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Enhancing Urban Water Sustainability through Efficient Water Management: A Case Study of Kolhapur

Mr. Kocheta Suraj Navalchand[1], Dr. Sourabh Kumar Singh[2], Dr. Narkhede Parag Govardhan[3]

[1]Research scholar, Department of Architecture, Shri Jagdishprasad Jhabarmal Tibrewala University, Rajasthan

[2]Guide, Department of Architecture, Shri Jagdishprasad Jhabarmal Tibrewala University, Rajasthan

[3]Co-guide, Department of Architecture, B.K.P.S College of Architecture, Pune, Maharashtra

Abstract: *Rapid urbanization in Indian cities has significantly altered natural hydrological processes, resulting in increased surface runoff, urban flooding, and drainage congestion. Kolhapur, a rapidly growing city in Maharashtra, has experienced recurrent flooding due to intense monsoon rainfall, encroachment of natural drainage channels, inadequate stormwater infrastructure, and poor maintenance of drainage networks. The devastating floods of 2019 highlighted the vulnerability of the city's stormwater management system. This study analyzes the existing stormwater drainage infrastructure of Kolhapur, identifies major challenges affecting drainage efficiency, and proposes comprehensive guidelines for developing resilient and sustainable stormwater drainage systems in growing Indian cities. The study utilizes secondary data, literature review, urban flood assessments, and drainage management practices. Results indicate that insufficient drainage capacity, blockage of natural watercourses, increased impervious surfaces, and lack of integrated planning are major contributors to urban flooding. The research recommends sustainable urban drainage systems (SUDS), GIS-based drainage planning, rainwater harvesting integration, regular maintenance programs, and climate-resilient infrastructure design. The proposed guidelines can support municipal authorities and urban planners in developing effective stormwater management strategies for future urban growth.*

Keywords: Stormwater Drainage, Urban Flooding, Sustainable Drainage Systems, Kolhapur, Urban Infrastructure, Climate Resilience, Flood Management

I. INTRODUCTION

Urban flooding has emerged as one of the most critical challenges confronting rapidly growing cities worldwide. In India, accelerated urbanization, land-use transformation, and increasing frequency of extreme rainfall events have intensified stormwater management problems. Traditional drainage systems designed decades ago are often incapable of handling current runoff volumes generated by extensive paved surfaces and unplanned urban development.

Kolhapur, located on the banks of the Panchganga River in Maharashtra, is particularly vulnerable to flooding due to its geographical setting, high monsoon rainfall, and expanding urban boundaries. Recent studies indicate that urban flooding in Kolhapur results from a combination of intense rainfall, inadequate drainage infrastructure, and insufficient resilience planning. The city's drainage network faces substantial pressure during monsoon seasons, causing waterlogging, transportation disruptions, infrastructure damage, and economic losses.

The objective of this study is to evaluate the existing stormwater drainage system of Kolhapur and formulate practical guidelines for efficient stormwater management applicable to growing Indian cities. Only 45% of the world's population had access to a sanitation service that was securely maintained in 2017. Those without access to suitable sanitation are 4.2 billion as per UN estimates. Water management and sanitation are related. Even though water management has drastically improved over the past century, impoverished, rural populations are still more likely to be without this crucial

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service. The majority of Indian cities are under increasing water stress and are exceeding the limitations on accessing rivers, other bodies of water, and surface water for drinking purposes [1]. Over 2 billion people live without trustworthy water services. Two billion individuals do not have access to a service that is securely managed to provide drinking water, according to a report issued by the WHO (World Health Organization) and UNICEF (United Nations International Children's Emergency Fund) in 2019. Over 140 million of those individuals use untreated surface water. Millions of people lose their life each year from waterborne illnesses such as cholera as a result of mismanaged water supplies.

II. STUDY AREA

2.1 Overview of Kolhapur

Kolhapur is situated in the southwestern region of Maharashtra and serves as an important commercial, educational, and industrial center. The city experiences a tropical monsoon climate characterized by heavy seasonal rainfall.

