Sustainable Urban Water and Flood Management: A Case Study of Delhi

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(Received:02.12.2025; Accepted: 10.01.2026)

Abstract

This paper provides a comprehensive evaluation of urban water and flood management challenges in Delhi, India, with emphasis on the interlinked issues of groundwater depletion, flood risk, deteriorating water infrastructure, and ineffective drainage networks. Rapid urbanisation, changing rainfall patterns, and unregulated groundwater extraction have intensified both water scarcity and flooding, highlighting the urgent need for adaptive and integrated management approaches. The study critically assesses the city's existing water governance and policy frameworks to understand their limitations in addressing these hydrological and infrastructural pressures. It further examines the role of climate adaptation measures in enhancing resilience against extreme rainfall and flooding events. By analysing Delhi's hydrological responses, infrastructure systems, and urban planning strategies, the research identifies policy gaps and institutional inefficiencies that exacerbate the city's vulnerability. The paper proposes sustainable yet practical solutions such as improved stormwater drainage design, decentralised rainwater harvesting, groundwater recharge initiatives, and stronger policy coordination to mitigate risks and ensure long-term water security. Aligning with the United Nations Sustainable Development Goals, particularly SDG 6 (Clean Water and Sanitation) and SDG 11 (Sustainable Cities and Communities), the study underscores that resilient and well-governed water systems are central to achieving sustainable urban development in Delhi.

Keywords: *Urban water management; Flood risk; Groundwater depletion; Water infrastructure; Drainage; Rainfall patterns; Climate adaptation; Water governance; Delhi; Policy; SDG 6; SDG 11*

INTRODUCTION

Rapid urbanisation and climate change have created unprecedented challenges for urban water management in megacities across the developing world. Delhi, India's National Capital Territory with a population exceeding 30 million, exemplifies the complex water crisis facing metropolitan areas in the 21st century (Census, 2011). The city faces a unique paradox where chronic water scarcity coexists with frequent devastating floods, creating a dual crisis that threatens sustainable urban development and residents' quality of life.

Urban water management challenges have intensified globally due to interconnected factors including population growth, unplanned urbanisation, ageing infrastructure, and climate variability (Chaudhuri and Sharma, 2020; Pendharkar, 2020; Saxena *et al*., 2015). In Delhi, these challenges manifest as dependency on external water sources, severe groundwater depletion, ageing distribution infrastructure with about 40% water losses, inadequate drainage systems, and changing precipitation patterns that have shifted flood vulnerability from July to May (IMD, 2024). Studies have shown that over 60% of groundwater monitoring wells in Delhi exhibit declining water level trends (CGWB, 2021; Saxena *et al*., 2015). Rapid urban growth, encroachment of floodplains, and increased impervious surfaces have significantly altered the city's hydrological balance, amplifying flood risk and reducing groundwater recharge (Pendharkar, 2020; Sharma and Kumar, 2022).

The traditional approach to water management in Delhi, characterised by dependence on grey infrastructure and reactive flood control, has proven inadequate in addressing these multifaceted issues. The fragmented institutional framework, with multiple agencies responsible for water supply, drainage, and flood management, has hindered coordinated planning and long-term resilience (MUD, 2022). Studies highlight that the intensity and frequency of extreme rainfall events in Delhi have increased in recent years, often exceeding the capacity of existing stormwater systems

(Chaudhuri and Sharma, 2020; Gupta *et al.*, 2021). Moreover, inadequate maintenance of drainage networks, unregulated groundwater abstraction, and pollution of the Yamuna River further aggravate the dual challenge of water scarcity and flooding (IMD, 2024; CGWB, 2021).

This research paper examines Delhi's urban water and flood management challenges by analysing key factors such as rainfall variability, drainage inefficiency, floodplain encroachment, and groundwater depletion. It also explores government initiatives and sustainable measures that can mitigate future flood risks and improve water security. The study aims to propose an integrated and resilient framework for urban water management in Delhi that can serve as a model for other Indian metropolitan cities facing similar challenges.

MATERIALS AND METHODS (MAIN HEADING)

This section covers the study area, methodology, data acquisition, hydrological modelling, and analysis.

