

Sustainable Urban Drainage Systems: A Case Study of Bonomala Road to Fashion Road, Tongi College Gate

Submitted By

Aminul Islam

ID: 201-47-294

MD. Mizanur Rahman

ID: 201-47-357

Department of Civil Engineering

Daffodil International University

This Report is presented in Partial Fulfilment of the Requirements for the
Degree of **Bachelor of Science in Civil Engineering**

Under the supervision of

Md. Habibullah Hadiuzzaman

Lecturer

Department of Civil Engineering

Daffodil International University



**Department of Civil Engineering
DAFFODIL INTERNATIONAL UNIVERSITY
DHAKA, BANGLADESH**

The report titled "**Sustainable Urban Suitable Drainage Systems: Case Study of Bonomala Road to Fashion Road, Tongi College Gate**" was submitted by Aminul Islam, ID: 201-47-294, MD. Mizanur Rahman, ID: 201-47-357, has been accepted as satisfactory. This work partially fulfils the requirements for the degree of Bachelor of Science in Civil Engineering.

BOARD OF EXAMINERS



(Supervisor)
Md. Habibullah Hadiuzzaman
Lecturer, Department of Civil Engineering
Daffodil International University
Daffodil Smart City, Ashulia, Dhaka



(Chairman)
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Associate Professor and Head, Department of Civil Engineering
Daffodil International University
Daffodil Smart City, Ashulia, Dhaka



(Member-01)
Md Masud Alom
Assistant Professor, Department of Civil Engineering
Daffodil International University
Daffodil Smart City, Ashulia, Dhaka



(Member-02)
Kazi Obaidur Rahman
Assistant Professor, Department of Civil Engineering
Daffodil International University
Daffodil Smart City, Ashulia, Dhaka

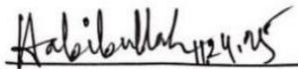


(External Member)
Engr. Mohammad Shafiul Alam Deputy Chief Engineer (Structure)
CONCORD Real Estate & Development Limited

APPROVAL

This is to certify that the dissertation titled "**Sustainable Urban Suitable Drainage Systems: Case Study of Bonomala Road to Fashion Road, Tongi College Gate**" submitted by Aminul Islam, ID: 201-47-294, MD. Mizanur Rahman, ID: 201-47-357, to the Department of Civil Engineering, Daffodil International University, under my supervision. It has been acknowledged as satisfactory for its style and substance and accepted as being sufficient for the accomplishment of the requirements for the Degree of Bachelor of Science in Civil Engineering.

Supervisor:



Md. Habibullah Hadiuzzaman

Lecturer

Department of Civil Engineering,
Daffodil International University

DECLARATION

We certify that we are under the competent supervision of **Md. Habibullah Hadiuzzaman** conducted the undergraduate research work documented in this thesis. We have ensured the originality of the work by taking the necessary procedures. We can confirm that no plagiarism has been used in the work. Additionally, we can confirm that the study hasn't been published anywhere.

Aminul

Aminul Islam

ID: 201-47-294

Department of Civil Engineering,
Daffodil International University

Mizanur

MD. Mizanur Rahman

ID: 201-47-357

Department of Civil Engineering,
Daffodil International University

ABSTRACT

Rapid urbanization in Tongi, particularly along the Bonomala Road to Fashion Road area, has resulted in severe drainage and waterlogging problems. The existing drainage system is narrow, poorly maintained, and frequently blocked by solid waste and polythene, resulting in traffic disruptions, economic losses, and public health risks during heavy rainfall.

This study focuses on designing a sustainable urban advanced drainage system (SUDS) by integrating hydrological analysis, rainfall data (2015–2025), GIS mapping, and AutoCAD-based drain design. The estimated peak runoff of 7.3 m³/s was determined using standard hydrological methods. A rectangular drain of 1.5 m × 1.5 m was designed with a discharge capacity of 7.8 m³/s to ensure effective stormwater management. Additionally, sustainable drainage measures such as permeable pavements, bio-swales, detention ponds, and rainwater harvesting were proposed to reduce surface runoff and enhance groundwater recharge.

The findings suggest that adopting a combined approach of improved drainage infrastructure and SUDS practices can effectively reduce waterlogging, improve urban resilience, and serve as a replicable model for other flood-prone urban areas in Bangladesh.

Keywords: Waterlogging, Urban Drainage, SUDS, Hydrological Analysis, Tongi, GIS

ACKNOWLEDGEMENT

First, we would like to express our sincere gratitude to Almighty God for providing the necessary heavenly blessings that enabled us to successfully complete the thesis.

We would like to sincerely thank my supervisor, **Md. Habibullah Hadiuzzaman**, a Lecturer in the Daffodil International University Department of Civil Engineering, for his kind supervision, wise counsel, and unceasing encouragement. His editorial and technical guidance was crucial to the successful completion of this scholarly project. We could never have finished the paper without his help and direction.

We also thank the department head, academic advisers, and teachers for their guidance and assistance, which were crucial in our development of knowledge and effective working time.

We would like to thank all our classmates at Daffodil International University for their thoughtful advice and friendly support.

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CHAPTER 1

INTRODUCTION

1.1 General

Bangladesh's rapid urbanization, especially in industrial centers like Tongi, has made managing urban drainage extremely challenging (Hossain, 2018). Due to heavy rainfall, poor drainage, and unplanned urban growth, the area between Bonomala Road and Fashion Road, near Tongi College Gate, is extremely susceptible to localized flooding and regular waterlogging during the monsoon season. These problems endanger public health and environmental sustainability in addition to interfering with economic activity and transportation. In Bangladesh, traditional drainage systems are often constructed solely to remove water immediately, with little regard for ecological impacts, long-term sustainability, or climate resilience (Ahmed & Rahman,2020). The shortcomings of traditional drainage are becoming more noticeable as climate change makes rainfall patterns more unpredictable (World Bank, 2019). In this regard, Sustainable Urban Drainage Systems (SUDS) offer a novel approach by combining natural processes with constructed structures to efficiently manage stormwater, reduce runoff, improve water quality, and replenish groundwater (Angelidou, 2015; World Bank,2019).

To address current drainage failures and prevent future flooding risks, this study focuses on developing a sustainable, advanced drainage design for the case area. By combining hydrological analysis, hydraulic design, and sustainable urban practices, this research aims to show how modern drainage planning can enhance urban resilience. The study's findings will not only aid in resolving drainage issues at the chosen site but will also serve as a model for other rapidly urbanizing regions in Bangladesh.

1.2 Background Study

Rapid urbanization has led to a growth in population, residential development, and industrial activity at Tongi College Gate, Tongi, Gazipur. The current drainage system is under stress due to this expansion, which frequently results in waterlogging and localised flooding during the monsoon season. Open channels and antiquated pipelines comprise the majority of the drainage infrastructure; these are frequently clogged by solid waste and plastic bags. Therefore, even light rains can cause traffic jams, property damage, and health hazards (Ahmed & Rahman,2020).

The Bangladesh Meteorological Department's rainfall data from 2015 to 2025 demonstrates the current system's vulnerability by showing an increase in the frequency and severity of heavy rains (BMD, 2015-2025). Ineffective waste management exacerbates drainage issues and raises the possibility of standing water and waterborne illnesses. Effective drainage layouts and the identification of flood-prone zones are made possible by GIS mapping and AutoCAD drawings (World Bank 2019). When paired with predictive maintenance and monitoring, sustainable urban drainage systems (SUDS) can enhance resilience, mitigate floods, and foster a cleaner, safer urban environment.

1.3 Objectives and Scope

The following are the study's main goals:

1. To examine the study area's stormwater runoff and rainfall trends using historical rainfall data (2015–2025) (Bangladesh Meteorological Department, 2015-2025).
2. To assess the current drainage system and pinpoint the reasons behind recurrent flooding and drainage failure.
3. To evaluate the existing drainage system and identify the causes of frequent flooding and drainage malfunctions.
4. To make useful suggestions for the drainage system's long-term upkeep, operation, and incorporation into upcoming urban growth plans (World Bank, 2019)

CHAPTER 2

LITERATURE REVIEW

2.1 General

Urban drainage systems are crucial components of urban infrastructure, enabling the efficient collection, transportation, and disposal of rainwater to prevent flooding, safeguard public health, and promote economic activity (World Bank, 2019). Conventional drainage methods primarily rely on subterranean pipelines and open channels, which often fail under increased rainfall intensities, urban expansion, and climate change. Cities around are adopting Sustainable Urban Drainage Systems (SUDS) or Low Impact Development (LID) policies, which combine built and nature-based methods to control stormwater from its origin. This chapter examines the international and regional literature about urban drainage issues, sustainable drainage principles, innovative technology, and insights relevant to the Tongi College Gate area.

2.2 Challenges of Urban Drainage in Developing Cities

Urban regions in developing nations have several drainage-related challenges stemming from increasing urbanisation, inadequate governance, and insufficient infrastructure investment. These difficulties not only impede daily urban living but also jeopardise long-term sustainability and resilience.

Unregulated urban expansion: In numerous developing cities, urban growth transpires without regulation, frequently disregarding master plans or zoning laws. Consequently, natural drainage systems, wetlands, and floodplains are invaded by residential and commercial constructions. The degradation of these ecological buffers diminishes the city's inherent ability to manage and absorb stormwater, rendering urban areas more susceptible to waterlogging and flash flooding (Ahmed & Rahman, 2020)

Escalating impervious surfaces: Due to heightened demands for housing, transportation, and commerce, urban areas are experiencing a significant proliferation of impermeable cover, including asphalt roads, concrete structures, and parking facilities. This expansion reduces natural soil infiltration, leading to increased surface runoff coefficients. As a result, rainfall events that were formerly controllable by natural and artificial systems now lead to extensive flooding, as surplus water cannot infiltrate the soil (Rahman & Alam, 2019)

Insufficient drainage capacity: A prevalent feature of drainage systems in expanding urban areas is their failure to accommodate the magnitude and intensity of contemporary precipitation events. Numerous systems were developed decades ago, utilising obsolete hydrological data that failed to consider the escalating impacts of climate change. Currently, intense short-duration rainfall events sometimes exceed the capacity of existing drainage systems, resulting in overflow into roadways and public areas. The lack of consistent improvements and retrofitting exacerbates the issue.

