ENHANCING THE STORM WATER MANAGEMENT, USING REAL TIME CONTROL AND GREEN INFRASTRUCTURE SYSTEMS

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Abstract - *Urban areas face rising floods and water scarcity, worsened by climate change, urbanization, and poor water management. This study examines Green Infrastructure Systems (GIS) and Real-Time Control (RTC) systems to enhance storm water management in cities, focusing on reducing surface runoff and improving rainwater harvesting in Chennai, India. The research evaluates the effectiveness of RTC technology and green infrastructure techniques, both individually and combined, under various rainfall conditions. By studying the Perumbakkam urban catchment in Chennai, the feasibility and performance of these strategies will be assessed. The aim is to provide insights for urban planning and policy, promoting resilient and sustainable water management infrastructure. The study involves site selection, and simulations using SWMM software to develop practical recommendations for integrating effective storm water management into urban development plans, aiming to mitigate flooding and address water scarcity.*

Key Words*: *Urban areas, Floods, Water scarcity, Climate change, Green Infrastructure Systems (GIS), Real-Time Control (RTC), Storm water management, Surface runoff, Rainwater harvesting.

1. INTRODUCTION

Urban environments are increasingly threatened by the dual challenges of rising floods and water scarcity, driven by climate change, urbanization, and inadequate water management. This paradoxical situation highlights the complex interplay of these factors. Cities are witnessing more frequent and intense floods, damaging infrastructure and economies while endangering lives. Concurrently, many regions face water scarcity, complicating efforts to maintain sustainable water supplies.

Flooding in urban areas is primarily due to changing climate patterns and increased rainfall intensity. Urbanization, with its expansion of impermeable surfaces and changes to natural drainage, exacerbates cities' flood vulnerabilities. As a result, urban planners and policymakers must implement resilient infrastructure and sustainable land-use practices to mitigate flood impacts and protect residents.

Water scarcity, another facet of the global water crisis, is caused by over-extraction from aquifers, pollution, population growth, and inefficient water management. This scarcity threatens community needs, industrial activities, and agriculture. With climate change disrupting precipitation patterns and worsening droughts, addressing water scarcity becomes increasingly critical.

To tackle these interconnected issues, holistic and integrated water management approaches are essential. Sustainable urban planning, investment in resilient infrastructure, and water conservation measures form the core of a comprehensive strategy.

This research aims to implement Green Infrastructure Systems (GIS) and Real-Time Control (RTC) systems in building campuses to improve storm water management, reduce surface runoff, and enhance rainwater harvesting.

This study examines Real-Time Control (RTC) storm water technology and green storm water infrastructure techniques, focusing on the flood-prone Perumbakkam area in Chennai. It assesses RTC and Green Infrastructure Systems (GIS) performance under various rainfall scenarios and analyzes their effectiveness in flood mitigation. The study aims to provide valuable insights for urban planning, civil engineering, environmental science, and public policy. It also seeks to enhance storm water management system efficiency and offer practical recommendations for integrating effective storm water strategies into future urban development plans.

1.1 Methodology

The methodology involves several steps: a literature study to understand the current issues in Chennai and introduce Real-Time Control (RTC) and Green Infrastructure Systems (GIS); a journal study to explore strategies for integrating RTC and different types of GIS; a case study to review projects that have implemented these technologies and their impact on flood control and storm water reuse; a live study selecting a flood-affected and water-scarce site in Chennai to analyze the feasibility of RTC and GIS strategies; and a simulation using SWMM software to evaluate the effectiveness of the proposed technologies in reducing surface runoff and enhancing water storage.

2. Current situation of flood and scarcity

Tamil Nadu, a state in southern India, endures significant seasonal fluctuations in water availability. It experiences periods of both excessive rainfall and severe drought.