Study Area

Delhi, the National Capital Territory of India, covers an area of 1,484 km² and serves as the political, economic, and cultural center of the country (Fig. 1). The city experiences a semi-arid climate with extreme seasonal variations, receiving an average annual rainfall of 650 mm, primarily during the monsoon season from June to September. However, recent climate data shows significant shifts in precipitation patterns, with May rainfall increasing dramatically over the past decades.

The study area encompasses the entire Delhi metropolitan region, including the historic city centre, planned residential colonies, unauthorised settlements, and peripheral rural areas. The topography is generally flat with elevations ranging from 213 to 305 meters above sea level, with the Yamuna River forming the eastern boundary. The geological formation consists mainly of alluvial deposits with varying degrees of permeability, affecting groundwater recharge and movement patterns.

Delhi's population has grown from 9.4 million in 1991 to over 30 million in 2021, making it one of the world's largest urban agglomerations. This rapid population growth, coupled with extensive urbanisation, has put tremendous pressure on water resources and infrastructure. The city's water demand has reached 1,140 million gallons per day (MGD) while supply capacity remains at approximately 935 MGD, creating a persistent supply deficit of about 200 MGD (UN, 2022).

Fig. 1: Location map of Delhi.

Methodology

The methodology adopted in this study employs a comprehensive, multi-disciplinary approach to examine urban water and flood management in Delhi. The research combines field-based data collection, including monitoring of water levels, flow rates, and drainage patterns, with hydrological and hydraulic modelling to simulate flood scenarios and water distribution dynamics. Historical rainfall and flood records, along with urban infrastructure data such as stormwater drains, canals, and wastewater systems, are analysed to identify critical flood-prone zones and assess the effectiveness of existing management strategies. Although stakeholder perspectives have not yet been incorporated, the study could be made more intensive and insightful by including surveys and interviews with municipal authorities, urban planners, and residents in future work. By combining quantitative modelling with historical data analysis, this methodology aims to provide actionable insights into sustainable urban water management and flood mitigation strategies for Delhi.

Data Acquisition

The data acquisition phase focused on gathering diverse datasets necessary for an integrated assessment of Delhi's urban water challenges. Multi-temporal satellite data, groundwater monitoring results, meteorological records, and infrastructure and socio-economic information were systematically compiled to support subsequent hydrological and flood risk modelling.

Satellite Data and Remote Sensing

Multi-temporal satellite imagery from various sources was acquired to analyse land use changes, urban expansion, and surface water dynamics. Landsat series data (Landsat-5 TM, Landsat-7 ETM+, and Landsat-8 OLI) spanning from 2000 to 2023 were downloaded from the USGS Earth Explorer platform (USGS, n.d.). High-resolution imagery from Sentinel-2 and SPOT satellites was also utilized for detailed infrastructure mapping and change detection analysis. The approach of integrating multi-temporal satellite data and spatial metrics follows methodologies similar to those demonstrated by (Aithal and Ramachandra, 2016) in their urban growth analysis of Delhi.

Groundwater Monitoring Data

Groundwater level data from 150+ monitoring wells across Delhi were obtained from the Central Ground Water Board (CGWB) for the period 2000-2023 (CGWB, 2021, 2022, and 2023). The data includes pre-monsoon and post-monsoon water levels, providing insights into seasonal variations and long-term trends. Groundwater quality parameters, including total dissolved solids (TDS), fluoride, nitrate, and heavy metal concentrations, were also analysed.

Meteorological Data

Long-term rainfall data (1950-2025) was acquired from the India Meteorological Department (IMD) for multiple stations across Delhi, including Safdarjung, Palam, Ridge, and Najafgarh. Temperature, humidity, and evapotranspiration data were utilised for water balance calculations and assessing the impact of climate change.

Infrastructure and Socio-economic Data

Data on water supply infrastructure, distribution networks, drainage systems, and treatment facilities were obtained from the Delhi Jal Board (DJB) and the Municipal Corporation of Delhi (MCD). Demographic data, water consumption patterns, and flood damage records were compiled from various government agencies and research institutions.