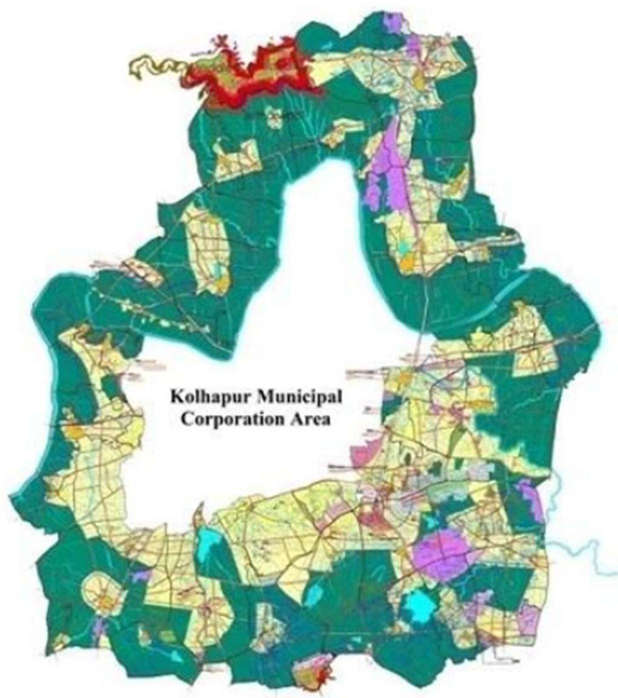

Figure 1. Kolhapur Municipal Corporation Area

Table 1. General Characteristics of Kolhapur

Parameter	Description
Location	Southwestern Maharashtra
Major River	Panchganga River
Average Annual Rainfall	1000–1500 mm
Climate	Tropical Monsoon
Major Flood Period	June–September
Urban Growth Trend	Rapid Expansion

The city's proximity to the Panchganga River and its tributaries increases flood susceptibility during periods of intense rainfall. Studies have identified numerous flood-prone zones within the urban area.

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III. LITERATURE REVIEW

Urban flood resilience studies conducted in Kolhapur indicate that inadequate drainage infrastructure and increasing urbanization significantly contribute to flood risks. Hivrale (2025) investigated urban flood challenges in Kolhapur and found that drainage deficiencies, infrastructure gaps, and prolonged monsoon rainfall substantially affect urban resilience. The study emphasized the need for integrated infrastructure planning and GIS-based vulnerability assessment.

Powar and Panhalkar (2024) performed flood susceptibility analysis using the Frequency Ratio Model and identified numerous flood-prone locations across Kolhapur. Their findings demonstrated that topography, land use changes, and drainage conditions significantly influence flood occurrence.

Patil (2023) developed an urban flood mitigation plan for the Panchganga River basin and concluded that uncontrolled urban growth and inadequate stormwater management have increased flood vulnerability throughout Kolhapur. The study recommended integrated drainage planning and watershed-based management approaches.

Tiware et al. (2022) investigated flood control measures around Kolhapur and proposed watershed management structures such as farm ponds, percolation ponds, and movable barriers. Their analysis indicated that appropriate interventions could significantly reduce peak flood discharge.

Recent municipal assessments have also highlighted the importance of regular drain cleaning and maintenance. Delays in drainage maintenance activities have been associated with increased flood risks during monsoon seasons.

IV. EXISTING STORMWATER DRAINAGE SYSTEM IN KOLHAPUR

The stormwater drainage network of Kolhapur consists of:

- Primary drainage channels
- Secondary stormwater drains
- Roadside drainage systems
- Natural streams and nullahs
- River discharge outlets

Despite the presence of these components, several limitations affect system performance.

Table 2. Existing Drainage Challenges

Challenge	Impact
Silt accumulation	Reduced carrying capacity
Encroachment on drains	Flow obstruction
Inadequate drain dimensions	Overflow during storms
Solid waste dumping	Blockage and backflow
Poor maintenance	Frequent waterlogging
Urban expansion	Increased runoff generation

V. RESEARCH METHODOLOGY

The primary objective of this study is to evaluate the effectiveness of the existing stormwater drainage system in Kolhapur and to develop practical guidelines for improving stormwater management in rapidly urbanizing Indian cities. The methodology combines both primary and secondary data collection approaches to obtain a comprehensive understanding of drainage infrastructure, flooding issues, and management practices.

4.1 Primary Data Collection

Primary data were collected through field investigations, site visits, and stakeholder interactions within the jurisdiction of the Kolhapur Municipal Corporation (KMC). Various flood-prone locations, major drainage channels, stormwater outfalls, and urbanized catchment areas were surveyed to assess the condition and performance of the existing drainage network.