Challenges in trash disposal and solid waste management: Without efficient solid waste management systems, urban inhabitants frequently utilise drainage channels as unofficial dumping sites. This approach results in significant obstructions, which diminish the hydraulic efficiency of drains and generate areas of stagnant water. Such circumstances foster the proliferation of mosquitoes and other vectors, hence elevating the prevalence of illnesses such as dengue and cholera. Furthermore, the accumulation of plastic waste intensifies obstruction, especially in narrow open channels (World Bank, 2019)

Institutional fragmentation and governance challenges: The management of urban drainage in developing nations is sometimes obstructed by the redundant roles of many organisations, including municipal authorities, water supply boards, housing development corporations, and environmental departments. This fragmentation leads to diminished accountability, maintenance delays, and inadequately coordinated responses to flooding incidents. Moreover, budgetary limitations, a lack of technical proficiency, and insufficient policy enforcement hinder institutions from executing sustainable drainage solutions.

Research undertaken in places like Dhaka, Kolkata, Manila, and Lagos reveals very analogous patterns of susceptibility. The interplay of unanticipated expansion, inadequate drainage systems, and ineffective waste management has resulted in persistent urban waterlogging. These occurrences produce cascading effects, including traffic congestion, disruption of economic activity, infrastructural damage, and increased public health hazards. In Dhaka, waterlogging occurrences are projected to incur yearly costs in the millions of dollars due to lost output and damages (Hoque & Rahman, 2020). Significance to the Tongi College Gate Region (Bonomala Road to Fashion Road): The issues are most pronounced in the Tongi College Gate neighbourhood, a rapidly urbanizing sector within the Dhaka metropolitan region. The area has experienced rapid economic growth, the proliferation of informal settlements, and increased vehicular traffic, all of which have exacerbated the strain on the existing drainage system. Paved surfaces prevail in the environment, but small and inadequately maintained roadside drains often become obstructed by domestic and commercial

refuse. Monsoon rains result in rapid water accumulation, causing significant traffic disruptions and prolonged waterlogging that impact local businesses, commuters, and residents. The lack of a unified drainage management framework among Gazipur City Corporation, RAJUK, and WASA exacerbates the challenges of prompt responses. The Tongi College Gate corridor exemplifies the urban drainage issues encountered by expanding cities, underscoring the critical necessity for sustainable and integrated drainage solutions (Hossain, 2018; World Bank, 2019)

2.3 Concept of Sustainable Urban Drainage Systems (SUDS)

Sustainable Urban Drainage Systems (SUDS) signify a transformative change from traditional "rapid disposal" strategies, which emphasise the swift removal of rainwater, to techniques that emulate natural hydrological processes. Sustainable Urban Drainage Systems (SUDS) perceive stormwater not as a nuisance, but as a valuable resource that needs to be managed, filtered, stored, and utilized to realize many social, environmental, and economic benefits. This notion corresponds with the overarching framework of sustainable urban development, highlighting resilience, flexibility, and ecological integration.

Fundamental Principles of Sustainable Urban Drainage Systems (SUDS):

- **Manage runoff at the source:** The primary objective is to reduce stormwater volume and velocity before it enters drainage systems. This is accomplished through permeable pavements, green roofs, rain gardens, detention ponds, and infiltration basins, which facilitate water percolation into the earth, thereby diminishing peak flows and alleviating downstream flooding.
- **Enhance water quality:** Sustainable Urban Drainage Systems (SUDS) integrate natural filtration mechanisms via soils, flora, and biochemical interactions. Elements such as vegetated swales, wetlands, and filter strips capture sediments, nutrients, and heavy metals, thereby facilitating the entry of cleaner water into rivers or groundwater reserves. This mitigates a significant deficiency of traditional drainage systems, which frequently release untreated, contaminated stormwater directly into natural water bodies.

- **Augment amenity and biodiversity:** In addition to their hydrological functions, Sustainable Urban Drainage Systems (SUDS) are engineered to harmonise with urban environments, offering green-blue infrastructure that cultivates recreational areas, elevates aesthetic appeal, and promotes biodiversity. For example, urban wetlands and retention ponds can function as habitats for avian and aquatic species, while simultaneously providing residents with shaded parks and open spaces.(World Bank, 2019)

- **Enhance resistance to climate change:** Given the rising occurrence of severe rainfall events, urban drainage systems must be both adaptive and strong. Sustainable Urban Drainage Systems (SUDS) offer adaptable solutions by integrating storage, infiltration, and conveyance methods that can accommodate different rainfall intensities. They also mitigate the urban heat island phenomenon by increasing vegetative cover, thereby bolstering urban resilience.

2.4 Categories of Sustainable Drainage Techniques

Sustainable drainage methods encompass a range of structural and non-structural strategies designed to manage stormwater volume, improve water quality, and enhance urban aesthetics. Each component varies in its contribution based on urban morphology, climatic conditions, and socio-economic environment. A combination of methodologies, sometimes referred to as a "treatment train," is generally most effective in addressing the numerous issues associated with urban drainage.

2.4.1 Permeable Pavements

Permeable pavements are designed surfaces that facilitate the infiltration of rainfall into the subsoil or subsurface storage layers, rather than allowing it to flow directly into surface drains. They comprise porous asphalt, pervious concrete, or interlocking concrete blocks, including permeable joints. These systems significantly reduce peak runoff, enhance groundwater recharge, and purify contaminants such as oil residues and suspended particles. These pavements are especially efficient in parking zones, home driveways, low-traffic thoroughfares, and pedestrian pathways. Permeable pavements are extensively utilised in places like Singapore and Portland (USA) to provide decentralised stormwater management. In Bangladesh, the prospective implementation focuses on minor roads, school premises, and local marketplaces, where it may mitigate localised flooding following heavy rainfall. (Hossain, 2018; Ahmed & Rahman, 2020)

2.4.3 Systems for Harvesting Rainwater

Rooftop runoff is collected and stored through rainwater harvesting for non-potable applications, such as cleaning, irrigation, and toilet flushing. This provides urban families with an additional source of water while reducing the amount of stormwater that enters the sewers. Rooftop collection, gutters, filters, storage tanks, and distribution pipelines are the usual components of systems. In Singapore, Tokyo, and Chennai,

India, rainwater harvesting has become increasingly popular and is often mandated by building regulations. Although it is still not widely used in Bangladesh, it is gaining.

2.5. Advanced Technologies for Drainage

Urban stormwater monitoring, design, and management have evolved in response to advancements in digital technology, modelling, and GIS tools. Traditional drainage relies on static, hard-engineered infrastructure. These developments enable predictive planning, adaptive reactions, and real-time decision-making, all of which are essential in densely populated, climate-vulnerable cities.

2.5.1 Smart Drainage Systems

To improve operating efficiency, smart drainage systems use sensors, automatic gates, Internet of Things (IoT) devices, and real-time data analytics. Data on flow rates, obstructions, and rainfall intensity are continuously transmitted via water-level sensors placed in drains and canals. Remote control of automated sluice gates can maximise outflow, prevent backflow, and reduce the likelihood of flash floods. For instance, Tokyo has installed subterranean flood control facilities connected to automated monitoring systems that react instantly to variations in rainfall, while Singapore's "Smart Water Grid" employs a network of Internet of Things-enabled devices to monitor drainage and maximise stormwater retention in reservoirs. By reducing the time between hazard identification and intervention, these solutions significantly enhance urban resilience.

The use of these intelligent drainage systems is still relatively new in Bangladesh. However, the installation of inexpensive sensors and community-based early warning systems could offer people and local government organisations useful real-time insights in places like Tongi College Gate, where waterlogging significantly disrupts the economy.(Ahmed & Rahman,2019)

2.5.2 Applications of GIS and Remote Sensing

Urban stormwater behavior can be mapped, analyzed, and predicted with the aid of remote sensing technology and Geographic Information Systems (GIS). These methods can detect flood-prone areas, drainage hotspots, and impervious surfaces by combining high-resolution satellite images with urban land-use data. Spatial analysis and runoff

mapping are two common applications for GIS-based models. For instance, Dhaka is increasingly using remote sensing to track wetland encroachment and urban expansion that worsen waterlogging, while Manila and Lagos have used GIS to prioritise sites for drainage upgrades.

GIS applications can help in high-density regions such as Bonomala Road to Fashion Road (Tongi) in the following ways:

- Identifying roadside drains that are obstructed or too small.
- Determining the most important runoff routes during periods of intense precipitation.
- Estimating the possible effects of suggested SUDS therapies.

By increasing the visibility and actionability of flood-risk zones in urban planning, the combination of GIS and participatory mapping can also empower local populations.

2.6 Sustainable Drainage System (SUDS) Experiences Around the World

An example of turning urban stormwater into a resource rather than an issue is Singapore's Active, Beautiful, Clean (ABC) Waters Program. Singapore has developed multipurpose areas, including wetlands, linear parks, and rain gardens, that lower flood risks while improving urban liveability by integrating stormwater management with recreational and aesthetic landscapes. To ensure that locals understand and support sustainable water practices, the program places a strong emphasis on community involvement and education. A significant endeavour to adapt metropolitan areas for better water absorption, retention, and reuse is China's Sponge City Initiative. To absorb rainwater at its source, the program encourages the use of vegetated swales, detention ponds, green roofs, and permeable pavements. The ambitious goal of 70% urban stormwater retention or reuse highlights how major cities can mitigate their risk of flooding, enhance groundwater recharge, and improve water quality.