Hydrological Modelling and Analysis

Groundwater Flow Modelling

Three-dimensional groundwater flow models were developed using MODFLOW software to simulate aquifer behaviour and predict future groundwater scenarios. The models incorporated hydrogeological parameters, pumping data, and recharge estimates to assess sustainable extraction limits.

Flood Risk Assessment

Flood hazard mapping was conducted using Digital Elevation Models (DEMs), rainfall intensity data, and hydrodynamic modelling. The HEC-RAS software was used to simulate flood scenarios for different return periods (10, 25, 50, and 100 years) and assess the performance of existing drainage infrastructure. The modelling approach aligns with the methodology applied by Husain *et al.* (2018) in their simulation of floods in the Delhi segment of the Yamuna River using HEC-RAS.

Climate Change Impact Modelling

Statistical downscaling techniques were applied to General Circulation Model (GCM) outputs to generate future climate scenarios for Delhi. The impacts of changing temperature and precipitation patterns on water demand, supply, and flood risks were quantified using integrated assessment models.

RESULTS AND DISCUSSION

This section presents the key findings derived from data analysis and hydrological assessment of Delhi's urban water system. It integrates trends in groundwater depletion,

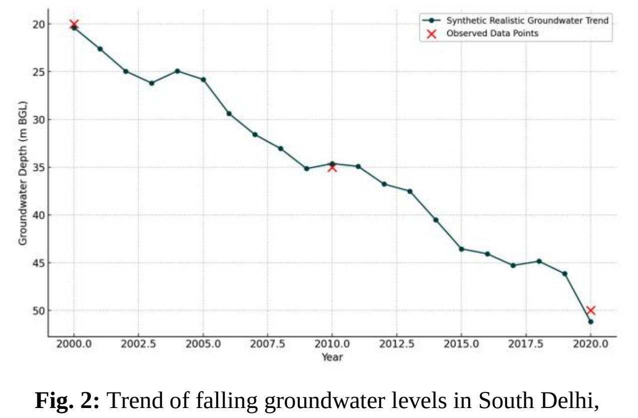

Fig. 2: Trend of falling groundwater levels in South Delhi, 2000–2020 (CGWB data).

Table 1: Groundwater Depletion trend in different zones in Delhi (2000-2023).

Zone	Depth in 2000 (m BGL)	Depth in 2023 (m BGL)	Depletion Rate (m/year)	Critical Wells (%)
South Delhi	20.3	52.1	1.38	85
Southwest Delhi	18.7	48.9	1.31	78
West Delhi	22.1	45.6	1.02	65
Central Delhi	15.4	35.2	0.86	52
East Delhi	12.8	28.4	0.68	45
North Delhi	14.2	32.7	0.80	48

variations in rainfall patterns, flood vulnerability, and the performance of existing drainage infrastructure to evaluate the overall urban water and flood management scenario. The discussion also interprets how these findings relate to policy, governance, and climate adaptation measures in Delhi.

Groundwater Depletion Crisis

The graph (Fig. 2) illustrates the continuous decline in groundwater levels in South Delhi between 2000 and 2020, derived from the data summarised in Table 1. Groundwater levels declined from approximately 20 m BGL in 2000 to over 50 m BGL by 2020, indicating an average depletion rate of about 1.5 m per year. Data from the Central Ground Water Board (CGWB, 2023) confirm that nearly 60% of monitoring wells across Delhi display declining trends, with certain zones—particularly in South and Southwest Delhi—experiencing depletion rates exceeding 2 m per year.

The spatial analysis reveals significant variations in depletion patterns across the National Capital Territory (NCT) of Delhi. The most critical areas include South Delhi (Hauz Khas, Greater Kailash, Defence Colony), Southwest Delhi (Dwarka, Najafgarh), and parts of West Delhi (Janakpuri, Rajouri Garden), as indicated in CGWB (2022; 2023). These zones are characterised by high population density, intensive groundwater extraction for domestic and commercial use, and limited natural recharge opportunities caused by extensive urbanisation.

The correlation between rapid urban development and groundwater depletion is clearly evident from the temporal analysis. Regions that have experienced accelerated construction and infrastructure growth show the steepest declines in groundwater levels. The replacement of permeable surfaces with built-up areas has substantially reduced natural recharge potential, while rising water demand from increasing populations has intensified extraction pressures (CGWB, 2022; CGWB, 2023).

