DEVELOPMENT OF STRATEGIES FOR MITIGATION OF URBAN FLOODING

Ph.D. THESIS

by

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2024

DEVELOPMENT OF STRATEGIES FOR MITIGATION OF URBAN FLOODING

A THESIS

Submitted in partial fulfilment of the
requirements for the award of the degree

of

DOCTOR OF PHILOSOPHY

in

CIVIL ENGINEERING

by

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled "**DEVELOPMENT OF STRATEGIES FOR MITIGATION OF URBAN FLOODING"** in partial fulfillment of the requirements for the award of the Degree of Doctor of Philosophy and submitted in the Department of Civil Engineering of the Delhi Technological University, Delhi is an authentic record of my own work carried out during a period from August, 2017 to September, 2024 under the supervision of Prof. T.Vijaya Kumar, Professor, Department of Civil Engineering, Delhi Technological University, Delhi, India.

The matter presented in this thesis has not been submitted by me for the award of any other degree or in any other Institution.

(RUCHIKA DABAS)

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

(Prof. T.Vijaya Kumar)
Supervisor

Date: September 23th, 2024

ACKNOWLEDGEMENTS

I wish to convey my profound gratitude and heartfelt appreciation to the individuals who have been instrumental in supporting and assisting me in the successful completion of this thesis. It is with deep gratitude that I express my appreciation for their contributions, and I would like to dedicate the following words to acknowledge their invaluable assistance.

First and foremost, I extend my deepest gratitude, special thanks, and heartfelt appreciation to my supervisor, **Prof . T.Vijaya Kumar**. His unwavering support throughout my PhD journey has been nothing short of remarkable. There were moments when I felt lost and demotivated, but his guidance and presence were my guiding lights. Professor Kumar's exceptional ability to motivate, lead, and pursue new frontiers in academia are qualities I deeply admire. Words cannot adequately express the depth of my gratitude for his support and cooperation.

I extend my heartfelt gratitude to Prof. Munendra kumar for helping me in objectives and simulation part of my research work. Words cannot adequately express the depth of my gratitude for his support and cooperation. I hold him in high regard and will always be respectful of his contributions.

I am equally appreciative of the support I received from the department head and DRC chairman, **Prof. Vijay K. Minocha**, during my doctoral journey. I hold him in high regard and will always be respectful of his contributions. I extend my sincere thanks to the Head, Civil Engineering Department, **Prof. K.C.Tiwari** and other faculty members of Civil Engineering department for providing me sensible guidance, faultless planning, helpful advice, and kind cooperation at various stages of my PhD journey.

I would also like to thank my friends and family members for their moral and emotional support all throughout my PhD journey.

(RUCHIKA DABAS)

ABSTRACT

This study focuses on the analysis of historical land use and land cover (LULC) changes in Delhi, aiming to predict future alterations and assess their hydrological impacts. The research is conducted in three primary phases: analyzing past LULC changes, detecting climate change trends, and mapping flood susceptibility to identify the best Low-Impact Development (LID) controls. The goal is to reduce flood risk by implementing suitable LID strategies in the context of LULC changes and climate change. The first phase involves a spatial-temporal analysis of LULC images using techniques to interpret patterns and changes over time. Spatial analysis examines LULC patterns within a specific area, identifying trends and relationships. Temporal analysis studies changes in LULC over time, revealing the drivers and impacts of these changes. Classified images from 2000, 2005, 2010, 2015, and 2020 demonstrate significant increases in built-up areas and reductions in vegetation and barren land. This data helps predict future LULC changes and their potential impacts on the study area's hydrological regime.A confusion matrix evaluates the precision of classified images, showing the number of true positives, true negatives, false positives, and false negatives. For example, the confusion matrix for the LISS III image for 2020 indicates an overall accuracy of 66% and a Kappa coefficient of 0.57, suggesting moderate performance. These metrics ensure the reliability of the LULC classification and subsequent analyses. LULC changes from 2000 to 2020 are quantified, revealing a significant increase in built-up areas, a decrease in barren land, and a reduction in vegetation. Built-up areas have grown 1.6 times in the last two decades, while vegetation cover has reduced by nearly half since 2000. These changes highlight the urbanization trends in Delhi and their potential impact on the environment.

The Mann-Kendall test detects trends in climate data, revealing significant changes in annual rainfall at a 0.05 significance level. Three out of four stations in Delhi show an increasing trend, while one indicates a downward trend. The Standardized Anomaly Index

(SAI) further identifies anomalies in rainfall data from 1970 to 2020, indicating normal and wet years compared to dry years.An Intensity-Duration-Frequency (IDF) curve is developed for Delhi using maximum rainfall data from 1971 to 2020. The curve illustrates the relationship between rainfall intensity, duration, and frequency, crucial for stormwater management and drainage system design. The IDF curve shows maximum rainfall intensities for different return periods, helping assess flood risk and design appropriate flood mitigation measures.