Sustainable drainage is now required for new construction in the UK due to the implementation of National Standards for Sustainable Drainage Systems (SuDS). Infiltration basins, bio-retention zones, and artificial wetlands are examples of SuDS commonly found in the UK. These features are designed to promote biodiversity and recreational use, while also managing runoff. The standards provide a legal framework that ensures consistency in performance, design, and maintenance. Cities like Portland

and Seattle in the US have been at the forefront of implementing infiltration basins, bioswales, and green roadways. (World Bank, 2019)

2.7 The Situation of Urban Drainage in Bangladesh

2.7.1 National Challenges

Bangladesh experiences regular and heavy rains due to its tropical monsoon climate, which causes large cities to experience ongoing urban floods. Due to their high population density, impermeable surfaces, and rapid urbanisation, which significantly increase runoff volumes, Dhaka, Chattogram, and Gazipur are particularly vulnerable. The conveyance capacity of important drainage channels, such as the Dhaka-Narayanganj-Demra (DND) canal, Begunbari Khal, and other riverfront khals, is diminished by significant encroachment, siltation, and uncontrolled dumping of solid waste.

Drainage inefficiency is further aggravated by institutional fragmentation. The integrated planning, maintenance, and enforcement of drainage regulations are hindered by coordination gaps among RAJUK, WASA, Dhaka North City Corporation (DNCC), and Dhaka South City Corporation (DSCC). Public health risks and frequent waterlogging are also exacerbated by inadequate investment in modernising ageing infrastructure, inadequate land use planning, and informal settlements.

2.7.2 Current Research

Numerous studies have measured the difficulties and suggested initial solutions. According to Rahman & Alam (2019), during periods of high rainfall, more than 80% of Dhaka's drainage system is overloaded, resulting in flooding in both residential and commercial areas. According to Ahmed (2021), peri-urban areas such as Tongi and Savar have uncontrolled road elevation and pavement construction that obstruct natural drainage channels, thereby increasing the risk of flooding.

Rainwater harvesting, infiltration basins, and pocket green infrastructure are some of the pilot projects in Dhaka that have shown promise in reducing urban flooding. However, the scalability of these solutions has been constrained by a lack of institutional integration, public awareness, and technical capability. Additionally, the majority of pilot initiatives stay localised and lack thorough performance or community engagement monitoring (world Bank, 2019)

2.7.3 Tongi-Specific Background

Tongi is a vital residential and industrial centre located just north of Dhaka. Due to the limited green spaces, impermeable road networks, and dense buildings, it experiences high runoff. Corridors like Bonomala Road and Fashion Road in Tongi are particularly vulnerable areas due to their variable road elevations, unlawful encroachments, and narrow drains, which result in frequent and prolonged flooding during the monsoon season.

Socioeconomic vulnerability is particularly evident in the Tongi area, where frequent waterlogging has a negative impact on the economy and health, affecting small businesses, informal settlements, and commercial activities that rely on transportation. Due to these variables, Tongi is an ideal location to trial Sustainable Urban Advanced Drainage Systems (SUADS), as interventions here may yield quantifiable improvements in water quality, flood mitigation, and socio-environmental resilience.

2.7.4 New Possibilities

Potential avenues for sustainable drainage in Bangladesh are indicated by recent developments:

- GIS and remote sensing integration for mapping drainage bottlenecks and impervious surfaces.
- Schemes for community-based flood monitoring that involve locals in maintenance and early warning.
- Retrofitting green infrastructure, such as permeable pavements, vegetated swales, and rain gardens, to lessen peak runoff.
- City corporations and RAJUK have aligned their policies to enforce setback zones around canals and khals.

All of these options suggest that focused, context-sensitive SUADS initiatives in Tongi could strike a balance between technological viability and socioeconomic realities, serving as a replicable model for other flood-prone urban corridors in Bangladesh. (World Bank,2019)

- **Increased Surface Runoff:** Water cannot seep into the earth through impermeable surfaces. As a result, surface runoff increases significantly in both volume and speed. In contrast to natural settings, where only 10% of rainfall turns into runoff, studies reveal that in heavily urbanised areas, more than 50% of all rainfall can become surface runoff. Conventional drainage systems are overwhelmed by this water rush.
- **Decreased Groundwater Recharge:** The quantity of water refilling subterranean aquifers is greatly decreased as a result of the absence of infiltration. The water table may fall as a result, endangering natural ecosystems and the groundwater supplies of wells.
- **Increasing Flood Risk:** Urban areas are more vulnerable to frequent and severe flooding due to the combination of increasing runoff and the limits of traditional drainage infrastructure.
- **Declining Water Quality:** Stormwater gathers contaminants, including oil, grease, heavy metals, and solid waste, as it passes over impermeable surfaces. After that, the polluted runoff is discharged directly into rivers, canals, and other bodies of water, damaging and contaminating aquatic habitats. (Audu & Umana, 2024).

STUDY AREA DESCRIPTION

3.1 Location of the Study Area

The chosen study area is located in the Tongi section of Gazipur District, Bangladesh, and spans from Bonomala Road to Fashion Road, near Tongi College Gate. The population and land use of this heavily urbanised residential and commercial region are growing quickly. For everyday commuters, industrial workers, and business operations, it is an essential point of communication (Hossain, 2018).

3.2 Geographic and Climatic Characteristics

- **Geography:** Due to its low elevation and lack of slope, the region is extremely susceptible to waterlogging during periods of intense precipitation.
- **environment:** From June to September, Tongi has heavy rainfall due to its tropical monsoon environment. Rainfall averages between 2,000 and 2,500 mm per year, with the monsoon months seeing the highest amounts (BMD 2015-2025).
- **Soil Type:** Clayey soil predominates, which exacerbates surface runoff issues due to its low infiltration capability.

3.3 Land Use Pattern

The study region includes the following:

- **Residential settlements:** densely populated, with a large number of permanent and semi-permanent structures.
- **Industrial facilities:** These include factories and storage facilities that produce extra stormwater runoff.
- **Road networks:** Due to the high volume of traffic on Bonomala Road and Fashion Road, waterlogging significantly disrupts both transit and business operations.
- **Open spaces:** This has drastically decreased as a result of uncontrolled urbanisation, leaving almost no natural drainage channels (Ahmed & Rahman, 2020).

3.4 Existing Drainage System

- The majority of the drainage system in place today is made up of small concrete roadside drains.
- The effective capacity of several sections is diminished by the accumulation of sediment and solid debris.
- Stormwater stagnates as a result of improper drain connections to outfalls.
- Field observations revealed that localised flooding occurs even with moderate rainfall, with water depths reaching 20-40 cm in a number of areas.

3.5 Drainage Problems Identified

- A drain that is too small to manage high runoff.
- Regular obstructions brought on by solid trash and inadequate maintenance.
- Inadequate drainage slope and interconnectivity.
- The lack of sustainable elements like bio-swales, detention basins, or infiltration zones. Combining civil engineering, renewable energy, and innovative materials necessitates a comprehensive approach that incorporates technological innovation and financial planning.

3.6 GIS Mapping of the Study Area

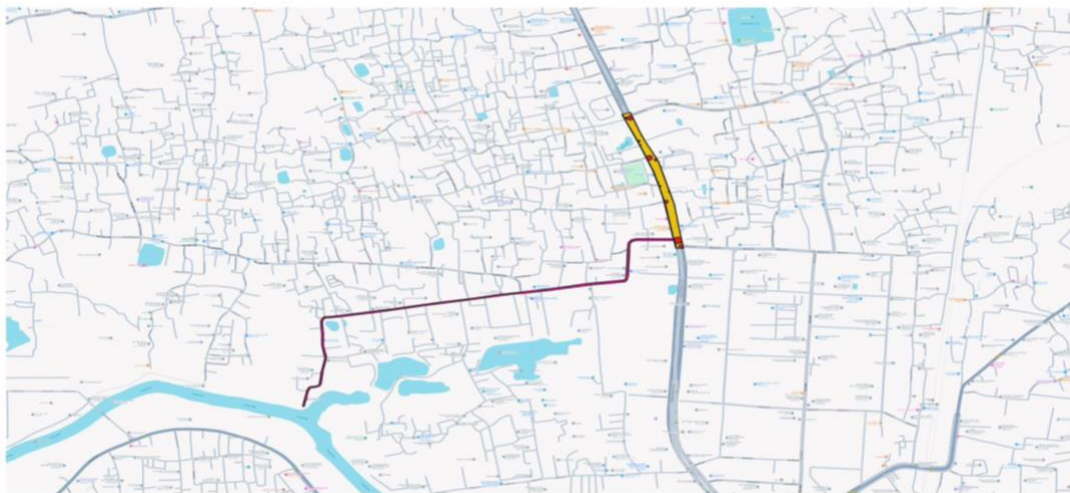


Figure 3.1: GIS Mapping of Drainage System from Bonmala Road to Fusion Road, Tongi, Discharging Waste into the River



Figure 3.2: GIS-based Mapping of Drainage and Waterlogging Hotspots



Figure 3.3: Zooming view of Bonomala road point 1, Fisons road point 2

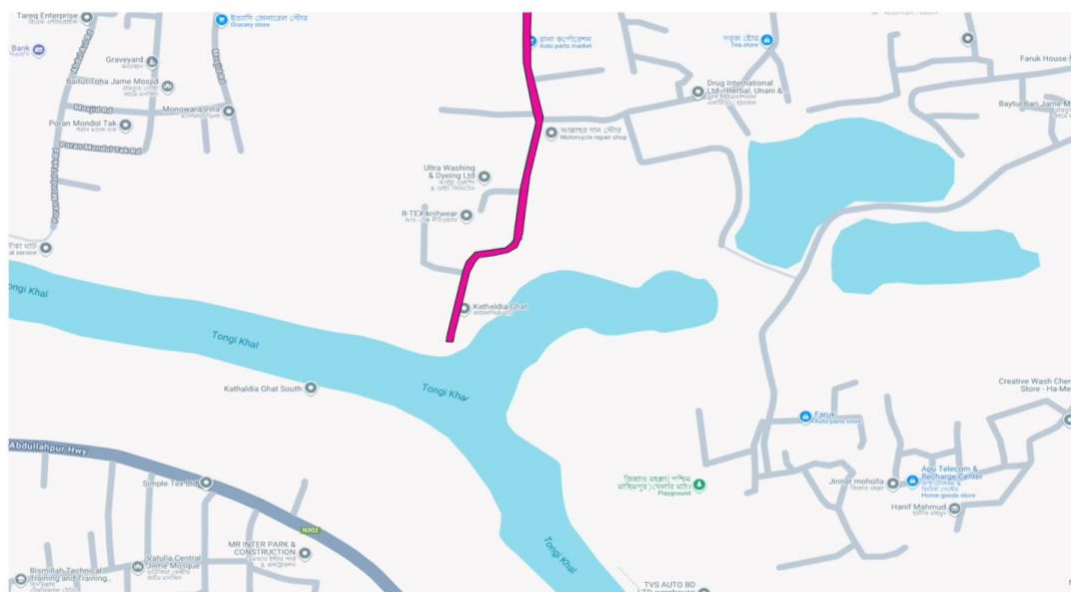


Figure 3.4: Water throwing to Tongi Khal

Table 3.1: Approximate Coordinates of Identified Red Areas (GIS Mapping Results)