Water Supply-Demand Imbalance

Delhi faces a persistent water-supply deficit of approximately 200 MGD, with demand reaching 1,140 MGD while supply capacity remains at 935 MGD (Parveen and Ahmad, 2024). This imbalance has severe implications for water security and forces dependence on costly alternatives such as tanker water supply and illegal groundwater extraction (Parveen and Ahmad, 2024). The analysis reveals that per-capita water availability has declined from 65 liters per day in some areas to as low as 30 liters per day, well below the minimum of about 50 liters per day considered acceptable for health and dignity (UN, 2022). The spatial distribution of water supply reveals significant inequities across different areas of Delhi. Planned colonies and affluent areas receive relatively better water supply (40-50 liters per capita per day) through piped networks, while unauthorised settlements and peripheral areas depend heavily on tanker supplies and groundwater extraction. This disparity creates social tensions and drives the growth of the informal water market, including the notorious “tanker mafia” that exploits water scarcity for profit. Infrastructure losses further exacerbate the supply–demand imbalance: the ageing distribution network, with pipes dating back to the 1960s and 1970s, experiences losses of up to 40% due to leakages, theft, and inefficient distribution practices. The analysis of water-supply infrastructure reveals that approximately 25% of the network requires immediate replacement or major repairs to reduce losses and improve efficiency (DJB, 2022).

Changing Rainfall Patterns and Flood Risk

The meteorological analysis reveals very significant changes in Delhi’s rainfall patterns over the past seven decades, with particularly significant increases in pre-monsoon precipitation (Bhattacharya, 2025). May rainfall has tripled from an average of 17 mm during the 1950s–1980s to 95 mm during the 2020s (Fig. 3), with 2025 recording the wettest May in over 100 years at 186 mm (Bhattacharya, 2025). This shift has fundamentally altered the city’s flood-risk profile, extending the vulnerable period from the traditional monsoon months to include May.

The analysis of extreme rainfall events shows an increasing frequency and intensity of heavy precipitation episodes. The number of days with rainfall exceeding 100 mm in May has increased from zero during 1950-1975 to five instances in the last 25 years. This trend is consistent with climate-change projections that predict more intense and erratic precipitation patterns in the Indo-Gangetic Plain (Bhattacharya, 2025).

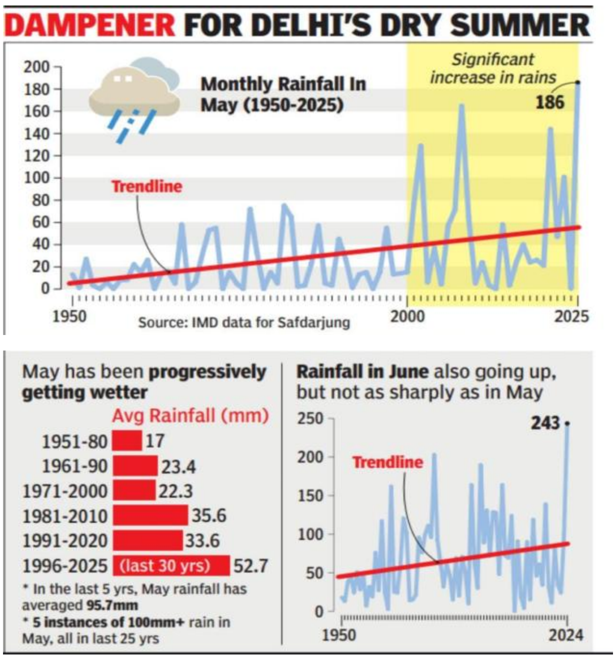

Fig. 3: Average May rainfall in Delhi (1950–2025), showing increasing variability and climate shift. (*Source: Bhattacharya., 2025*)

The changing rainfall patterns have overwhelmed Delhi’s drainage infrastructure, which was designed based on historical monsoon patterns. The existing drainage network, designed for peak flows during July-September, cannot handle the intense pre-monsoon precipitation in May. This mismatch between infrastructure capacity and changing climate patterns has contributed to the increase in urban flood hotspots from 4 in 2000 to 18 in 2023.

