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Advanced Flood Management System Based on G-CANS Project

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ABSTRACT

Floods are a type of natural disaster that can cause heavy destruction to life and property. It is a condition when rainwater accumulates at a place, flooding populated areas. They can also lead to the loss of numerous lives. At times, it can be highly dangerous and can wipe off an entire village or city. It is impossible to stop a natural disaster, but the effects of the disaster can be reduced.

This paper presents an advanced flood management system inspired by Tokyo's G-CANS Project and explores its potential application in Mumbai, India. The study includes rainfall and flood data analysis, evaluation of existing drainage systems, and adaptation of G-CANS infrastructure to Mumbai's conditions. A working model was prepared to demonstrate feasibility and design modifications. The results indicate that implementing a similar underground discharge channel in Mumbai could significantly mitigate urban flooding, protect infrastructure, and save lives.

Keywords—Flood Management, G-CANS Project, Mumbai Floods, Stormwater Drainage, Underground Discharge Channel.

INTRODUCTION

Floods are among the most destructive natural disasters in urban areas, causing loss of life, infrastructure damage, and long-term socio-economic impacts. Coastal megacities are particularly vulnerable due to high population density, rapid urbanization, and exposure to both heavy rainfall and tidal influences. Mumbai, India's financial capital, faces recurrent floods almost every monsoon season, disrupting daily life and causing significant economic losses.

The catastrophic flood of 26 July 2005, when the city received 944 mm of rainfall in 24 hours, highlighted the inadequacy of its flood management systems. Despite measures such as the Brihanmumbai Stormwater Drain (BRIMSTOWAD) project, the city continues to face severe flooding during extreme rainfall events.

Multiple factors contribute to Mumbai's flood vulnerability. The stormwater drainage system, designed in the early 20th century, handles only 25 mm per hour of rainfall, far less than the intensity experienced during heavy monsoons. Rapid and unplanned urbanization has led to encroachment of rivers, drains, and wetlands, reducing natural drainage capacity. The Mithi River, once a vital waterway, has lost much of its conveyance ability due to encroachments and pollution. Tidal effects from the Arabian Sea further hinder stormwater discharge, while weak governance and fragmented institutional responsibilities compound the challenge.

Globally, cities have adopted innovative solutions for flood management. Tokyo's Metropolitan Area Outer Underground Discharge Channel (G-CANS Project) is one of the most notable examples. This massive underground facility consists of silos, tunnels, and a giant reservoir designed to divert floodwaters safely into the Edo River. Completed in 2006, G-CANS has protected Tokyo from several severe floods, demonstrating the effectiveness of large-scale infrastructure in managing urban flood risks.

Given the limitations of Mumbai's existing systems, adapting a G-CANS-like project offers a potential long-term solution. By diverting and storing excess floodwaters underground, such infrastructure could reduce flooding in low-lying areas and protect lives, livelihoods, and infrastructure. However, adaptation requires careful assessment of geological conditions, financial feasibility, governance capacity, and socio-economic impacts. Importantly, floods disproportionately affect Mumbai's vulnerable communities living in informal settlements, making inclusive flood management strategies essential.

This research seeks to explore the applicability of the G-CANS concept in Mumbai. By analyzing rainfall data, drainage limitations, and lessons from international practices, it aims to propose a feasible and sustainable framework for urban flood resilience.

LITERATURE REVIEW

Urban flooding is a critical challenge in many megacities, particularly those located in coastal zones with high population density and rapid urbanization. Floods not only disrupt urban systems but also cause long-term socio-economic and health impacts. The literature on flood management emphasizes both structural and non-structural approaches, with examples ranging from Tokyo's large-scale underground flood diversion projects to smaller-scale drainage improvements in South and Southeast Asian cities. These studies collectively highlight the urgent need for integrated flood management solutions tailored to local conditions.

Mishra (2014) examined stormwater management in Tokyo, demonstrating how the city adopted infiltration, storage, and diversion systems to address groundwater depletion and increased flooding. His study emphasized that numerical simulation, geospatial tools, and integrated stormwater policies are essential in modern flood management. Saraswat et al. (2016) provided a comparative perspective by studying Bangkok, Hanoi, and Tokyo, showing that while Tokyo relies on large-scale gray infrastructure, other cities use hybrid systems that combine ponds, wetlands, and engineered drains. Their findings suggest that community acceptance and governance are just as important as engineering interventions.

