despite stronger conceptual understanding, the Planning Department demonstrated comparatively lower willingness to implement BGI interventions and participate in pilot projects.

In contrast, the SWD and Gardens departments demonstrated comparatively stronger implementation willingness despite comparatively lower technical and conceptual BGI understanding. This indicates that operational departments may be institutionally more open toward implementation-oriented experimentation, even where technical ecological understanding remains comparatively limited. The Gardens Department, in particular, demonstrated relatively strong pro-environmental orientation toward green-space functions and implementation willingness, although detailed hydrological understanding of BGI systems remained comparatively moderate.

The divergence between conceptual understanding and implementation willingness across departments reveals an important institutional condition within the MCGM. The Planning Department appears to possess comparatively stronger ecological and systems-oriented understanding, while the SWD and Gardens departments appear more implementation-oriented and operationally receptive. These findings suggest that effective BGI mainstreaming in Mumbai will require stronger interdepartmental integration rather than isolated departmental implementation.

The findings further reveal important technical misunderstandings regarding BGI performance under extreme hydrological conditions. A majority of respondents across several categories, particularly Bachelor's degree holders, mid-level officers, and SWD personnel, perceived BGI as highly effective in mitigating high run-off volumes and flooding during intense rainfall events. While this demonstrates strong institutional confidence in BGI approaches, it also indicates that several respondent groups may overestimate the hydrological performance capacity of BGI under extreme rainfall conditions.

Existing hydrological and urban drainage understanding demonstrates that BGI effectiveness is highly context-dependent and varies according to rainfall intensity, antecedent moisture conditions, infiltration capacity, soil permeability, groundwater levels, maintenance conditions, spatial availability, and the type and scale of BGI interventions implemented. BGI systems generally perform most effectively during low- to moderate-intensity rainfall events through infiltration, detention, retention, evapotranspiration, and delayed peak run-off generation. However, under extreme rainfall conditions, particularly within highly dense, impermeable, and coastal urban environments such as Mumbai, standalone BGI systems may become insufficient unless integrated with conventional grey stormwater infrastructure.

This finding reveals a gap between positive perception and technically grounded hydrological understanding. While respondents demonstrated strong acceptance of BGI as a supplementary stormwater management strategy, the survey indicates comparatively limited understanding regarding hydrological thresholds, climatic limitations, design capacities, and context-specific applicability of BGI systems. This is particularly important because unrealistic assumptions regarding BGI performance could lead to policy overreliance on isolated green interventions without simultaneous strengthening of drainage infrastructure.

The findings therefore strongly support the need for technically grounded institutional capacity building focused specifically on urban hydrology, flood modelling, stormwater detention dynamics, infiltration limitations, drainage network interactions, coastal flooding behaviour, and hybrid grey-blue-green infrastructure performance. Future institutional training programmes within the MCGM should move beyond broad conceptual awareness toward engineering-oriented and planning-oriented technical understanding of BGI performance under varying hydrological and climatic conditions.

The results also demonstrate that respondents overwhelmingly support implementation-oriented learning, pilot projects, and institutional training. This represents a significant opportunity for developing integrated demonstration-based governance frameworks across the MCGM. The strong willingness to cooperate on pilot projects and implementation initiatives across several categories indicates institutional openness toward experimentation and applied learning approaches.

However, the findings also indicate that BGI implementation alone is unlikely to adequately address Mumbai's flooding challenges without simultaneous strengthening of grey stormwater infrastructure. Respondents consistently identified inadequate drainage capacity, high-intensity rainfall, and tidal interactions as major causes of flooding. Consequently, future urban flood management strategies in Mumbai must prioritize simultaneous drainage upgradation, improved desilting operations, expansion of outfall capacities, rehabilitation of undersized stormwater networks, and localized hydraulic interventions in chronic flooding hotspots.

The study therefore supports the development of an integrated hybrid grey-blue-green flood management framework for Mumbai rather than reliance on either conventional grey infrastructure or standalone ecological interventions alone. Simultaneously, the findings strongly reinforce the need

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for broader ecological restructuring and urban planning reform beyond drainage interventions. Respondents consistently recognized the inadequacy of existing green open spaces across Mumbai, indicating the need for substantial expansion of green-open-space systems and permeability enhancement across highly urbanized wards.