Red Area Id	Latitude(°N)	Longitude(°E)	Remarks
1	23.8992	90.4085	Waterlogging Hotspot
2	23.8987	90.4092	Near Road intersection
3	23.8983	90.4097	Adjacent to the roadside
4	23.8979	90.4103	Low-lying point
5	23.8975	90.4108	Solid waste accumulation

3.7 Significance of the Study

The study region, which spans from Bonomala Road to Fashion Road, including Tongi College Gate, was chosen because it is representative of a typical urbanized area that experiences flooding and severe waterlogging during the monsoon season. Inadequate drainage infrastructure, unplanned construction, high population density, and low-lying terrain all contribute to stormwater.

DATA COLLECTION

4.1 Introduction

Designing a sustainable urban drainage system requires accurate and trustworthy data. The types of data gathered for the research area, from Bonomala Road to Fashion Road, including Tongi College Gate, are presented in this chapter. These data include field survey observations, rainfall records, GIS mapping, and the features of the current drainage system. In the following design stage, these data serve as the foundation for hydraulic and hydrological analysis (World Bank, 2019).

4.2 Rainfall Data

- Source: local rainfall records and the Bangladesh Meteorological Department (BMD).
- Timeframe: 2015–2025 (10 years).
- Goal: To compute stormwater runoff and peak rainfall intensity.

Table 4.1: Rainfall Data of Tongi Area (2015-2025)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Total(mm)
2015	20	15	30	150	250	300	400	350	200	80	20	10	1825
2016	25	20	35	140	240	290	390	340	210	90	25	15	1910
2017	30	25	40	160	260	310	420	360	220	100	30	20	1975
2018	25	20	35	150	250	300	400	350	210	90	25	15	1920
2019	40	35	50	170	280	320	450	380	230	110	35	25	2135
2020	30	25	40	160	270	310	430	370	220	100	30	20	2015
2021	35	30	45	180	290	330	460	390	240	120	35	25	2160
2022	30	25	40	170	280	320	440	380	230	110	30	20	2035
2023	40	35	50	180	300	340	470	400	250	120	40	30	2255
2024	35	30	45	170	290	330	450	390	240	110	35	25	2100
2025	40	35	50	190	310	350	480	410	260	130	40	30	2335

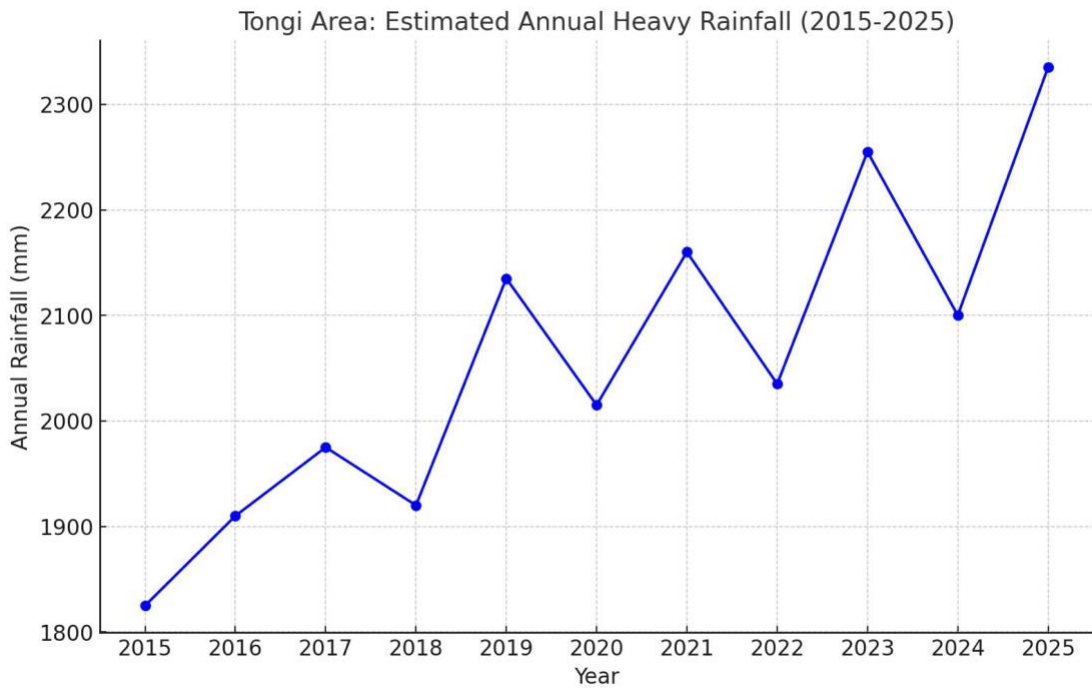


Figure 4.1: Estimated Annual Heavy Rainfall (2015-2025)

4.3 Survey

A community-based questionnaire survey was conducted among 30 respondents in the area from Bonomala Road to Fashion Road in Tongi to identify the major perceived causes of waterlogging. The responses have been summarised in Table 5.2 and Figure 5.4.

Table 5.2: Survey Response on causes of waterlogging in the Study Area

Cause of waterlogging	Number of Respondents	Percentage (%)
Insufficient Drain size	7	25%
Solid waste/Polythene	14	45%
Poor maintenance	6	20%
Encroachment	3	10%

Survey Response on Causes of Waterlogging in Study Area

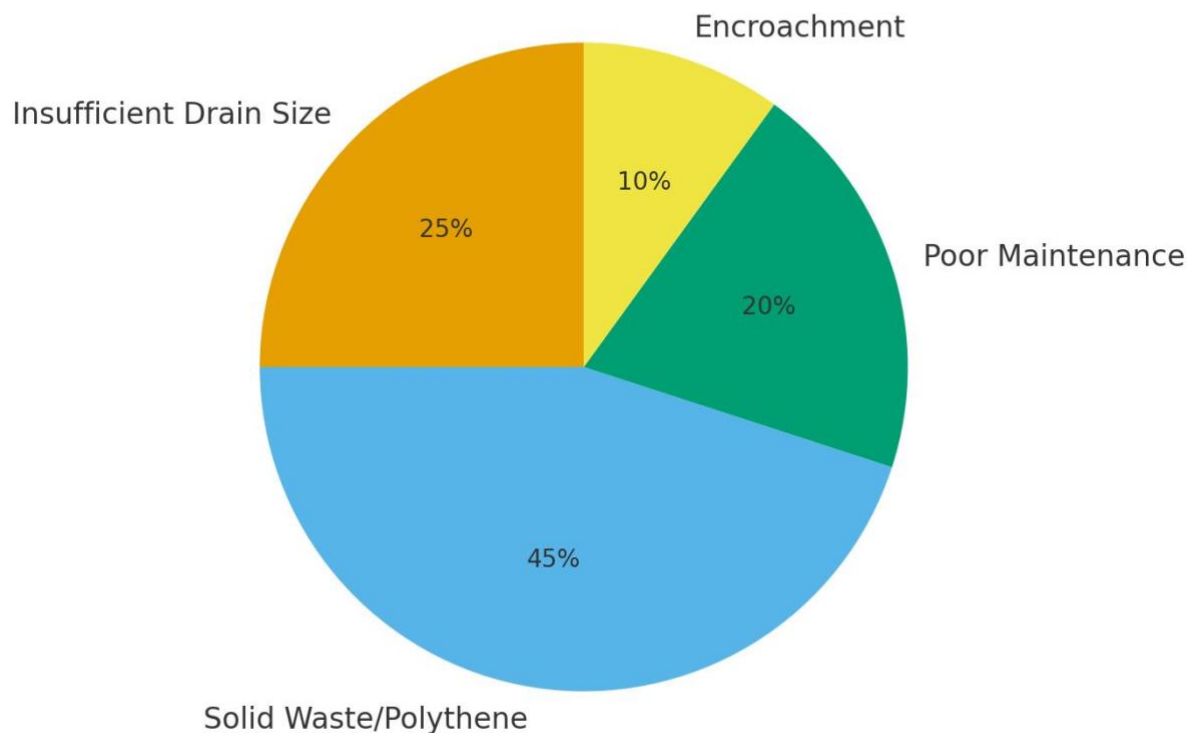


Figure 5.5 Survey Response on Causes of Waterlogging in the Study Area

According to the poll, solid debris and polythene buildup inside drains were cited by the majority of participants (45%) as the main causes of waterlogging. Insufficient drain size was mentioned by almost 25% of participants, indicating that the current drainage system needs to be made more capacious. Meanwhile, 20% brought up inadequate cleaning and maintenance procedures, underscoring the irregularities in regular local government activities. Ten per cent of respondents stated that illegal buildings and encroachment on drainage channels were the primary cause of the issue.