McCaslin (2018) highlighted the pressures of climate change on stormwater infrastructure. Rising sea levels and extreme rainfall events are overwhelming outdated systems, particularly in older cities. While green infrastructure helps reduce surface runoff, McCaslin argued that gray infrastructure such as tunnels and pumping stations remains necessary to manage extreme events. The financial costs are high, but the benefits outweigh the risks of inaction. This aligns with the philosophy behind Tokyo's Metropolitan Area Outer Underground Discharge Channel, commonly known as the G-CANS Project, which has successfully prevented severe flooding since its completion in 2006.

In the Indian context, several studies focus on Mumbai, a city that faces recurrent flooding. Ranger et al. (2011) projected that under high-emission climate scenarios, the probability and severity of flood events would increase significantly, with damages tripling by the 2080s. They stressed that adaptation measures such as drainage improvement and better insurance coverage could reduce future losses. Choudhury et al. (2010) specifically modeled the Mithi River using HEC-RAS, showing that telescopic channelization could reduce water levels and improve flood conveyance, providing quantitative evidence of the effectiveness of structural interventions.

Kadave et al. (2017) analyzed why Mumbai continues to experience floods despite repeated government initiatives. They pointed to outdated drainage capacity (limited to 25 mm/hour), encroachments, tidal surges, and weak implementation as major factors. Their findings reveal that governance failures are as critical as technical shortcomings in exacerbating vulnerability. Zope et al. (2015) studied land use changes in the Mithi catchment, demonstrating how rapid urbanization reduced infiltration and increased runoff, leading to higher flood risk. Their modeling produced floodplain maps that highlighted the interactions between rainfall, runoff, and tidal influence.

The socio-economic dimension of flooding has also been widely studied. Patankar (2019) showed that floods disproportionately affect low-income households in Mumbai, who often live along drains and rivers. These populations have limited adaptive capacity and are at greater risk of health issues and economic losses. Dhiman et al. (2020) extended this discussion to other Indian coastal cities such as Chennai and Kolkata, recommending integrated adaptation strategies that combine structural interventions with participatory governance and climate-resilient urban planning.

International literature on G-CANS offers valuable lessons for Mumbai. Bobylev (2007) described G-CANS as the world's largest underground floodwater diversion facility, with silos 65 meters deep and tunnels stretching 6.4 km. The facility can discharge 200 cubic meters of water per second, effectively preventing Tokyo from experiencing severe typhoon-related floods. While costly, its economic benefits through avoided damages are substantial. The project demonstrates that large-scale infrastructure, though resource-intensive, can offer sustainable protection for megacities under increasing climate threats.

From these studies, several critical insights emerge. First, climate change is intensifying flood risks worldwide, necessitating forward-looking adaptation strategies. Second, stormwater management requires a mix of structural and non-structural measures, with both drainage infrastructure and land use planning playing essential roles. Third, while large-scale projects like G-CANS provide strong protection, they must be adapted to local contexts in terms of geology, governance, and socio-economic conditions. Finally, inclusivity is vital: without addressing the needs of vulnerable communities, floods will continue to exacerbate inequality.

Despite extensive research, there is a gap in applying lessons from mega-projects like G-CANS to Indian contexts. Most Indian studies have focused on drainage improvement, channelization, and risk assessment, but none have systematically evaluated the feasibility of underground flood diversion systems. This gap provides the basis for exploring how G-CANS-like infrastructure could be adapted to Mumbai's conditions, offering an innovative approach to one of India's most pressing urban challenges.

3. Objectives

1) Assessment of Flood Vulnerability in Mumbai.
2) Study and Adaptation of the G-CANS Model.
3) Development of a Conceptual Working Model.
4) Proposal of a Feasible Flood Management Framework for Mumbai.

4. Methodology

The methodology adopted for this study was designed to systematically analyze the causes of flooding in Mumbai, study Tokyo's G-CANS Project, and evaluate its adaptation potential through both conceptual analysis and a working model. The approach combined data collection, hydrological assessment, comparative analysis, and physical demonstration. The methodology is summarized in the following subsections.

4.1 Data Collection and Review

The first step involved the collection of secondary data related to rainfall intensity, stormwater drainage capacity, and past flood events in Mumbai. Government reports, academic research, and field data were reviewed to understand the hydrological conditions of the city. The 26 July 2005 flood was used as a benchmark case due to its unprecedented intensity (944 mm rainfall in 24 hours). Maps of low-lying areas, the Mithi River basin, and the locations of lakes such as Vihar and Powai were studied. This provided the spatial basis for identifying the most flood-prone regions.