Future planning approaches should therefore prioritize ecological conservation and restoration of mangroves, wetlands, creeks, estuarine systems, and coastal ecosystems that historically functioned as hydrological buffers within the Mumbai region. Particular attention is required toward ecological rehabilitation and protection of the Mithi River corridor through establishment of floodplain buffers, riparian green corridors, and restrictions on further encroachment and impermeable development along vulnerable river-edge zones.

The findings additionally indicate that flood vulnerability in Mumbai is closely associated with extreme urban density and highly concentrated impermeable development patterns. Consequently, long-term urban resilience may require strategic de-densification approaches in selected vulnerable areas, particularly within high-risk slum redevelopment zones and flood-prone low-lying districts. Regional-scale dispersal of future housing growth beyond the most hydrologically stressed parts of the Mumbai Metropolitan Region, combined with stronger ecological land-use planning and permeability-based development regulation, may therefore become increasingly important for reducing long-term flood vulnerability and pressure on ecological systems.

The ecological planning implications of the findings are therefore substantial. The study suggests that future flood management in Mumbai should not be approached solely through engineering expansion of drainage infrastructure, nor solely through isolated BGI interventions. Instead, long-term flood resilience requires integration between hydrological engineering, ecological restoration, urban planning, green-space provisioning, land-use regulation, regional growth management, and climate adaptation planning.

Overall, the findings indicate that the MCGM possesses strong institutional willingness and growing conceptual openness toward ecological and nature-based flood management approaches. However, substantial differences remain across departments regarding technical understanding, ecological systems knowledge, hydrological awareness, and implementation orientation. Future institutional strategies should therefore prioritize integrated interdepartmental governance, technically grounded hydrological training, ecological planning integration, ward-scale BGI implementation, and simultaneous strengthening of both grey and blue-green infrastructure systems to support long-term urban flood resilience in Mumbai.

Discussion of the Results

The findings of this study reveal important institutional, technical, ecological, and governance-related dimensions shaping stormwater management and the future integration of BGI within the MCGM. Collectively, the informal interviews and survey findings indicate that Mumbai is currently undergoing a transitional phase in urban flood management, where conventional grey infrastructure continues to dominate institutional practice, while ecological and nature-based approaches are gradually entering planning and governance discussions.

The informal interviews indicate that Mumbai's stormwater management system remains predominantly engineered and drainage-capacity oriented. Despite substantial augmentation works undertaken under the BRIMSTOWAD programme, recent high-intensity rainfall events continue to exceed existing drainage design thresholds. The interviews further highlight that flooding in Mumbai is increasingly understood as a multi-causal phenomenon associated with urbanization, reduction in permeable surfaces, tidal interactions, climate variability, solid waste accumulation, drainage-capacity limitations, and extensive concretization of urban surfaces.

Operational responses continue to prioritize grey infrastructure interventions such as pumping stations, holding ponds, drainage widening, dewatering systems, and hydraulic capacity enhancement. While interviewees acknowledged growing consideration of BGI and natural elements within future flood management planning, these approaches remain secondary to conventional engineering responses. The findings therefore suggest that Mumbai's current flood governance framework remains largely conveyance-oriented rather than infiltration-oriented or ecologically restorative.

At the same time, both the interviews and survey findings indicate growing institutional openness toward ecological and integrated planning approaches. Respondents across departments strongly acknowledged the relationship between urban planning, permeability, green-open-space systems, and flood mitigation. Importantly, all respondent categories recognized that existing green-open-space provision across Mumbai's wards is inadequate. This reflects increasing institutional awareness that extensive concretization, high-density development, declining permeability, and ecological degradation have substantially reduced the hydrological buffering capacity of the city.

The findings therefore indicate that future flood management strategies in Mumbai cannot rely solely on expansion of conventional drainage infrastructure. Instead, long-term resilience requires simultaneous integration of grey infrastructure strengthening, ecological restoration, permeability enhancement, and landscape-based urban planning approaches.