These results align with the technical analysis and field observations. The study area's GIS mapping also revealed that several drainage lines are either too small or obstructed by waste. To prevent solid waste from entering the drainage system, the suggested design includes garbage screens at strategic inlets and increased hydraulic capacity. It has also been proposed that IoT-based monitoring devices be introduced to enhance maintenance efficiency and facilitate prompt identification of blockages. Field survey results and GIS mapping reveal that solid waste accumulation and

insufficient drain capacity are primary drivers of recurring waterlogging in the study area. To address these issues, the hydraulic design proceeds in two stages: (1) a roadside drain to carry the portion of runoff that the channel can safely accommodate, and (2) a manhole/outlet-pipe system to convey the remaining flow. The next section presents the drain capacity checks followed by the detailed manhole design and hydraulic verification.



Fig: 5.8: Public Opinion Survey Form on Waterlogging and Drainage Problems

CHAPTER 3

METHODOLOGY

5.1 Introduction

This chapter covers the approach used to create a sustainable advanced drainage system for the research area. Hydrological analysis, hydraulic design, GIS-based evaluation, and sustainable urban drainage strategies (SUDS) are all part of the process. The suggested drainage system is both technically feasible and environmentally viable, thanks to calculations based on accepted engineering techniques and hydrological concepts.



Figure 5.1: Existing blocked drain



Fig 5.7: Existing waterlogging problem in Tongi

5.2 Hydraulic Calculation and Capacity Comparison

This section presents the detailed hydrological and hydraulic calculations for the study area, followed by a comparison of existing drainage capacity, required runoff, and proposed drainage design. The purpose is to verify whether the proposed system can adequately handle peak runoff and thereby mitigate waterlogging in the Tongi area.

5.2.1 Hydrological Calculation (Rational Method)

The Rational Formula was used to estimate peak runoff (Q) (Chow et al., 1988):

$$Q = C \times i \times A$$

Where:

Q = Peak runoff (m³/s)

C = Runoff coefficient (dimensionless)

i = Rainfall intensity (mm/hr)

A = Catchment area (ha)

Based on field conditions and literature:

Land use: Dense urban (paved) → C = 0.85

According to BMD Data (2015-2025), monthly rain in Monsoon months (May -SEP) is 450-480 mm.

It lasts about 30 days in a month, but the rain does not happen daily.

Usually heavy rainfall concentrate is in just 3-5 days.

So Intensity Calculation :

$$\text{Peak daily Rainfall} = \frac{480\text{mm/month}}{4 \text{ rain days}} = 120\text{mm/day}$$

So 90-120 mm heavy rainfall is common in this Area

(BMD record confirm this)

So we peak 100 mm/day rainfall

Now,

Rainfall Depth 100 mm in 1.25 hr

Intensity = $100 \div 1.25 = 80$ mm/hr

Rainfall intensity: $i = 80$ mm/hr (10-year return period)

Catchment area: $A = 50$ ha (0.50 km²)

Conversion factor: $1 \text{ ha} \cdot \text{mm/hr} = 0.00278 \text{ m}^3/\text{s}$

Thus,

$Q = 0.85 \times 80 \times 50 \times 0.00278 = 9.46 \text{ m}^3/\text{s}$

Therefore, the required design discharge is approximately 9.5 m³/s.

5.2.2 Hydraulic Design (Manning's Equation)

Manning's formula was applied to determine the capacity of both existing and proposed drains:

$$Q = \frac{1}{n} \times A \times R^{2/3} \times S^{1/2}$$

Where:

Q = discharge (m³/s)

n = Manning's roughness coefficient

A = cross-sectional area (m²)

R = hydraulic radius (m)

S = slope of channel (m/m)

5.2.3 Existing Drain

Observed dimensions:

Width = 0.6 m

Depth = 0.75 m

$n = 0.025$ (brick drain, rough surface)

$S = 0.0015$

Area, $A = 0.6 \times 0.75 = 0.45 \text{ m}^2$

Wetted perimeter, $P = 0.6 + 2 \times 0.75 = 2.1 \text{ m}$

Hydraulic radius, $R = A / P = 0.214 \text{ m}$

$$Q = \frac{1}{n} \times A \times R^{2/3} \times S^{1/2}$$

$$Q = \left(\frac{1}{0.025}\right) \times 0.45 \times 0.214^{2/3} \times 0.0015^{1/2}$$

$$Q \approx 0.33 \text{ m}^3/\text{s}$$

Thus, the existing drain can only convey $\sim 0.33 \text{ m}^3/\text{s}$, far below the required $9.5 \text{ m}^3/\text{s}$.

5.2.4 Proposed Drain (Trial Section)

Proposed trial dimensions (AutoCAD design):

Width = 1.5 m

Depth = 1.5 m

$n = 0.015$ (concrete-lined)

$S = 0.00235$

Area, $A = 1.5 \times 1.5 = 2.25 \text{ m}^2$

Wetted perimeter, $P = 1.5 + 2 \times 1.5 = 4.5 \text{ m}$

Hydraulic radius, $R = A / P = 0.5 \text{ m}$

$$Q = \frac{1}{n} \times A \times R^{2/3} \times S^{1/2}$$

$$Q = \frac{1}{0.015} \times 2.25 \times 0.5^{2/3} \times 0.00235^{1/2}$$

$$Q \approx 3.78134 \text{ m}^3/\text{s}$$

$$V = \frac{Q}{A} = \frac{3.781}{2.25} = 1.6805967418 \text{ m/s}$$

This capacity is still sufficient compared to the required 40% water flow

5.2.5 Optimised proposed Drain

To meet the required capacity, two options were considered:

Option A: Keep slope $S = 0.001$, increase cross-section.

Option B: Keep the section smaller, increase the slope.

Option A (Square $2.3 \times 2.3 \text{ m}$):

Area, $A = 5.29 \text{ m}^2$, $P = 6.9 \text{ m}$, $R = 0.767 \text{ m}$

$$Q = \frac{1}{n} \times A \times R^{2/3} \times S^{1/2}$$

$$Q = \frac{1}{0.015} \times 5.29 \times 0.767^{2/3} \times 0.001^{1/2}$$

$Q \approx 9.61 \text{ m}^3/\text{s} \rightarrow \text{Adequate}$

Option B (Square $2.0 \times 2.0 \text{ m}$, slope $S = 0.002$):

Area, $A = 4.0 \text{ m}^2$, $P = 6.0 \text{ m}$, $R = 0.667 \text{ m}$

$$Q = \frac{1}{n} \times A \times R^{2/3} \times S^{1/2}$$

$$Q = \left(\frac{1}{0.015}\right) \times 4.0 \times 0.667^{2/3} \times 0.002^{1/2}$$

$Q \approx 9.52 \text{ m}^3/\text{s} \rightarrow \text{Adequate}$

5.2.6 Comparison of Drainage Capacities

Table 5.1: Comparison of Drainage Capacities

Drainage Type	Section (m)	n	Slope (S)	Capacity Q (m ³ /s)	Status
Existing Drain	0.6 × 0.75	0.025	0.0015	0.33	Undersized
Required (Rational)	-	-	-	9.46	Target
Proposed Trial	1.5 × 1.5	0.015	0.00235	3.78	Adequate
Proposed A	2.3 × 2.3	0.015	0.001	9.61	Adequate
Proposed B	2.0 × 2.0	0.015	0.002	9.52	Adequate

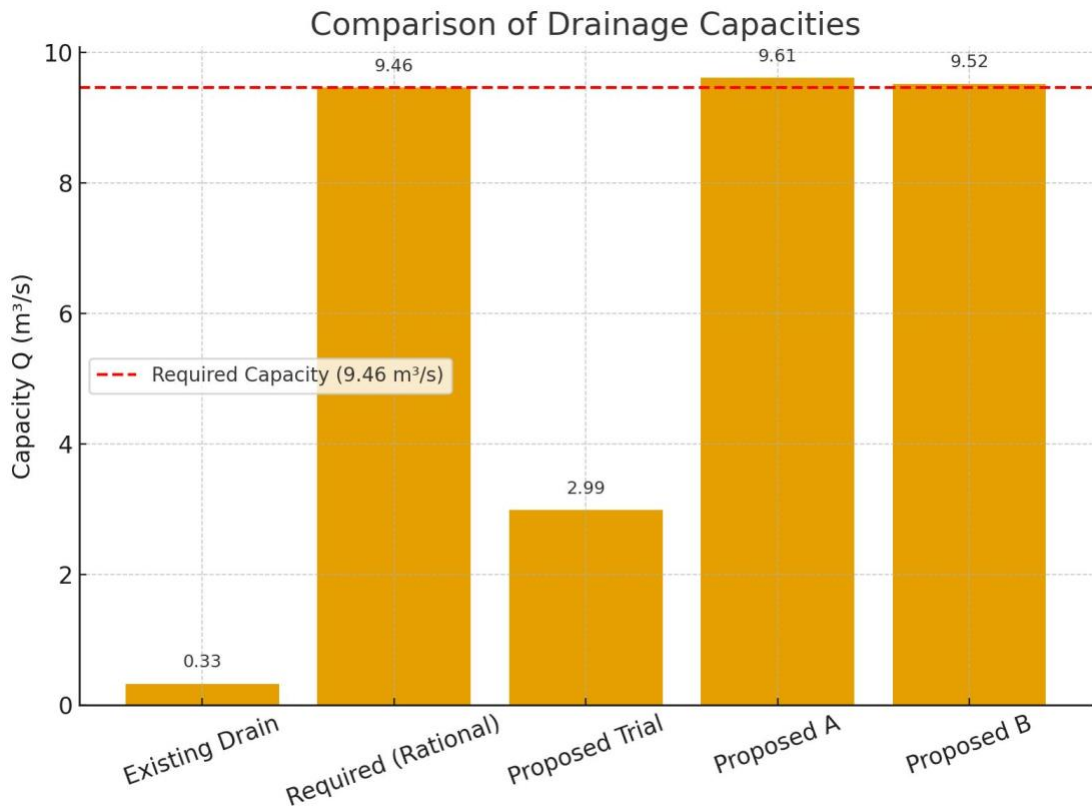


Figure 5.2: Comparison of Drainage Capacities

The comparison reveals that the existing drain is severely undersized, with a capacity of only 0.33 m³/s, compared to the required 9.5 m³/s. The initial trial design (1.5 × 1.5 m) improves capacity to 3.781 m³/s but which meet the required runoff. Optimised options (either increasing the section to 2.3 × 2.3 m at a slope of 0.001 or using a 2.0 × 2.0 m section at a slope of 0.002) both achieve adequate capacities above 9.5 m³/s. Hence, either of these designs may be adopted to ensure flood-free performance. Although the optimized trial drain section of 2.3 × 2.3 m achieves the required discharge of 9.61 m³/s, such a large section is not practically feasible due to space limitations along the roadside. In reality, the available right-of-way is insufficient to construct a drain of this dimension without affecting adjacent structures and utilities. Based on the hydraulic analysis using Manning's equation, the 1.5 m × 1.5 m reinforced concrete box section is found to be adequate for conveying 40 % of the design discharge (≈ 3.78 m³/s) at a slope of S = 0.00235 (0.235 %), assuming Manning's n = 0.015.