Location	Major basin name	Month	Water stress
Chennai, India	India East Coast	December	Low - Medium (10-20%)
Chennai, India	India East Coast	November	Low - Medium (10-20%)
Chennai, India	India East Coast	October	Low - Medium (10-20%)
Chennai, India	India East Coast	September	Low - Medium (10-20%)
Chennai, India	India East Coast	August	Low - Medium (10-20%)
Chennai, India	India East Coast	July	Low - Medium (10-20%)
Chennai, India	India East Coast	June	Low - Medium (10-20%)
Chennai, India	India East Coast	May	Low - Medium (10-20%)
Chennai, India	India East Coast	April	Low - Medium (10-20%)
Chennai, India	India East Coast	March	Low - Medium (10-20%)
Chennai, India	India East Coast	February	Low - Medium (10-20%)
Chennai, India	India East Coast	January	Low - Medium (10-20%)

Table -1: Water stress level throughout the year

Chennai, the coastal capital with a population of 10 million, faced a "Day Zero" crisis in the summer of 2019 when its four main reservoirs completely dried up. Conversely, the city also suffers from frequent and severe flooding, such as the record-breaking rains in 2015 that resulted in hundreds of deaths.

Chennai, the most densely populated district in Tamil Nadu, despite being the smallest in area, encompasses much of Greater Chennai, previously divided among Tiruvallur, Kanchipuram, and Chengalpattu districts. The city experiences a typical oppressive tropical climate with temperatures ranging from 26 to 35°C and an average annual rainfall of 1400 mm. The majority of rainfall occurs from September to December, brought by northeast monsoon winds and often triggered by cyclones in the Bay of Bengal. Thus, Chennai endures the paradox of severe flooding during the monsoon season and acute water shortages in the summer months.

The rapid pace of urbanization is a primary cause of flooding, as expanding urban areas reduce green spaces and increase concrete surfaces, overwhelming drainage systems. Encroachment on lakes, wetlands, and natural drainage channels for construction disrupts water flow, while outdated and poorly maintained drainage infrastructure, initially designed for smaller populations, cannot handle the increased runoff. Climate change intensifies heavy rainfall events, further straining these systems. Water scarcity in Chennai arises from the city's inability to capture and store concentrated monsoon rainfall, overexploitation of groundwater, and significant losses from leaky distribution networks and inefficient agricultural practices. Pollution exacerbates the problem, making many water bodies unusable. In response, the Chennai Metropolitan Water Supply and Sewerage Board has initiated measures like desalination, sewage treatment reuse, and rainwater harvesting. The city aims for a 75% wastewater reuse rate and is reallocating industrial freshwater to domestic use, while piloting indirect potable reuse plants to enhance water security and resilience.

2.1 Real time control system and Green infrastructure solutions

Real-time control (RTC) enhances storm water management by using sensors and automated systems to optimize infrastructure, reduce flood risk, improve water quality, and adapt to changing conditions. It maximizes existing resources cost-effectively, offering a proactive and efficient solution to urbanization and climate change challenges.

Fig -1: Real time control system

Green infrastructure for storm water management uses natural systems to manage runoff in urban areas. Key methods include green roofs, which absorb rainwater and reduce heat; permeable pavements that allow water infiltration, reducing runoff and pollution; rain gardens that filter water and enhance biodiversity; bio retention swales that filter and infiltrate water, reducing floods; detention tanks that manage runoff flow; and rainwater harvesting tanks that store rainwater for various uses.

3. Literature review

Urban flooding poses a growing threat due to climate change and rapid urbanization. This journal article collection explores two promising solutions: real-time control (RTC) systems and green infrastructure (GI). RTC systems utilize rainfall forecasts to optimize rainwater harvesting and detention basins, improving water supply, flood control, and pollutant removal (e.g., [3, 4, 5]). Studies like Altobelli et al. (2023) demonstrate significant efficiency gains in non-potable water savings (32-90%) and discharge volume reduction (11-31%) using RTC [3]. However, challenges such as cost, maintenance, and regulatory hurdles require further investigation (e.g., [5]).