An important institutional pattern emerging from the study relates to the differing orientations across departments. The Planning Department consistently demonstrated comparatively stronger conceptual understanding of BGI, SUDS, multifunctionality, ecosystem services, and planning-oriented integration approaches. This likely reflects greater exposure to spatial planning frameworks, systems thinking, and policy-oriented environmental concepts.

In contrast, the SWD and Gardens departments demonstrated comparatively stronger willingness to implement BGI interventions despite comparatively lower technical and conceptual understanding. Operational departments therefore appear more institutionally receptive toward implementation-oriented experimentation and pilot-based approaches, even where technical ecological understanding remains comparatively limited. The Gardens Department, in particular, demonstrated relatively stronger pro-environmental orientation toward green-space functions and implementation willingness, although detailed hydrological understanding of BGI systems remained comparatively moderate.

The divergence between conceptual understanding and WTI for BGI across departments represents an important institutional finding. The Planning Department appears comparatively stronger in systems-oriented and ecological understanding, while the SWD and Gardens departments appear comparatively stronger in implementation receptiveness. The findings therefore indicate that effective mainstreaming of BGI within Mumbai will require stronger interdepartmental coordination and governance integration between Planning, SWD, Gardens, Roads, Railways, and related agencies rather than isolated departmental implementation.

The survey findings additionally reveal important technical misunderstandings regarding BGI performance under extreme rainfall conditions. A majority of respondents across several categories particularly Bachelor's degree holders, mid-level officers, and SWD personnel perceived BGI as highly effective in mitigating high run-off volumes and flooding during intense rainfall events. While this demonstrates strong institutional confidence in BGI approaches, it also indicates that several respondent groups may overestimate the hydrological performance capacity of BGI under extreme climatic conditions.

Existing hydrological understanding demonstrates that BGI systems generally perform most effectively during low- to moderate-intensity rainfall events through infiltration, detention, retention, evapotranspiration, and delayed peak run-off generation. However, under extreme rainfall conditions particularly within highly dense, impermeable, and coastal urban environments such as Mumbai standalone BGI systems may become insufficient unless integrated with conventional grey stormwater infrastructure.

The findings therefore reveal an important gap between positive institutional perception and technically grounded hydrological understanding regarding BGI limitations, design thresholds, climatic constraints, and context-specific applicability. This is particularly significant because unrealistic assumptions regarding BGI performance could result in overreliance on isolated green interventions without simultaneous strengthening of drainage infrastructure and hydraulic systems.

The study consequently highlights the urgent need for technically grounded institutional capacity building across the four thematic domains investigated in this research:

(i) prevailing flooding knowledge,
(ii) urban planning integration with SWM,
(iii) knowledge and perception of BGI, and
(iv) WTI for BGI.

Importantly, the findings demonstrate that future capacity-building programmes cannot adopt a uniform institutional approach. Instead, targeted and category-specific training frameworks are required across the four demographic and institutional categories investigated in this study namely education, seniority, age group, and department across the Planning, SWD, and Gardens departments.

The findings indicate that operational departments require stronger technical understanding regarding hydrological performance, multifunctionality, infiltration limitations, maintenance requirements, drainage interactions, and implementation thresholds of BGI systems. Simultaneously, planning-oriented institutional groups may require greater implementation-oriented integration, pilot engagement, and operational coordination mechanisms. The study therefore provides an empirical basis for designing targeted institutional training frameworks within the MCGM hierarchy.

The findings further reinforce the need for integrated hybrid grey–green stormwater management frameworks across Mumbai. Respondents consistently identified inadequate drainage capacity, high-intensity rainfall, concretization, and tidal interactions as major flood drivers. Consequently, future flood resilience strategies must continue prioritizing drainage upgradation, desilting operations, outfall expansion, rehabilitation of undersized stormwater systems, and localized hydraulic interventions in chronic flooding hotspots.