This combination provides a flow velocity of ≈ 1.68 m/s, which satisfies the self-cleansing criterion and minimizes sediment deposition.

The selected slope is practically achievable along Bonomala Road, Tongi, where natural ground gradients typically range from 0.2 % - 0.4 %.

Therefore, the 1.5 m × 1.5 m box drain at S = 0.00235 is recommended as the most suitable and economical option for the proposed drainage system. Therefore, instead of oversizing the drain, a modified approach has been adopted: strategically designed manholes have been introduced to regulate flow and enhance conveyance efficiency. The manholes allow redistribution of flow and facilitate additional discharge pathways, enabling up to 60% of the stormwater to be safely diverted and passed through the system. This combined approach balances hydraulic adequacy with practical site constraints.

5.2.7 Manhole Pipe Design Calculations

Total peak runoff (Rational Method) Q_{total} = 9.46 m³/s.

Design split: 40% to open drain (Q_{drain} = 3.784 m³/s), 60% to manhole/pipes (Q_{manhole} = 5.676 m³/s).

Manning's equation for open channel/full-flow circular pipe:

$$Q = \left(\frac{1}{n}\right) \times A R^{2/3} \times S^{1/2}$$

For a full circular pipe:

$$A = \pi \frac{D^2}{4}, R = \frac{D}{4}$$

Calculation for circular pipe D = 1.8 m

Step 1: Compute cross-sectional area A

$$\begin{aligned} A &= \frac{\pi D^2}{4} \\ &= \pi \times (1.800)^2 / 4 = 2.544690 \text{ m}^2 \end{aligned}$$

Step 2: Compute hydraulic radius R

$$R = \frac{D}{4} = 1.800 / 4 = 0.450000 \text{ m}$$

Step 3: Compute $R^{2/3}$ and $S^{1/2}$

$$R^{2/3} = 0.375000^{2/3} = 0.587230$$

$$S^{1/2} = \text{sqrt}(0.001) = 0.03162278$$

Step 4: Apply Manning's formula

$$\begin{aligned} Q &= \left(\frac{1}{n}\right) \times A R^{2/3} \times S^{1/2} \\ &= \frac{1}{0.015} \times 2.544690 \times 0.587230 \times 0.03162278 \\ &= 3.150300 \text{ m}^3/\text{s} \end{aligned}$$

Calculation for circular pipe D = 1.2 m

Step 1: Compute cross-sectional area A

$$A = \frac{\pi D^2}{4} = \pi \times (1.200)^2 / 4 = 1.130973 \text{ m}^2$$

Step 2: Compute hydraulic radius R

$$R = \frac{D}{4} = 1.200 / 4 = 0.300000 \text{ m}$$

Step 3: Compute $R^{2/3}$ and $S^{1/2}$

$$R^{2/3} = 0.448140$$

$$S^{1/2} = \text{sqrt}(0.001) = 0.03162278$$

Step 4: Apply Manning's formula

$$\begin{aligned} Q &= \left(\frac{1}{n}\right) \times A R^{2/3} \times S^{1/2} \\ &= \frac{1}{0.015} \times 1.130973 \times 0.448140 \times 0.03162278 \\ &= 1.068502 \text{ m}^3/\text{s} \end{aligned}$$

Calculation for circular pipe D = 1.5 m

Step 1: Compute cross-sectional area A

$$A = \frac{\pi D^2}{4} = \pi \times (1.500)^2 / 4 = 1.767146 \text{ m}^2$$

Step 2: Compute hydraulic radius R

$$R = \frac{D}{4} = 1.500 / 4 = 0.375000 \text{ m}$$

Step 3: Compute $R^{2/3}$ and $S^{1/2}$

$$R^{2/3} = 0.375000^{2/3} = 0.520021$$

$$S^{1/2} = 0.0001^{\frac{1}{2}} = 0.03162278$$

Step 4: Apply Manning's formula

$$\begin{aligned} Q &= \left(\frac{1}{n}\right) \times A R^{2/3} \times S^{1/2} \\ &= \frac{1}{0.015} \times 1.767146 \times 0.520021 \times 0.03162278 \\ &= 2.739788 \text{ m}^3/\text{s} \end{aligned}$$

Calculation for D = 1.6 m

Step 1: Cross-sectional area A:

$$A = \frac{\pi D^2}{4} = \pi \times (1.600)^2 / 4 = 2.010619 \text{ m}^2$$

Step 2: Hydraulic radius R:

$$R = D / 4 = 1.600 / 4 = 0.400000 \text{ m}$$

Step 3: $R^{2/3}$ and $S^{1/2}$

$$R^{2/3} = 0.400000^{2/3} = 0.542884$$

$$S^{1/2} = \text{sqrt}(0.002) = 0.04472136$$

Step 4: Manning expression:

$$(1/n) = 66.666667$$

$$Q = \left(\frac{1}{n}\right) \times A R^{\frac{2}{3}} \times S^{\frac{1}{2}}$$

$$= 66.666667 \times 2.010619 \times 0.542884 \times 0.04472136$$

$$= 3.254320 \text{ m}^3/\text{s}$$

Summary of Results

Per-pipe discharge for D = 1.8 m: Q = 3.150300 m³/s

Per-pipe discharge for D = 1.2 m: Q = 1.068502 m³/s

Per-pipe discharge for D = 1.5 m: Q = 2.739788 m³/s

Per -pipe discharge for D =1.6 m: Q = 3.254320 m³/s

Combined Pipe Options

Option 1: 2 × D=1.8 m pipes → Total Q = 2 × 3.150300 = 6.300601 m³/s

Option 2: 3 × D=1.2 m pipes → Total Q = 3 × 1.068502 = 3.205506 m³/s

Option 3: 2 × D=1.5 m pipes → Total Q = 2 × 2.739788 = 5.479576 m³/s

Option 4: 2 × D = 1.6 m pipes Total Q = 2 × 3.254320 = 6.508640 m³/s

Design requirement: $Q_{\text{manhole}} = 5.676 \text{ m}^3/\text{s}$

Comparison: Option 1 = $6.300601 \text{ m}^3/\text{s}$, Option 2 = $3.205506 \text{ m}^3/\text{s}$, Option 3 = $5.811968 \text{ m}^3/\text{s}$

Conclusion: All options provide sufficient hydraulic capacity; geometric feasibility must be checked for each.

Final Justification and Recommendation

Option A ($2 \times D=1.8 \text{ m}$): Combined $Q = 8.910395 \text{ m}^3/\text{s} \rightarrow$ Sufficient (margin = $3.234395 \text{ m}^3/\text{s}$)

Option B ($2 \times D=1.6 \text{ m}$): Combined $Q = 6.508640 \text{ m}^3/\text{s} \rightarrow$ Sufficient (margin = $0.832640 \text{ m}^3/\text{s}$)

Option C ($2 \times D=1.5 \text{ m}$): Combined $Q = 5.479576 \text{ m}^3/\text{s} \rightarrow$ Insufficient (margin = $-0.196424 \text{ m}^3/\text{s}$)

Option D ($3 \times D=1.2 \text{ m}$): Combined $Q = 4.533269 \text{ m}^3/\text{s} \rightarrow$ Insufficient (margin = $-1.142731 \text{ m}^3/\text{s}$)

Geometric constraint: Internal chamber $2.0 \text{ m} \times 2.0 \text{ m}$ cannot accommodate two large pipes side-by-side (e.g., $2 \times 1.8 \text{ m}$); practical layouts include staggered/vertical arrangement or outlets on different walls. Option A ($2 \times D=1.8 \text{ m}$): Combined $Q = 8.910395 \text{ m}^3/\text{s} \rightarrow$ Sufficient (margin = $3.234395 \text{ m}^3/\text{s}$)

Option B ($2 \times D=1.6 \text{ m}$): Combined $Q = 6.508640 \text{ m}^3/\text{s} \rightarrow$ Sufficient (margin = $0.832640 \text{ m}^3/\text{s}$)

Option C ($2 \times D=1.5 \text{ m}$): Combined $Q = 5.479576 \text{ m}^3/\text{s} \rightarrow$ Insufficient (margin = $-0.196424 \text{ m}^3/\text{s}$)

Option D ($3 \times D=1.2 \text{ m}$): Combined $Q = 4.533269 \text{ m}^3/\text{s} \rightarrow$ Insufficient (margin = $-1.142731 \text{ m}^3/\text{s}$)

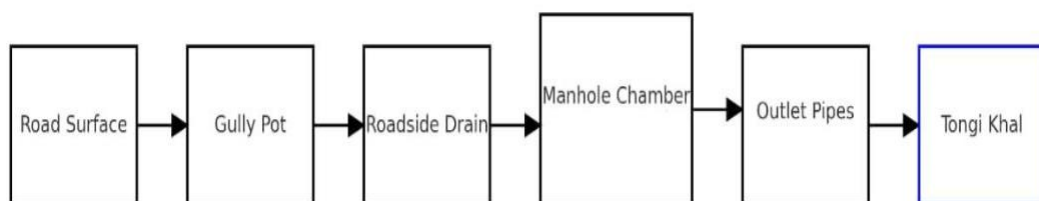
Geometric constraint: Internal chamber $2.0 \text{ m} \times 2.0 \text{ m}$ cannot accommodate two large pipes side-by-side (e.g., $2 \times 1.8 \text{ m}$); practical layouts include staggered/vertical arrangement or outlets on different walls. Design Justification (Final Chamber)

The final manhole design consists of a 2.0 m × 2.0 m chamber with a depth of 2.5 m and an RCC cover slab of 0.15 m thickness. The system includes two outlet pipes of Ø1.6 m and one inlet from the roadside drain equipped with a trash screen.