Urban Flood Vulnerability Assessment

The flood-risk assessment reveals that approximately 35 % of Delhi’s urban area is vulnerable to flooding during extreme rainfall events (Nithin, 2024). Low-lying areas along the Yamuna floodplain, including parts of East Delhi, North Delhi, and Central Delhi, are particularly susceptible to river flooding. Additionally, numerous locations across the city experience waterlogging due to inadequate drainage capacity and poor maintenance.

The spatial analysis identifies several critical flood hotspots:

- Yamuna floodplain areas: including Civil Lines, ISBT, and parts of Shahdara (Nithin, 2024).
- South Delhi low-lying areas: Minto Bridge underpass, ITO intersection, and parts of Lajpat Nagar (Nithin, 2024).
- West Delhi industrial areas: Najafgarh drain catchment and industrial zones (Nithin, 2024).
- Unauthorized colonies: scattered across the city with inadequate drainage infrastructure (Nithin, 2024).

The flood-vulnerability assessment incorporates multiple factors, including topography, drainage density, land use patterns, and infrastructure quality (Nithin, 2024). The results show that unauthorised settlements are disproportionately affected by flooding due to their location in flood-prone areas and lack of proper drainage infrastructure (Nithin, 2024).

Infrastructure Performance Assessment

The assessment of water management infrastructure in Delhi reveals significant gaps and performance deficits across multiple components of the city’s water system, including water supply, drainage, and wastewater treatment (DJB, 2024).

Water Supply Infrastructure

Delhi’s total treatment plant capacity stands at approximately 935 MGD across nine major water treatment plants. However, the city experiences high distribution losses ranging between 35–40% due to ageing pipelines and unauthorised water connections. The Delhi Jal Board’s Summer Action Plan 2024 highlights that the existing storage capacity is insufficient to balance daily demand fluctuations, while water quality issues persist due to source pollution from the Yamuna and contamination within the distribution network (DJB, 2024).

Drainage Infrastructure

Delhi has a total of nearly 3,000 km of major drains, with many operating at 80–90% capacity during normal monsoon conditions. The Drainage Master Plan for NCT of Delhi, prepared by the Irrigation & Flood Control Department and IIT Delhi, indicates that several key drains—such as Najafgarh, Supplementary, and Barapullah—suffer from reduced carrying capacity due to siltation, encroachments, and structural damage (Irrigation & Flood Control Department & IIT Delhi, 2018). Moreover, the plan notes that design standards are still based on historical rainfall intensities from 1976, making the system inadequate to manage current rainfall patterns intensified by climate change (IFCD-IITD, 2018).

Wastewater Treatment

Delhi operates 35 sewage treatment plants (STPs) with an installed capacity of around 596 MGD. However, only about 450 MGD is actually treated, with the remainder discharged untreated into the Yamuna (DJB, 2024). Effluent quality from several STPs fails to meet the Central Pollution Control Board (CPCB) norms, leading to poor reuse potential. The Summer Action Plan 2024 emphasises the need for tertiary treatment expansion to enable reuse for horticulture, construction, and groundwater recharge (DJB, 2024).

Technological Solutions and Innovations

Recent policy studies emphasise that advanced technologies such as Remote Sensing, GIS, and IoT-enabled systems can significantly enhance Delhi's water management performance (CWC, 2023; Irrigation & Flood Control Department & IIT Delhi, 2018). Remote sensing data, particularly InSAR and SAR, have been used for groundwater depletion and land subsidence monitoring across Delhi's floodplain areas (CGWB, 2023). GIS-based flood modelling also enables real-time flood extent mapping for emergency response (CWC, 2023). Smart water management innovations proposed in the Delhi Jal Board's 2024 plan include the use of IoT-enabled water quality sensors, smart meters for leak detection, and automated pump control systems for groundwater optimisation (DJB, 2024).

Sustainable Solutions Framework

Based on the overall analysis, the study proposes an integrated Sustainable Urban Water and Flood Management Framework, aligning with the Drainage Master Plan (2018) and the DJB Summer Action Plan (2024).