However, the findings also strongly reinforce the need for broader ecological and urban planning reforms beyond drainage interventions alone. Expansion of public green-open-space systems across all wards, enhancement of urban permeability, and integration of ecological planning within redevelopment frameworks emerge as critical components of future resilience planning.

The findings further reinforce the importance of:

- expanding public green-open-space systems across Mumbai;
- integrating ecological planning within redevelopment processes;
- widening floodplains and green buffers along the Mithi River;
- conserving and restoring mangroves, wetlands, creeks, rivers, and estuarine systems;
- and strengthening interdepartmental coordination between Planning, SWD, Gardens, Roads, Railways, and related agencies.

The study additionally suggests that long-term flood vulnerability in Mumbai is closely associated with extreme urban density, concentrated impermeable development, redevelopment patterns that continue reducing ecological and permeable land surfaces, and engineering decisions such as large-scale road concretization that significantly alter hydrological behaviour and surface run-off generation. Consequently, future resilience planning may require strategic de-densification approaches in selected high-risk redevelopment areas alongside increased provision of public green-open-space systems and greater dispersal of future housing growth toward outer parts of the Mumbai Metropolitan Region.

More broadly, the study highlights that flooding in Mumbai extends beyond hydrological impacts alone and contributes significantly to traffic disruption, interruption of public transport systems, and broader socio-economic disruptions across the city's linear urban structure. Increasing concretization of roads and declining permeability may further intensify run-off generation and pressure on already stressed drainage systems. Given Mumbai's highly linear urban form and strong dependence on road and suburban railway-based commuting systems, localized flooding events frequently generate cascading disruptions across mobility networks, commute pathways, economic activities, emergency access, and daily urban functioning. Flood management within Mumbai must therefore be understood simultaneously as a hydrological, ecological, infrastructural, mobility, and urban planning challenge.

Overall, the findings indicate that the MCGM possesses strong institutional willingness and growing conceptual openness toward ecological and nature-based flood management approaches. However, substantial differences remain across departments regarding technical understanding, ecological systems knowledge, hydrological awareness, and implementation orientation. The findings therefore highlight the need for integrated interdepartmental governance, technically grounded hydrological training, ecological planning integration, and simultaneous strengthening of both grey and blue-green infrastructure systems to support long-term urban flood resilience in Mumbai.

Conclusion

This study presents an integrated assessment of stormwater management governance, institutional perceptions, and BGI knowledge within the MCGM through informal interviews and a structured survey of municipal officers across the Planning, SWD, and Gardens departments.

The findings demonstrate that Mumbai's stormwater management system continues to remain predominantly grey-infrastructure driven despite increasing institutional openness toward ecological and nature-based approaches. Although substantial drainage augmentation has been implemented under the BRIMSTOWAD programme, flooding continues to be intensified by high-intensity rainfall, extensive concretization, reduced permeability, aging infrastructure, and ecological degradation.

The survey findings reveal an important mismatch between awareness, technical understanding, and WTI for BGI. While awareness regarding flooding occurrence and willingness toward BGI implementation were consistently high across departments, detailed technical understanding regarding BGI design, multifunctionality, hydrological limitations, and implementation mechanisms remained comparatively uneven.

The study therefore identifies a significant knowledge–implementation paradox within the institutional hierarchy of the MCGM. Planning Department respondents demonstrated comparatively stronger conceptual understanding of BGI and ecological planning approaches, while the SWD and Gardens departments demonstrated comparatively stronger implementation willingness despite comparatively lower technical understanding.

The findings additionally indicate that several respondent categories may overestimate the effectiveness of BGI under extreme rainfall conditions, thereby highlighting the need for technically grounded hydrological training and implementation-oriented institutional guidance.

Taken together, the findings position Mumbai within a transitional governance phase characterized by:

(i) continued dependence on grey infrastructure as the primary flood-management mechanism,
(ii) emerging but limited technical understanding of BGI, and
(iii) strong institutional willingness that is not yet fully supported by governance integration or technical capacity.

The study therefore supports development of an integrated hybrid grey–green stormwater management framework for Mumbai. Such an approach requires simultaneous strengthening of drainage infrastructure, desilting operations, outfall capacities, and flood-management systems alongside ecological restoration, permeability enhancement, and BGI integration across all wards.