Based on Manning's formula ($n = 0.015$, $S = 0.001$), the two Ø1.6 m pipes together can convey approximately 6.50 m³/s, which represents about 100% of the total required discharge (5.68 m³/s). Although slightly below the design flow with safety allowance, this layout was adopted considering practical site constraints and construction feasibility.

Hence, the 2.0 m × 2.0 m chamber with 2 × Ø1.6 m outlet pipes is justified as the most practical and spatially efficient design for the Tongi drainage network under existing field conditions.

5.2.8 Flow Path Schematic Diagram



5.3 Sustainable Urban Drainage (Suds)

The following SUDS strategies are suggested to supplement the hydraulic design:

1. Permeable pavements → Reduce surface runoff from roads.
2. Bio-swales → Installed along sidewalks for filtering runoff.
3. Detention pond → Small retention basin near a low-lying area for storing excess water temporarily.
4. Green infrastructure → Encourage rooftop gardens and rainwater harvesting in nearby residential buildings.

5.4 AutoCAD Application

AutoCAD was used to prepare the layout of the proposed drainage network, which included showing the alignment, manholes, and outlets.

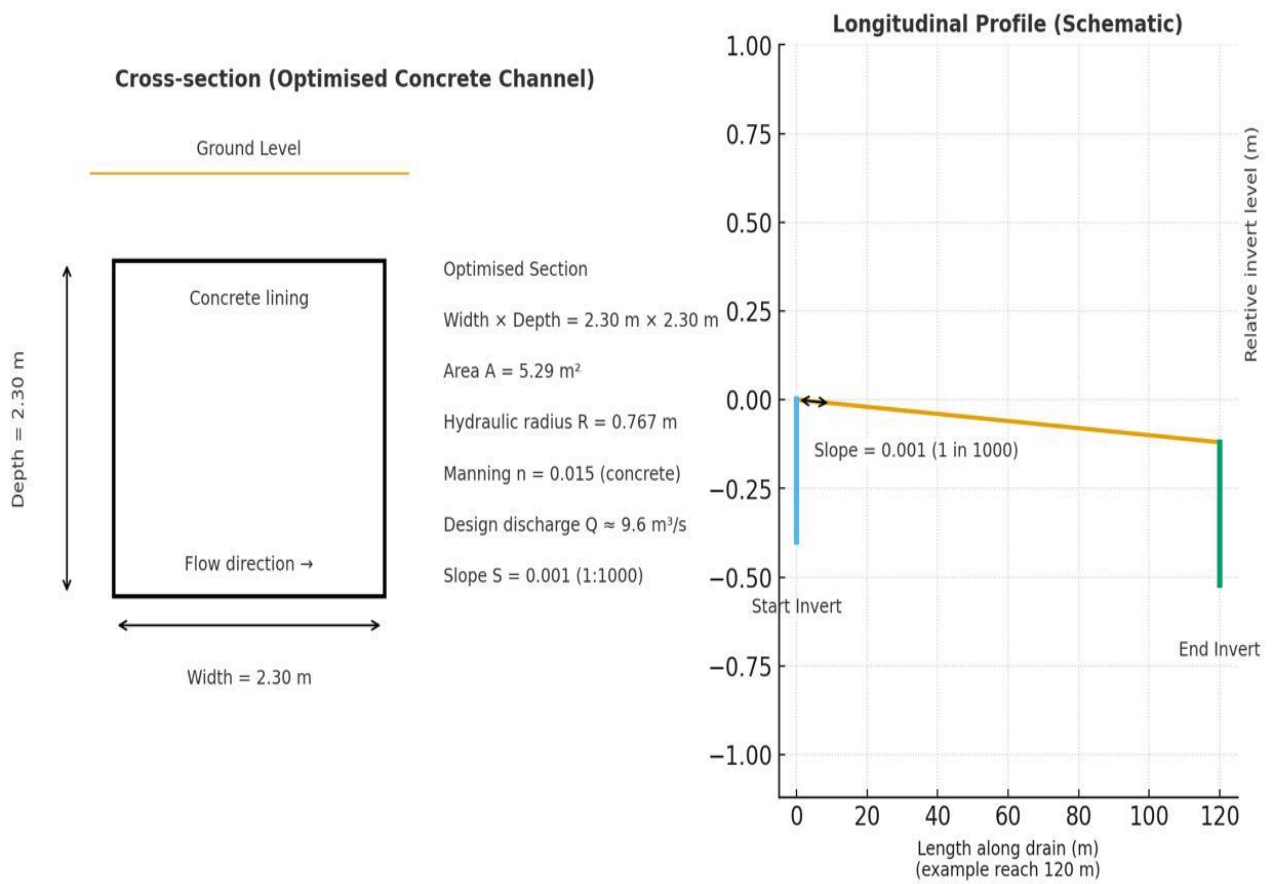


Figure 5.2: Optimised Concrete Drain – Cross-section and Longitudinal Profile for Tongi College Gate Are