Information regarding drainage infrastructure, maintenance practices, flood occurrences, and stormwater management strategies was obtained through discussions with municipal engineers, planning officials, and technical personnel from the Kolhapur Municipal Corporation. Field observations were conducted to identify issues such as drain blockage, sediment accumulation, encroachments, inadequate drain capacity, and improper waste disposal practices affecting stormwater flow.

Photographic documentation was carried out during site visits to record the physical condition of drains, waterlogging locations, and drainage bottlenecks. Interviews were conducted with local residents, business owners, and community representatives residing in flood-prone areas to understand their experiences related to urban flooding and drainage performance during monsoon seasons.

Case studies of selected residential, commercial, and institutional areas were undertaken to examine the implementation of sustainable stormwater management practices such as rainwater harvesting systems, permeable pavements, recharge pits, detention ponds, and green infrastructure measures. Discussions with facility managers and property owners provided valuable insights into the effectiveness and challenges associated with these systems.

4.2 Secondary Data Collection

Secondary data were collected from a variety of published and unpublished sources to support the analysis of stormwater drainage systems in Kolhapur. Relevant information was gathered from government reports, municipal records, environmental status reports, urban development plans, academic journals, conference proceedings, and technical guidelines related to urban drainage and flood management.

Hydrological and meteorological data, including rainfall records, flood reports, watershed information, and drainage network maps, were obtained from government agencies and publicly available databases. Additional information on sustainable urban drainage systems (SUDS), low-impact development techniques, climate-resilient infrastructure, and urban flood mitigation strategies was collected through an extensive review of scientific literature.

Reports published by national and international organizations were also examined to understand global best practices in stormwater management and their applicability to Indian urban environments. Newspaper articles, municipal reports, and environmental assessments were reviewed to identify recent flooding events, drainage improvement projects, and emerging challenges within Kolhapur.

4.2.1 Review of Global Stormwater and Water Management Initiatives (2021–2022)

The period between 2021 and 2022 marked a significant shift in global attention toward water management and climate resilience. During the Twenty-Sixth Conference of the Parties (COP26) held in Glasgow, water was recognized as a critical component of climate adaptation and mitigation strategies. The conference highlighted the interdependence between climate systems and water resources through the widely acknowledged principle that “Climate is Water and Water is Climate.”

The Glasgow Climate Pact emphasized the need for integrated approaches that combine natural ecosystems, technological innovations, governance frameworks, and international cooperation to strengthen water resilience. The agreement encouraged countries to adopt sustainable water management practices capable of addressing increasing climate-related risks such as flooding, droughts, and extreme rainfall events.

For urban stormwater management, these global initiatives highlighted the importance of nature-based solutions, sustainable drainage systems, watershed restoration, and resilient infrastructure planning. Such approaches are particularly relevant for rapidly growing cities where conventional drainage systems are increasingly unable to cope with changing rainfall patterns and expanding impervious surfaces.

India further strengthened its commitment toward climate action during COP26 through the announcement of the “Panchamrit” initiative, which established long-term sustainability goals, including achieving net-zero carbon emissions by 2070. The initiative emphasized sustainable resource management, renewable energy adoption, and climate-resilient urban development.

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From the perspective of stormwater management, international recommendations advocate integrated planning approaches that combine drainage infrastructure, green infrastructure, land-use planning, and ecosystem-based solutions. The adoption of permeable surfaces, rainwater harvesting systems, urban wetlands, bioswales, and detention basins has been identified as an effective strategy for reducing urban flood risks while enhancing groundwater recharge and environmental sustainability.

The lessons derived from global water and climate initiatives provide valuable guidance for improving stormwater drainage systems in Indian cities such as Kolhapur, where rapid urbanization and increasing climate variability necessitate more resilient and sustainable drainage infrastructure.

Table No. 3 – Pledges of "Panchamrit"

Sr. No.	Name	Quantity	Year
01	Non-fossil energy capacity	500 GW	2030
02	Renewable energy	50%	2030
03	Reduce carbon emissions	1 Billion Ton	2030
04	Carbon intensity reduction	45%	2030
05	Net Zero	—	2070

Source: Government of India, COP26 Panchamrit Commitments [12].

4.2.2 Current Situation of Water and Sanitation in India

India is currently facing one of the most severe water crises in its history, making water resource management a national priority. Rapid population growth, urbanization, industrial expansion, and unsustainable groundwater extraction have placed tremendous pressure on the country's available water resources. Despite having a large population dependent on freshwater resources, access to safe and reliable drinking water remains a significant challenge in many regions.