Green infrastructure, on the other hand, leverages natural elements like rain gardens and bios wales to manage storm water runoff and mitigate flood risk. Case studies across the globe showcase the effectiveness of GI in reducing flood events and improving water quality (e.g., [6, 8, 9]). The research by Webber et al. (2023) highlights the value of catchment-scale GI implementation, where multiple smaller interventions collectively deliver significant flood management benefits [9].

Integrating RTC with Nature-Based Solutions (NBS) like green roofs, bio retention, and detention basins provides significant benefits for urban water management (Articles 10, 12). RTC improves water quality in bio retention systems, enhances storage capacity in green roofs, and optimizes water quantity and quality management in detention basins (Article 10). However, major challenges arise during the planning stage, including decisions about centralized vs. decentralized systems, modelling, forecasting, and monitoring costs (Article 10).

Green roofs with storage layers reduce runoff and increase evapotranspiration more effectively than conventional designs (Articles 11, 12). Optimal storage layer depth, vegetation type, substrate depth, and weather conditions are critical factors influencing their performance (Articles 11, 12, 13). Additionally, green roofs significantly mitigate floods by reducing surface runoff and peak flow rates (Articles 12, 13).

Permeable pavements, a form of Low Impact Development (LID), substantially decrease surface runoff and peak flood flow (Articles 14, 15, 16). Permeable roads outperform other pavements in reducing runoff coefficient and peak flow (Article 14). Pavement thickness, void ratio, and surface material are influential, with thicker gravel layers enhancing runoff delay and retention (Article 15).

Rain gardens are effective GI tools for managing storm water pollution, reducing runoff volume and flow, removing pollutants, and promoting groundwater recharge (Article 17). Their saturated hydraulic conductivity improves over time, enhancing long-term drainage capacity (Article 18).

Bio retention systems have traditionally focused on hydrologic control, with limited research on contaminant removal (Article 18). Assessing water balance provides insights into bio retention system dynamics (Article 18). Analysing historical rainfall data and simulating future scenarios can predict climate change impacts on these systems (Article 19).

While both RTC and GI offer independent solutions, the most effective approach may lie in their combined application. Integrating real-time control with green infrastructure creates a more holistic strategy for urban flood management.

Overall, combining GI and RTC offers significant advantages for urban water management, though challenges in planning and implementation require careful address. The inference from these findings suggests that while GI and RTC present a promising path for sustainable urban drainage, a strategic approach in the initial planning and design phases is essential for realizing their full potential.

Fig -2: Green In

3.1 Case studies

As cities expand rapidly, existing storm water management systems struggle to handle the increased runoff, leading to flooding and water quality problems. Fortunately, innovative solutions exist. Combining green infrastructure (GI) with real-time control (RTC) systems offers a promising approach, as evidenced by successful case studies around the world. This integration can effectively address the challenges posed by urban storm water and create more sustainable management practices.These case studies highlight a suite of GI technologies effectively employed to manage storm water runoff. Green roofs, exemplified by one of the case study, capture and filter rainwater, reducing peak runoff by up to 40% while offering insulation benefits. Rain gardens, strategically placed like those at the Universities in California, utilize native plants and engineered soils to filter and infiltrate storm water, preventing pollutants from entering waterways. Permeable pavements, implemented at all the studied case studies allow rainwater to soak into the ground, replenishing groundwater reserves and reducing surface runoff. Detention tanks, employed in the cases, store excess storm water during heavy rain events, mitigating flood risks.

Beyond capturing and storing storm water, RTC systems optimize the performance of these GI elements. These intelligent control systems, at the studied projects, continuously monitor rainfall, water levels, and other parameters throughout the storm water management system. Utilizing this data, they can make real-time adjustments to optimize the system's performance and ensure efficient water use. One of the case study at city level, further demonstrates the power of a layered RTC system, employing local, global, and global predictive control strategies to prevent flooding across the entire city.