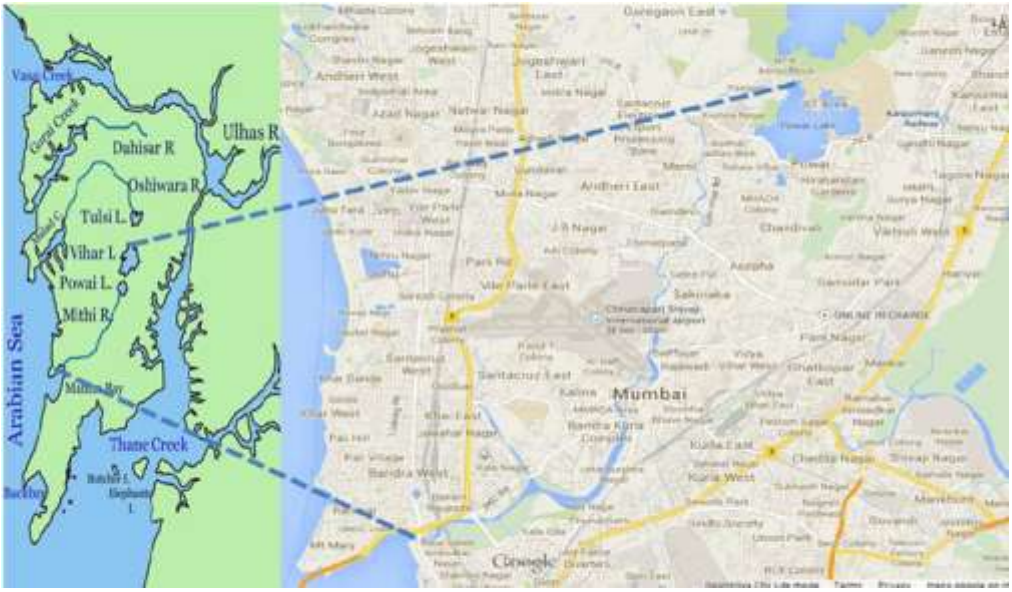

Fig. 1. Map of Mumbai highlighting critical flood zones.

4.2 Identification of Causes of Flooding

Based on the data, the major causes of flooding were categorized as:

1. **Inadequate drainage** – the system was designed for 25 mm/hr rainfall, far below actual storm intensities.
2. **Encroachment and pollution** of the Mithi River and other natural channels, reducing conveyance capacity.
3. **Tidal backflow** from the Arabian Sea, which prevents natural discharge during high tide.
4. **Unplanned urbanization** leading to increased impervious surfaces and reduced infiltration.

These insights confirmed that structural upgrades alone may not suffice, and large-scale diversion systems must be considered.

4.3 Study of the G-CANS Project

The Tokyo Metropolitan Area Outer Underground Discharge Channel (G-CANS) was studied in detail through technical reports and academic sources. The system consists of five vertical silos (65 m deep and 32 m in diameter), interconnected by 6.4 km of underground tunnels, and a massive water tank supported by 59 pillars. Excess water from rivers and drains is diverted into the silos, conveyed through tunnels, and pumped into the Edo River.

The design philosophy of G-CANS provided the basis for conceptualizing a similar system for Mumbai. The adaptability of the system was analyzed by comparing hydrological and geographical conditions between Tokyo and Mumbai.

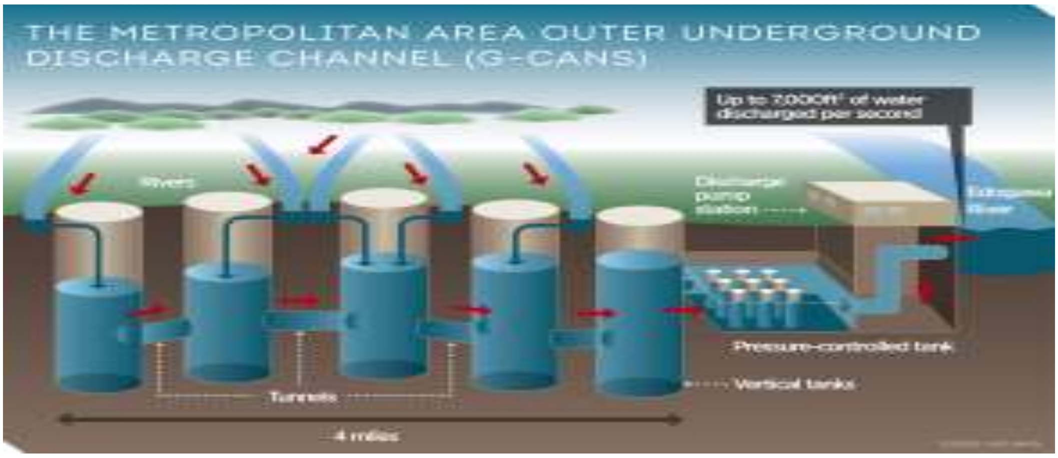

Fig. 2. Cross-sectional schematic of Tokyo's G-CANS facility.