More than half of India's population continues to face difficulties in obtaining safe drinking water, and water scarcity affects millions of people annually. According to reports by NITI Aayog, approximately 200,000 deaths occur each year due to inadequate access to safe drinking water. If current consumption patterns continue, India may have access to only about half of its projected water demand by 2030. The country is also the world's largest user of groundwater, accounting for nearly one-fourth of global groundwater extraction, exceeding the combined groundwater usage of several developed nations.

The decline in groundwater levels, deterioration of water quality, and inadequate wastewater management have further intensified the crisis. India ranks among the lower-performing countries in terms of water quality, highlighting the urgent need for effective water conservation and management strategies. NITI Aayog has estimated that severe water shortages could result in a reduction of nearly 6% in the nation's Gross Domestic Product (GDP), demonstrating the significant economic implications of water insecurity.

Water scarcity also poses serious threats to food security, as agriculture remains the largest consumer of freshwater resources in India. Insufficient water availability can adversely affect crop productivity, rural livelihoods, and overall agricultural sustainability. Projections indicate that by 2030, nearly 40% of the country's population may not have adequate access to safe drinking water if corrective measures are not implemented. These challenges emphasize the importance of adopting integrated water management practices, promoting water conservation technologies, enhancing wastewater recycling, and strengthening policy interventions to ensure sustainable water resource utilization.

4.2.3 Current Situation of Water and Sanitation in Kolhapur (Based on Environmental Status Report 2015–16)

Kolhapur is comparatively fortunate in terms of water availability due to the presence of abundant natural water resources, including rivers, lakes, and favorable groundwater conditions. The city is located along the banks of the Panchganga River, which serves as a major source of water supply and plays a crucial role in the region's hydrological system. The Panchganga River is formed by the confluence of five rivers—Kasari, Kumbhi, Tulsi, Bhogawati, and Dhamani—at

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Prayag Sangam. In addition, several natural streams and nallahs function as stormwater drainage channels, conveying surface runoff during the monsoon season.

Groundwater conditions in and around Kolhapur have traditionally remained favorable due to the city's geographical and climatic characteristics. Monitoring stations established by the Central Ground Water Board (CGWB) in nearby locations such as Khupire, Washi, and Gokul Shirgaon provide valuable information regarding groundwater levels and trends within the region.

The Kolhapur Municipal Corporation (KMC) supplies approximately 120–130 million liters of water per day (MLD) to meet the city's domestic, commercial, and institutional requirements. The average per capita water supply is estimated at approximately 135 liters per capita per day (LPCD), which aligns with national urban water supply standards. Raw water collected from syphon wells undergoes treatment at designated water treatment plants before being distributed throughout the city.

The water distribution network is organized into 22 supply zones and supported by a comprehensive storage infrastructure consisting of 28 reservoirs, including 20 Elevated Service Reservoirs (ESRs) and 8 Ground Service Reservoirs (GSRs), with a combined storage capacity of approximately 53 million liters. This infrastructure helps maintain a continuous and reliable water supply across various parts of the city.

To address wastewater management challenges, the Kolhapur Municipal Corporation has implemented regulations aimed at reducing environmental pollution and promoting wastewater treatment and reuse. These regulations mandate the installation of individual sewage treatment plants (STPs) and water recycling systems under specific conditions, including residential developments containing more than 20 dwelling units, building projects exceeding 4,000 square meters of area, hospitals with more than 40 beds, and commercial establishments consuming over 10,000 liters of water per day.

As part of its commitment to sustainable wastewater management, pilot Decentralized Wastewater Treatment Systems (DEWATS) have been established at locations such as Salokhe Park, Rajendranagar, and Isolation Hospital. These systems, each having a treatment capacity of approximately 10 cubic meters per day, provide a cost-effective and reliable solution for wastewater treatment. Treated wastewater generated from these facilities is utilized for non-potable purposes such as landscape irrigation and gardening, thereby reducing dependence on freshwater resources.

The reuse of treated wastewater has demonstrated encouraging results, with nearly 20,000 liters of water being recycled daily for irrigation purposes in certain facilities. Furthermore, municipal authorities have emphasized the importance of constructing and maintaining properly designed septic tanks in areas not connected to centralized sewerage networks. Strict compliance with wastewater treatment regulations is recommended for new developments, and periodic inspections and audits are necessary to ensure effective implementation.