The benefits of these combined GI and RTC approaches are evident across the presented case studies. Rainwater harvesting systems, provide a sustainable water source for irrigation and other non-potable uses, reducing reliance on municipal supplies by up to 40%. The natural filtration capabilities of GI significantly improve water quality, as observed in all the university case studies. Permeable pavements and infiltration practices, employed in all the university case studies, contribute to groundwater recharge.

In conclusion, the projects studied offer compelling evidence for the effectiveness of green infrastructure and real-time control systems in sustainable storm water management. These strategies can significantly reduce municipal water use, improve water quality, mitigate flood risks, and replenish groundwater reserves. By embracing these advancements, cities can create more resilient and water-secure urban environments.

4. Live study Perumbakkam: A Tale of Two Worlds

Perumbakkam, a Chennai suburb located along the IT corridor, presents a stark contrast between its ecological past and urban present. Home to institutions, high-end residences, slums, agricultural land, and remnants of a floodplain, the area boasts a unique character of carrying water. The Arsankhazhani Lake sits within its boundaries, flanked by hills and tanks. Neighbouring forests further enhance its ecological significance.

However, Perumbakkam's population of 28,130, residing on a mere 5.88 square kilometres, paints a picture of high density. This rapid urbanization has come at a cost. A comparison of old and new maps reveals a dramatic transformation of the landscape.

The 1954 map showcases a vast green expanse, the Perumbakkam marshland, dotted with water bodies and a network of natural drains. This intricate system facilitated the flow of water from the Pallikarnai marsh to the Buckingham Canal and ultimately, the sea. Unfortunately, development has disrupted this delicate balance.

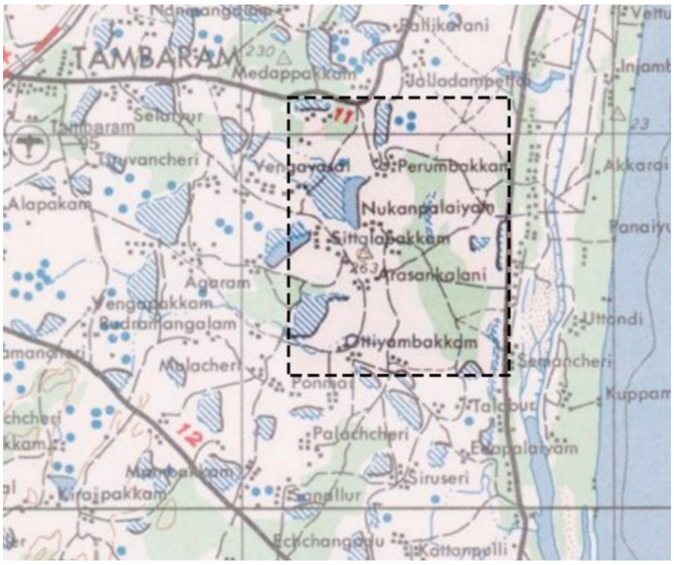

Fig -2: Perumbakkam's map in 1954 almost covered with green patch

Fig -3: Land use of Perumbakkam in 2016 master plan by CMDA

The construction of major apartment complexes, starting around 2008, coincided with increased water stagnation events. Blockages in natural drains, some dating back to the establishment of Satyabhama University in the 1990s, only exacerbated the issue. This vulnerability became tragically evident during the 2015 Chennai floods.

The area's natural tendency to collect water, coupled with the destruction of marshland and blocked drains, led to substantial flooding. The inadequate storm water drainage network and flawed building design further compounded the damage. Shockingly, immediate attention seemed to bypass the slum tenements, leaving them in a precarious position.