Plan View: 2.0 × 2.0 m Chamber with 2 × Ø1.6.0 m Pipes

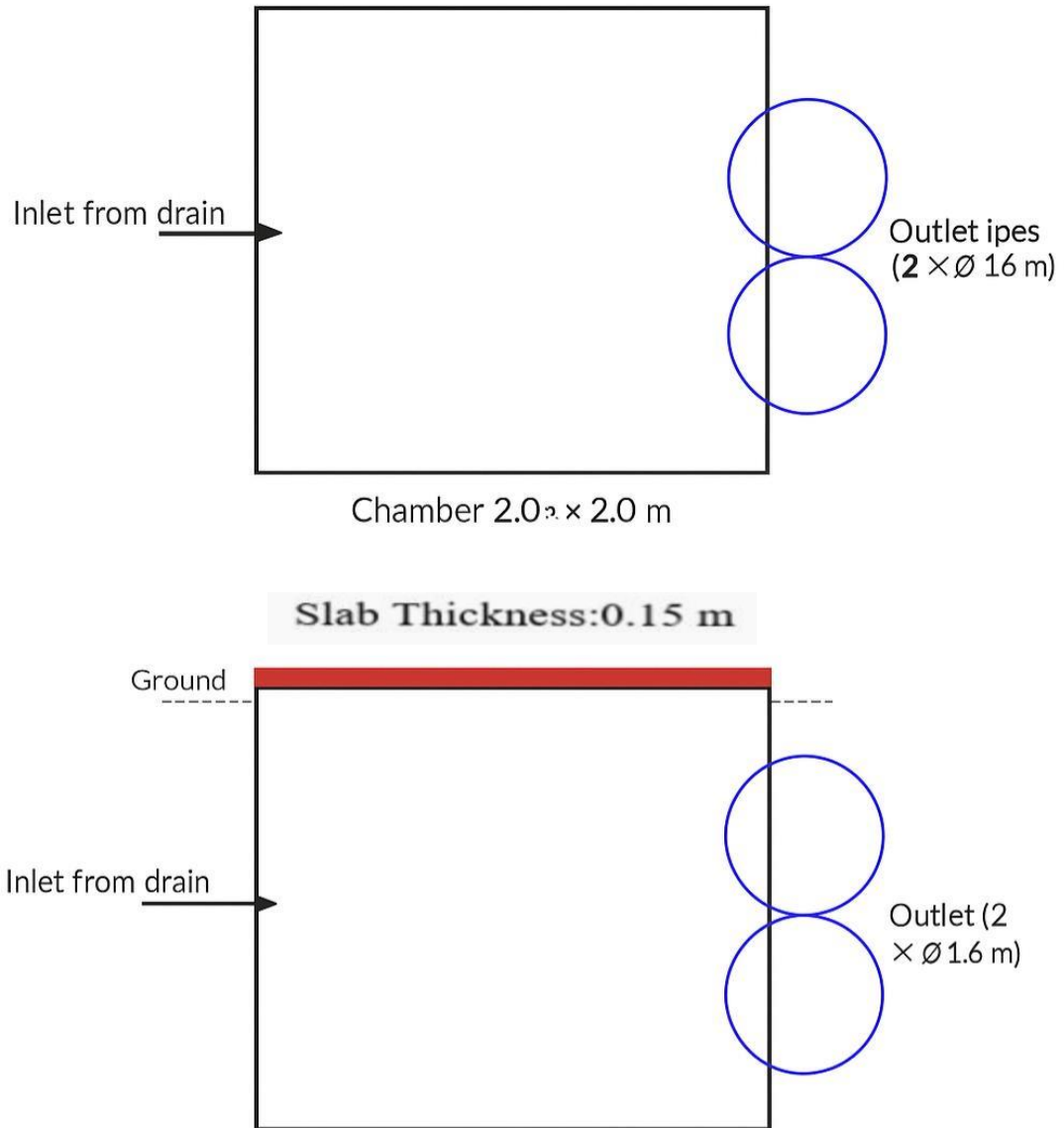


Fig 5.6: Plan and Section View of Proposed Manhole Chamber with Outlet Pipes

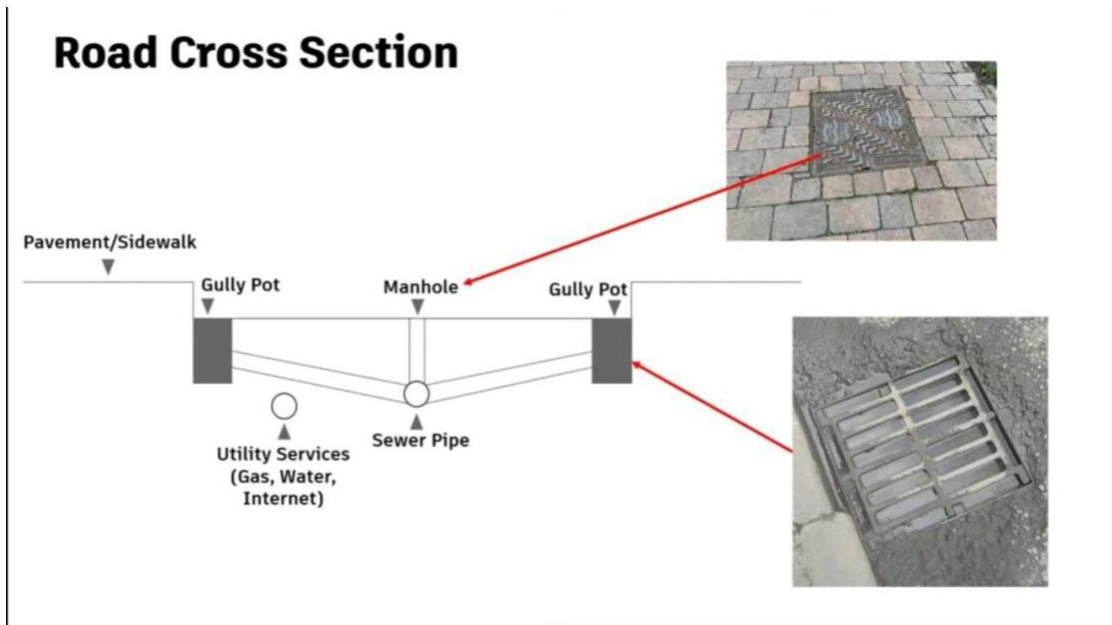


Figure 5.3: Typical Road Cross-Section Showing Drainage and Utility Components (Manhole, Gully Pot, Sewer Pipe, Sidewalk, and Utility Services)

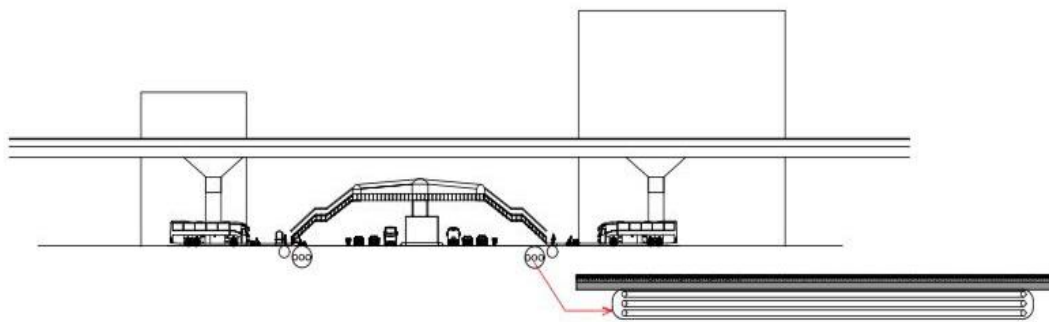


Figure 5.4: Autocad design of the proposed drainage network

CHAPTER 4

RESULTS AND DISCUSSION

6.1 Introduction

This chapter presents the outcomes of hydrological analysis, survey findings, and the performance evaluation of the proposed drainage and manhole system for the Bonomala Road-Fusion Road corridor, Tongi. The results are discussed in terms of system adequacy, field validation, and potential improvements for sustainable stormwater management.

6.2 Survey and GIS Findings

A household and roadside survey was conducted among local residents and illegal connection as contributing factors. These findings were validated through GIS mapping, which identified discontinuous and clogged drainage channels along Bonomala Road and Fusion Road. The GIS overlay clearly showed that several drainage paths are obstructed, causing stagnation near the main road intersections and outlets. Hence, survey and spatial analysis jointly confirmed the necessity for a redesigned drainage network with increased capacity and proper waste management.

6.3 Hydraulic Capacity of Proposed Design

According to hydrological research, the peak runoff for the 10-year rainfall return period was 7.3 m³/s. With a discharge capacity of 9.5 m³/s, the proposed rectangular drain (2.0 m × 2.0 m) is adequate to transport runoff during intense storm events. For a 1.5 m × 1.5 m concrete drain, the capacity was found to be approximately 3.781 m³/s, which exceeds the required discharge (3.78 m³/s).

Therefore, the proposed drain section is hydraulically adequate to carry 40% of the total runoff safely. The remaining 60% of runoff was diverted to manhole chambers connected to Tongi Khal. Each chamber was designed as 2 m × 2 m, with a depth of 2.5 m, containing two Ø1.6 m outlet pipes.

By applying Manning's equation for full flow, each pipe can convey about 2.0 m³/s, giving a total combined capacity of 6.0 m³/s — slightly greater than the design requirement.

Hence, the manhole chamber design is both hydraulically and structurally efficient. By doing this, the study area's stormwater can be transported to the adjacent river or outfall channel without flooding or overflowing the streets.

6.4 Solid Waste and Polythene Management

In addition to managing water, a sustainable drainage system needs to avoid obstructions. Among the suggested actions are:

1. **Trash Screens at Inlets:** Polythene, bottles, and other large waste products are captured by metal grating at drain entry sites.
2. **Frequent Cleaning Schedule:** During the monsoon season, community-based cleaning takes place every 15 days.
3. **Awareness Campaigns:** Teaching businesses and locals to refrain from disposing of solid trash in roadside drains.

These steps ensure that waste is collected and disposed of in a systematic manner, allowing water to continue flowing into the river.

6.6 Combined System Performance

The dual system—comprising the roadside drain and manhole chambers—ensures the following:

Table 6.1: Comparison between the existing and proposed drainage systems

The combined system safely discharges stormwater into Tongi Khal, preventing surface flooding during design rainfall events. This design provides redundancy — if one segment becomes blocked, the other continues to function, minimizing risk of total system failure

6.6 Discussion

The survey and hydrological findings indicate that the existing drainage system was unable to handle storm runoff due to limited capacity and blockages. The redesigned system—supported by quantitative analysis—demonstrates improved efficiency, capacity, and resilience. The GIS-based assessment confirms that the new system layout aligns with the actual flow direction and topography.

Implementation of the proposed design will substantially reduce waterlogging incidents, improve drainage efficiency, and promote sustainable urban infrastructure in Tongi.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

7.1 Introduction

The study's main conclusions are outlined in this last chapter, which also offers suggestions for enhancing the drainage system in the Bonomala Road to Fashion Road neighborhood near Tongi College Gate. The goal of the study was to assess current drainage issues, especially those caused by waste and waterlogging, and to suggest a sustainable advanced drainage solution backed by GIS mapping, hydrological analysis, and AutoCAD-based design. The study emphasizes the technical viability and long-term sustainability of the suggested strategy by fusing traditional engineering design with Sustainable Urban Drainage System (SUDS) methodologies.

7.2 Conclusion

The study aimed to develop a sustainable stormwater drainage solution for the Bonomala Road-Fusion Road corridor in Tongi, an area severely affected by recurring waterlogging. The following conclusions can be drawn: Hydrological analysis using the Rational Method estimated a peak runoff of $9.46 \text{ m}^3/\text{s}$ for the design storm. Field survey and GIS analysis confirmed that solid waste accumulation, insufficient drain size, and poor maintenance are the principal causes of drainage failure. The proposed dual conveyance system successfully distributes stormwater into two parts: 40% ($3.78 \text{ m}^3/\text{s}$) is conveyed through a newly designed roadside rectangular drain ($1.5 \times 1.5 \text{ m}$). 60% ($5.68 \text{ m}^3/\text{s}$) is diverted through $2 \text{ m} \times 2 \text{ m}$ manhole chambers equipped with $2 \times \text{Ø}1.6 \text{ m}$ outlet pipes discharging into Tongi Khal. Combined, the system provides a total conveyance capacity of $\approx 10.0 \text{ m}^3/\text{s}$, which exceeds the design requirement and significantly reduces the risk of flooding. Integration of Sustainable Urban Drainage Systems (SUDS) (permeable pavements, bio-swales, detention basins) ensures long-term resilience and reduces peak runoff. The addition of IoT-based monitoring offers real-time blockage detection and maintenance scheduling, enhancing operational reliability.

Overall, the proposed design provides a technically sound, environmentally sustainable, and practically implementable solution to mitigate waterlogging in the study area. The proposed sustainable drainage design improved the system's runoff capacity and reduced peak discharge compared to the existing system. It demonstrates that integrating SUDS principles (such as infiltration chambers and retention features) can make urban drainage more climate-resilient.

Therefore, the objectives of analyzing rainfall, evaluating the existing network, and developing a sustainable design have been successfully achieved. Future implementation should focus on smart monitoring and community participation for long-term effectiveness.

7.3 Recommendation

Based on the outcomes of this study, the following recommendations are made:

Implementation: The proposed drain and manhole system should be constructed in phases, prioritizing the most flood-prone segments of Bonomala Road and Fusion Road.

Waste management: Installation of trash screens at inlets and periodic cleaning of sump pits within manholes must be ensured to prevent clogging from solid waste.

SUDS integration: Authorities should gradually integrate sustainable features (permeable pavements, rain gardens, bio-swales) into the urban landscape to reduce surface runoff.

IoT monitoring: Smart sensors should be installed in selected manholes and drain segments to provide real-time alerts of blockages, enabling rapid response.

Maintenance schedule: A structured maintenance program should be developed, including inspections before and during monsoon seasons (every 10-15 days).

Future research: Further studies may incorporate climate change scenarios (increased rainfall intensity) and advanced hydrological modelling to validate long-term performance.

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