Overall, Kolhapur possesses relatively strong water resources and infrastructure compared to many urban centers; however, increasing urbanization, population growth, wastewater generation, and climate variability necessitate continuous improvements in water conservation, wastewater recycling, and integrated urban water management practices to ensure long-term sustainability.

VI. RESULT AND DISCUSSION

Kolhapur city has been facing increasing water scarcity due to a significant reduction in water levels of the Panchganga and Bhogawati rivers, which constitute the primary sources of municipal water supply. The situation has worsened as water releases from upstream reservoirs have been restricted by the irrigation department. Simultaneously, elevated temperatures and prolonged dry conditions have compelled farmers in upstream regions to extract substantial quantities of water for agricultural irrigation. These factors have collectively contributed to a considerable decline in the water level at the Shingnapur Barrage, the main water intake source for the Kolhapur Municipal Corporation (KMC).

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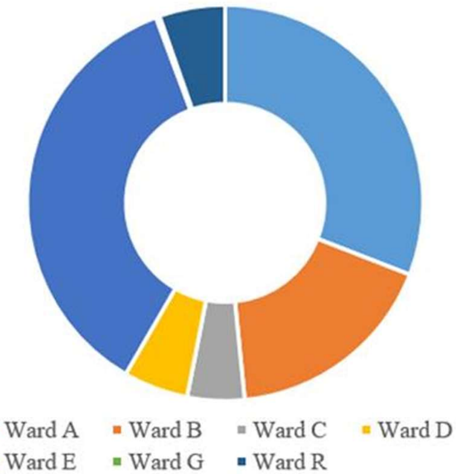

Figure No. 02: Ward-wise distribution of water connections in Kolhapur Municipal Corporation.

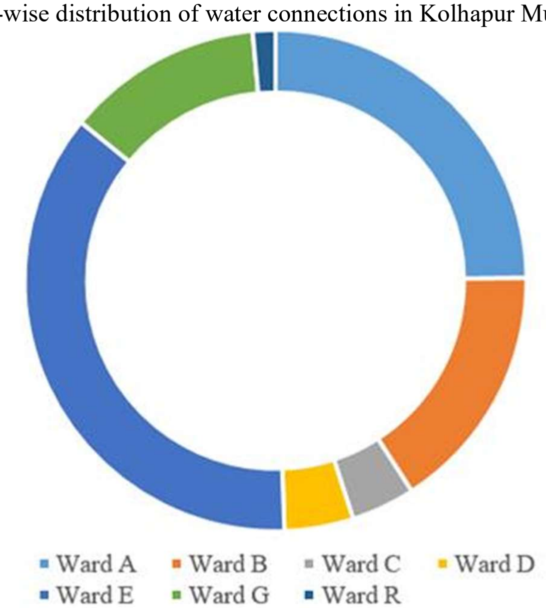

Figure No. 03: Trend showing the increase in water demand and water connections in Kolhapur city.

The table presents ward-wise water connections, water demand, revenue collection, outstanding balance, and collection efficiency within the Kolhapur Municipal Corporation jurisdiction. Ward D recorded the highest collection efficiency (95.65%), while Ward G exhibited the lowest collection efficiency (82.08%). Overall, the municipal corporation achieved a water revenue collection efficiency of approximately 91.19%.

Table No. 02 – Ward-wise Water Connections as per Kolhapur Municipal Corporation

Ward	No. of Connections	Demand (₹)	Collection (₹)	Balance (₹)	Collection (%)
A	37,622	1,188,324,522	1,108,158,600	79,394,256	93.25
B	21,320	767,101,887	710,826,857	55,504,453	92.66
C	5,679	197,406,963	177,842,838	19,294,684	90.09
D	6,450	212,679,558	203,438,195	9,049,599	95.65

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E	43,741	1,744,091,846	1,604,416,813	135,451,626	91.99
G	378	60,566,359	49,712,853	10,715,315	82.08
R	6,537	69,957,275	61,932,784	7,925,830	88.53
Total	**121,727**	**4,785,225,610**	**4,363,741,940**	**413,773,963**	**91.19**

In addition to the reduced availability of water resources, the city has witnessed a rapid increase in the number of water connections owing to population growth, urban expansion, and rising domestic and commercial water demand. According to records maintained by the Kolhapur Municipal Corporation, the continuous growth in water connections has placed additional pressure on the existing water supply infrastructure. This increasing demand, coupled with limited water availability, highlights the urgent need for efficient water resource management, conservation measures, and sustainable utilization practices within the city.

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