4.4 Conceptual Adaptation for Mumbai

After studying G-CANS, a conceptual framework for Mumbai was proposed. The design involves constructing underground silos near the Mithi River and adjoining lakes to collect excess water during extreme rainfall. These silos would connect to tunnels directing the water towards pumping stations located along the coastline for safe discharge into the Arabian Sea.

Potential locations were identified based on flood-prone zones and availability of space. The design accounted for Mumbai's unique challenges, such as tidal interference and high groundwater levels.

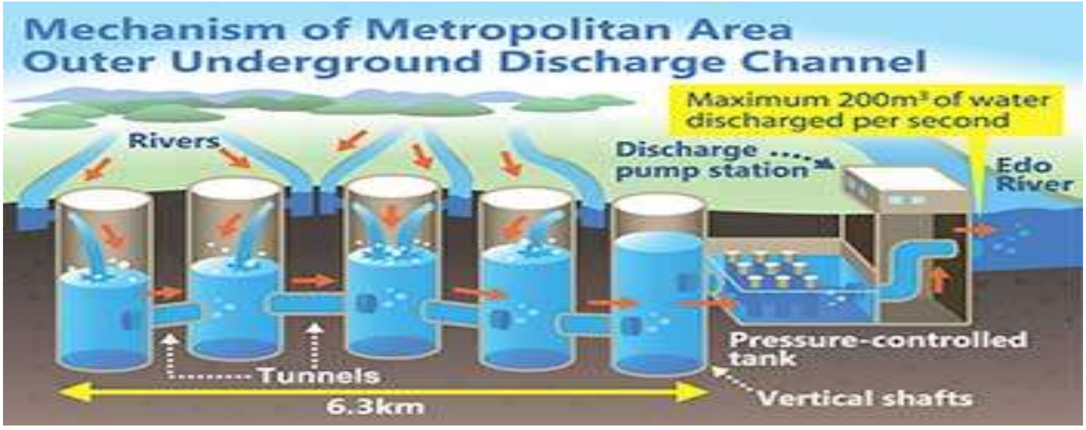

Fig. 3. Proposed adaptation of G-CANS principles for Mumbai.

4.5 Development of Working Model

To demonstrate the feasibility of this concept, a scaled working model was developed. The model included miniature representations of rainfall input, river/lake overflow, silos, underground tunnels, and pumping stations. The setup was designed to simulate excess water diversion during rainfall. The working model allowed observation of how floodwater can be redirected from surface sources into underground storage and later pumped out. It served as a proof of concept, helping visualize the hydraulic functioning of the proposed system.

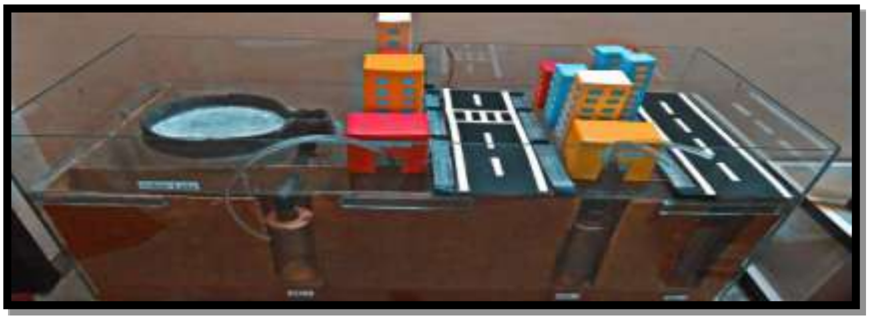

Fig. 4. Physical working model demonstrating floodwater diversion.

4.6 Simulation of Flood Scenarios

The working model was tested under simulated "normal rainfall" and "extreme rainfall" conditions. Under normal rainfall, the surface channels were sufficient for drainage. Under extreme rainfall, however, the model showed how overflow could be captured by silos and redirected to the tunnel system. This confirmed the potential effectiveness of underground diversion in reducing surface flooding.

The methodology also compared the differences between Tokyo and Mumbai conditions. For example, while Tokyo faces riverine flooding from typhoons, Mumbai experiences a combination of intense rainfall and tidal surges. The adaptation must therefore integrate pumping stations capable of discharging water even during high tides.