Sustainable Urban Drainage Systems (SUDS)

Measures such as permeable pavements, bioswales, green roofs, and constructed wetlands are recommended to enhance infiltration and stormwater quality (IFCD-IITD, 2018).

Groundwater Management and Recharge Enhancement

The CGWB advocates installation of recharge wells and use of treated wastewater for aquifer replenishment, alongside stricter monitoring of extraction limits (CGWB, 2023).

Water Supply System Optimisation

The DJB 2024 Plan recommends replacing 40% of ageing distribution pipelines within 10 years and deploying smart distribution controls to minimise non-revenue water losses (DJB, 2024).

Flood Risk Reduction Measures

The Drainage Master Plan 2018 suggests capacity augmentation of critical drainage corridors and restoration of 20% of encroached floodplain zones to mitigate flood risk (IFCD-IITD, 2018).

Policy and Governance Recommendations

The successful implementation of sustainable water management solutions requires coordinated policy interventions and institutional reforms:

Integrated Water Management Authority

Establishment of a single agency responsible for all aspects of water management, coordinating between agencies, and developing unified planning and implementation protocols. (Bhaduri, 2024)

Regulatory Framework

Revision of building codes to mandate water conservation and flood-resilient design; establishment of groundwater extraction licensing and monitoring systems; water pricing reforms to promote conservation and cost-recovery (CSE, 2023)

Financial Mechanisms

Use of green bonds for funding sustainable infrastructure development; introduction of user fees for stormwater management services; incentives for private-sector participation in water infrastructure. (Vikas *et al.*, 2021)

Capacity Building and Public Participation

Training programs for technical personnel in modern water-management techniques; public-awareness campaigns on water conservation and flood preparedness; community participation in monitoring and maintenance of water infrastructure. (Kumar, 2025)

CONCLUSIONS

This comprehensive study reveals the complex and interconnected nature of Delhi's water management challenges, characterised by severe groundwater depletion, persistent supply deficits, and increasing flood risks due to changing climate patterns. The analysis demonstrates that traditional approaches focused on supply augmentation and grey infrastructure are insufficient to address the scale and complexity of current challenges.

The key findings indicate that groundwater levels have declined by over 30 meters in critical areas over two decades, while flood vulnerability has expanded significantly due to both climate change and inadequate infrastructure adaptation. The tripling of May rainfall patterns has fundamentally altered Delhi's flood risk profile, requiring urgent adaptation of drainage systems and emergency response protocols.

The proposed integrated solutions framework offers a pathway toward sustainable water management through the combination of green infrastructure, technological innovations, and institutional reforms. The implementation of SUDS, enhanced groundwater recharge, smart monitoring systems, and improved governance structures can collectively address both water scarcity and flood risks while building long-term resilience.

The success of these interventions depends on coordinated action across multiple stakeholders, sustained financial investment, and strong political commitment to long-term sustainability over short-term fixes. The experiences and lessons learned from Delhi's water management challenges and solutions can provide valuable insights for other rapidly growing megacities facing similar pressures from urbanisation and climate change.

Future research should focus on developing more sophisticated predictive models for groundwater-surface water interactions, evaluating the long-term performance of green infrastructure solutions, and assessing the social and economic impacts of different policy interventions. The integration of artificial intelligence and machine learning techniques with remote sensing data offers promising opportunities for improving water resource monitoring and management efficiency.

Finally, the study emphasises that sustainable urban water management is not merely a technical challenge but requires fundamental changes in how cities approach water as a shared resource, integrate water considerations into urban planning processes, and engage communities in water stewardship activities.

Acknowledgement

The authors are grateful to the Central Ground Water Board, India Meteorological Department, Delhi Jal Board, and the Remote Sensing and GIS community, as well as various academic institutions, for providing essential data and technical support for this research. We sincerely thank NIT Kurukshetra and our professor, Dr. Surinder Deswal, for his guidance, encouragement, and valuable feedback throughout the study.

Grant Support Details

The present research did not receive any financial support.

Conflict of Interest

The authors declare no conflicts of interest regarding the publication of this manuscript. All ethical guidelines, including data privacy, research integrity, and publication ethics, have been strictly followed.

Life Science Reporting

No life science research was conducted as part of this study.

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