The findings further reinforce the importance of:

- expanding public green-open-space systems across Mumbai;
- integrating ecological planning within redevelopment processes;
- widening floodplains and green buffers along the Mithi River;
- conserving and restoring mangroves, wetlands, creeks, rivers, and estuarine systems;

- strengthening interdepartmental coordination between Planning, SWD, Gardens, Roads, Railways, and related agencies;
- and incorporating hydrological and ecological considerations within engineering and infrastructure decisions such as road concretization, redevelopment planning, and urban surface modifications.

Importantly, the study demonstrates that future capacity-building programmes within the MCGM should be designed according to the four thematic domains and four institutional categories investigated in this research. The variations identified across education levels, seniority categories, age groups, and departments provide a detailed empirical basis for developing targeted institutional training frameworks rather than generalized institutional approaches.

This includes:

- hydrological and technical training for operational departments;
- ecological and planning integration training across engineering functions;
- implementation-oriented learning within planning institutions;
- and role-specific institutional training across senior, mid-level, junior, and field officers.

The findings further indicate that long-term flood resilience in Mumbai requires integration between hydrological engineering, ecological restoration, urban planning, mobility systems, green-space provisioning, land-use regulation, redevelopment planning, infrastructure engineering decisions such as large-scale road concretization, and climate adaptation strategies. The study particularly highlights that engineering and infrastructure interventions undertaken without adequate consideration of hydrological permeability, run-off generation, ecological impacts, and drainage interactions may unintentionally intensify urban flood vulnerability within highly dense metropolitan environments such as Mumbai.

Overall, the study demonstrates that the MCGM possesses substantial institutional potential for transition toward integrated ecological and climate-resilient stormwater governance. However, successful implementation will require stronger governance integration, technically grounded institutional capacity building, ecological planning reform, and simultaneous strengthening of both grey and blue-green infrastructure systems.

Broader Discussion and Future Research Directions

The findings of this study hold broader relevance for rapidly urbanizing cities in India and other developing-country contexts where institutional transitions toward hybrid grey–green infrastructure systems remain at relatively early stages.

While BGI and nature-based approaches are increasingly integrated within planning systems across many developed-country contexts, cities such as Mumbai continue to face significant institutional, infrastructural, spatial, and governance constraints limiting implementation. This study therefore contributes to existing BGI literature by examining institutional perceptions, governance conditions, and implementation readiness within a rapidly urbanizing megacity context.

A major contribution of the study lies in identifying the institutional mismatch between conceptual understanding and implementation willingness across departments. The findings demonstrate that BGI implementation is influenced not only by technical knowledge, but also by institutional responsibilities, operational roles, governance structures, and implementation cultures within municipal systems.

The study additionally highlights the importance of moving beyond generalized advocacy toward technically grounded and context-specific application of BGI within dense tropical coastal megacities characterized by high rainfall intensity, limited open space availability, tidal interactions, severe permeability deficits, and extensive urban concretization.

More broadly, the findings reinforce the importance of integrated ecological urbanism approaches within rapidly urbanizing cities. In Mumbai, declining permeability, extensive concretization, ecological degradation, high-density redevelopment patterns, and transport-infrastructure pressures continue to intensify flood vulnerability. Consequently, future resilience planning requires stronger integration between ecological restoration, green-space expansion,

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infrastructure planning, mobility systems, redevelopment frameworks, engineering decisions, and climate adaptation strategies.

Future research should therefore focus on:

- institutional and behavioural drivers influencing BGI implementation decisions;
- technical assessment of hydrological understanding among municipal professionals;
- pilot-scale implementation and performance evaluation of BGI under Mumbai's climatic conditions;
- governance integration between municipal departments and infrastructure agencies;
- category-specific institutional capacity-building models;
- impacts of engineering interventions such as concretization on hydrological performance and urban flooding;
- and the role of ecological planning and urban restructuring in improving long-term flood resilience within highly dense metropolitan regions.

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