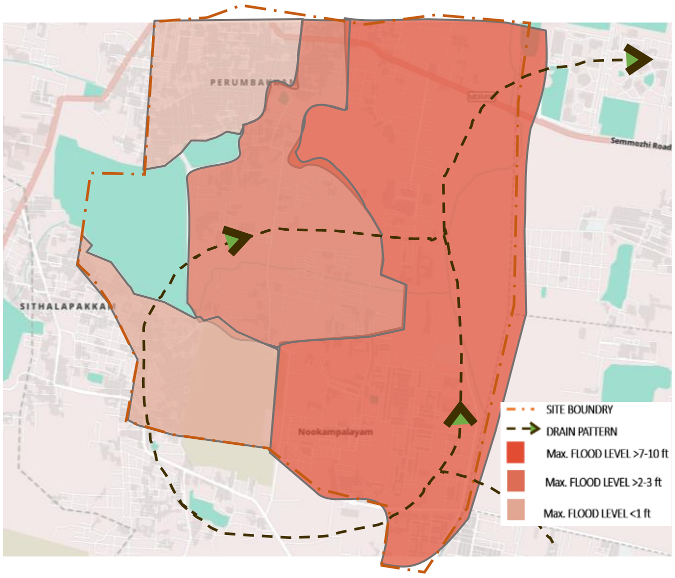

Fig -4: Map showing the "S" shape water drain along with area with high to low flooding area

The natural water flow pattern, resembling an "S" shape, channelled water from the Perumbakkam Eri towards the slum tenements. The convergence point near the PSBB School intensified the flow, inundating these settlements. The self-sustaining storm water drain network proved insufficient to handle the burden.

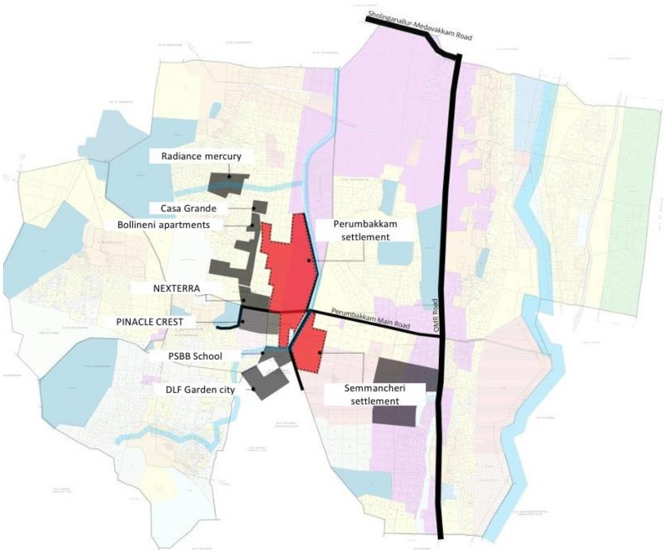

Fig -5: Map showing the neighbouring buildings

Encroachment on crucial drainage areas has resulted in water stagnation near Global Hospitals and neighbouring areas (fig 5.). A proposed canal project to expand the existing drain aims to address this, but concerns about inadequate capacity calculations remain.

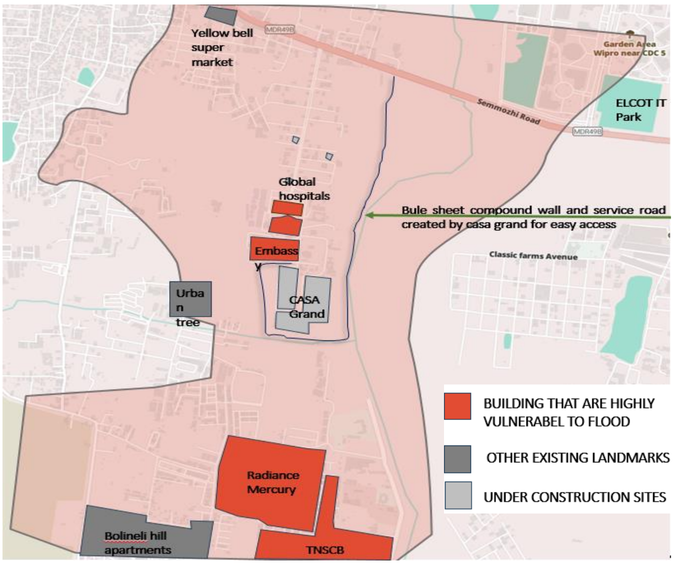

Fig -6: Map showing the important landmarks and their vulnerability to flood.