4.7 Evaluation and Analysis

The outcomes of the methodology were evaluated across four dimensions:

- **Hydrological Feasibility:** The model confirmed the ability to divert large volumes of excess water underground.
- **Geographical Suitability:** Mumbai's coastal geology allows for underground construction, though high groundwater levels pose challenges.
- **Economic Considerations:** While construction costs are high, avoided losses from floods may justify investment.
- **Governance and Implementation:** Coordination among multiple agencies, land acquisition, and long-term maintenance emerged as critical issues.

RESULTS AND DISCUSSION

The study revealed critical insights into the causes, impacts, and potential solutions for urban flooding in Mumbai. Analysis of rainfall and drainage data showed that the city's stormwater network, designed in the early 20th century, is grossly inadequate for current conditions. With a drainage capacity of only 25 mm/hr, the system is unable to cope with extreme rainfall events that often exceed 100 mm/hr during peak monsoon periods. The 2005 flood case demonstrated how the combination of high-intensity rainfall, tidal backflow, and encroachment of waterways can lead to catastrophic flooding, causing both infrastructural and socio-economic losses.

The conceptual adaptation of Tokyo's G-CANS model for Mumbai provided promising results. By integrating underground silos, tunnels, and pumping stations, excess stormwater from lakes, rivers, and low-lying areas could be diverted and temporarily stored, reducing the burden on surface drainage networks. The comparative study highlighted similarities between Tokyo and Mumbai in terms of urban flood risks, while also noting differences. Unlike Tokyo, which primarily manages typhoon-related riverine floods, Mumbai experiences a combination of pluvial and tidal flooding. Therefore, the adaptation requires higher-capacity pumping systems to overcome tidal backflow.

The scaled working model successfully demonstrated the feasibility of such a system. Under simulated extreme rainfall conditions, the model redirected excess water from the Mithi River and adjoining catchments into underground storage, later discharging it safely. This confirmed the potential of underground diversion channels to mitigate surface flooding. The experiment also emphasized the importance of integrating the system with existing drainage to achieve maximum efficiency.

Economic and governance aspects were also considered. While large-scale infrastructure like G-CANS involves high construction and maintenance costs, the avoided damages from recurring floods could justify the investment. The socio-economic analysis indicated that vulnerable populations, particularly those in informal settlements, would benefit significantly from reduced flood exposure. However, challenges remain in land acquisition for silo construction, coordination among multiple agencies, and financing of such a mega-project.

Overall, the results suggest that adopting a modified G-CANS-inspired system for Mumbai is both technically feasible and socially beneficial. The discussion underscores the need for a phased implementation strategy, beginning with pilot projects in the most flood-prone areas, followed by gradual scaling. Such an approach could provide Mumbai with a sustainable and long-term solution to its chronic flooding problem.

CONCLUSION

Mumbai's recurring floods highlight the urgent need for innovative and large-scale flood management strategies. The analysis of rainfall data, drainage infrastructure, and historical flood events revealed that the city's stormwater system is inadequate to handle extreme monsoon conditions, especially when compounded by tidal influences and unregulated urban development. Despite various government initiatives, flooding continues to disrupt livelihoods, damage infrastructure, and expose vulnerable populations to significant risks.

The study of Tokyo's Metropolitan Area Outer Underground Discharge Channel (G-CANS) provided valuable insights into how large-scale engineering solutions can effectively mitigate urban flooding. The project's design, involving underground silos, tunnels, and pumping stations, demonstrated how excess stormwater can be diverted and safely discharged. When conceptually adapted for Mumbai, the model indicated strong potential for reducing flood severity by diverting excess water from lakes, rivers, and low-lying areas into underground storage.

The working model prepared as part of this research successfully demonstrated the feasibility of this approach. Under simulated extreme rainfall conditions, the model redirected overflow, proving that such a system could reduce waterlogging and improve drainage performance in flood-prone zones. Although challenges such as high construction costs, land acquisition, and governance coordination exist, the long-term benefits—such as reduced damages, improved urban resilience, and protection of vulnerable communities—outweigh these difficulties.

In conclusion, adopting a modified G-CANS-inspired system for Mumbai represents a promising and sustainable solution to the city's flooding problem. While technical feasibility has been demonstrated, the next steps must include detailed feasibility studies, cost–benefit analysis, and phased pilot implementations. Integrating such mega-infrastructure with ongoing improvements in drainage and urban planning could transform Mumbai's flood management, making the city more resilient to climate change and safeguarding its future as India's financial hub.

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