Ironically, this water-rich area faces severe water scarcity during summers. Residents rely on expensive trucked water for both drinking and daily needs. Even the relatively new apartment buildings struggle with limited water supply. The current infrastructure simply cannot meet the growing demand.

Perumbakkam's story highlights the consequences of uncontrolled development on natural ecosystems. The urgent need for sustainable water management and infrastructure development that prioritizes the well-being of all residents cannot be ignored.

4.1 Modelling and simulation

Fig -7: Map highlighting the area selected for the study

This study investigates the application of a storm water simulation model in Perumbakkam, India, focusing on a historically flood-prone area near the Global Hospital. The 175-acre site encompasses a mix of residential, commercial, and institutional land uses, divided into five sub-catchments for analysis. The model incorporates a detailed drainage network design based on site contours and culminating in discharge to the Okkiyam Madavu channel and Buckingham Canal. Manning's formula was employed to determine the optimal drain size considering peak runoff, imperviousness, and channel characteristics. Hourly rainfall data from December 2023 serves as the model's time series input. Additionally, the study explores the implementation of Green Infrastructure (GI) and Real-Time Control (RTC) technologies within each sub-catchment. These strategies include detention tanks with RTC pumps, green roofs with or without storage, permeable pavements, and bios wales. Detention tank sizing and pump control rules for the RTC system will be determined based on separate calculations and referenced journals, respectively. This research contributes to the exploration of sustainable storm water drainage solutions in rapidly urbanizing areas by evaluating the effectiveness of combined GI and RTC approaches through simulation modeling.

4.2 Results

The analyzed system stores approximately 11, 61800 liters of water, which can fulfill roughly 14.34% of the daily non-potable water needs of a 27,000 person population. The study demonstrates that RTC and GI can significantly reduce surface runoff while saving water. Integrating RTC with other GI technologies offers promising avenues for further reduction in runoff and increased water savings in urban areas. Additionally, exploring RTC integration with other GI systems can potentially minimize water loss during heavy floods.

4.3 Discussion

This study investigated smart drainage (RTC) and green spaces (GI) for managing city rainwater. Both showed promise. Upgrading existing systems with RTC improved efficiency, while combining it with rainwater harvesting could potentially reuse 90% of storm water and reduce discharge by 31%.

Green solutions like green roofs, special pavements, and rain gardens were identified as sustainable options. Choosing the best method depends on the location and pollutants. Green roofs with storage significantly reduced runoff, while pavements minimized its depth and rain gardens filtered pollutants.

The study stressed the importance of maintaining the system and collaboration between designers and operators. Real-time data and simulations were crucial for optimization. The analysed system using storm water management modelling software could save 14% of a community's daily non-potable water needs.

Overall, smart drainage and green spaces offer significant potential for sustainable urban water management. Addressing challenges like cost and maintenance will make these solutions even more effective.

4.4 Inference and Recommendations

Various green solutions like rooftop gardens, special pavements, and rain gardens proved effective for storm water management, with the best choice depending on the environment and pollutants. Green roofs with storage significantly reduced runoff volume, while pavements minimized its depth and rain gardens filtered impurities.

The study stressed the importance of maintaining these systems and collaboration between designers and operators. Real-time data and simulations were essential for optimal performance. The analysed system's water savings potential highlights the value of both smart drainage (RTC) and green infrastructure (GI).

Future research should focus on integrating these approaches, like combining RTC with various green solutions. Developing advanced forecasting models and exploring cost-effective implementation strategies are also crucial. Additionally, research on hybrid designs for green infrastructure, user-friendly design tools, and long-term performance monitoring would be beneficial. Social aspects, life cycle assessments, and policy frameworks also warrant investigation. By focusing on these areas, we can create more well-rounded and sustainable solutions for managing urban storm water.

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