Landsat 8 satellite data and the NDVI and MNDWI indices are used to investigate the Urban Heat Island (UHI) effect and flood susceptibility. The NDVI map shows vegetation cover, while the MNDWI map highlights water bodies. Land Surface Temperature maps, derived from thermal image analysis, reveal temperature variations across Delhi, helping identify UHI areas. The Urban Heat Island Index (UHII) further confirms the presence of UHI in the study area.LID techniques are suggested at two scales: intermediate and catchment. Intermediate-scale LID focuses on neighborhood or sub-watershed levels, implementing techniques like rain gardens, green roofs, infiltration trenches, permeable pavement, bioretention systems, and swales. Catchment-scale LID encompasses entire watersheds, integrating LID principles into land use and development policies. LULC maps and Wetness Index calculations help select suitable sites for LID implementation.LULC significantly impacts the selection of LID techniques. Urban areas with high impervious surfaces benefit from techniques that reduce runoff, such as green roofs and rain gardens. A Digital Elevation Model (DEM) helps derive the Wetness Index, indicating hydrological and ecological conditions. The Topographic Wetness Index (TWI) is calculated using flow accumulation and slope, identifying areas with high and low wetness values for LID site selection.LID performance is assessed by the percentage reduction in flow depth and volume for each technique. The study shows that LID practices like swales, bioretention, green gardens, and permeable pavement significantly reduce stormwater volume and flow depth. Swales achieve the highest reduction, followed by bioretention, green gardens, and permeable pavement. This study provides a comprehensive analysis of historical and future LULC changes, climate change trends, and flood susceptibility in Delhi. By identifying suitable LID techniques and their performance, the research offers valuable insights for sustainable urban water management. Implementing appropriate LID controls can significantly reduce flood risk, mitigate the impacts of urbanization, and improve water quality in Delhi.

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List of Abbreviation

LID: Low Impact Development

LULC: Land Use Land Cover

MLC: Maximum Likelihood Classification

SWMM: Storm Water Management Model

HSAs: Hydrologically Sensitive Areas

AHP: Analytical Hierarchy Process

MCDA: Multi-Criteria Decision Analysis

VSA: Variable Source Area

BMP: Best Management Practices

IRS: Indian Remote Sensing

LISS: Linear Imaging Self Scanning Sensor

RS: Remote Sensing

GIS: Geographic Information System

DEM: Digital Elevation Model

IDF: Intensity-Duration-Frequency

EPA: Environmental Protection Agency

TIRS: Thermal Infrared Sensor

NIR: Near Infrared

TWI: Total Wetness Index

SAI : Standardized Anomaly Index

Mathematical Symbols Used

Px(wi) – Probability of a data point belonging to class **wi**.

σi (Sigma) – Standard deviation or variance.

μi (Mu) – Mean value of the class.

e – Base of natural logarithms.

x – Brightness value in the context of image classification.

χi – Estimated variance of the class measurements.

R- Rainfall

T-Temperature

t- Time

CHAPTER 1: INTRODUCTION

"Protecting our planet and nourishing our future with crops that thrive in less water is not just a choice; it's our duty to cultivate a sustainable world for generations to come."

-Unknown

1.1 BACKGROUND

The well-designed gravity drainage system of the Indus Valley civilization's towns (c. 2500 BC), such as Mohenjo-Daro (now in Pakistan) and Lothal (in Gujarat, India), is frequently mentioned when discussing drainage in India.India has 28 States, 9 Union Territories, and 377 million urban residents, according to the 2011 census. This figure is predicted to increase to over 600 million by 2031. The term "UA" means "A continuous urban spread constituting a town and its adjoining outgrowths (OGs), or two or more physically contiguous towns together with or without outgrowths of such towns." 53 UAs/Towns have a population of one million or more each, out of the 7935 towns in India. There are 468 UAs/towns with a population of at least 100,000. An efficient storm drainage system is essential for a city to prevent flooding during heavy rainfall events. A poorly designed or inadequate storm drainage system can lead to catastrophic flooding, resulting in property damage, loss of life, and economic loss. In addition, flooding can cause public health issues, including waterborne diseases and contamination of drinking water sources. An efficient storm drainage system helps to ensure that rainwater is effectively managed and directed away from urban areas, preventing it from pooling in low-lying areas or flowing into nearby water bodies. This prevents erosion, sedimentation, and pollution of water sources, which can harm aquatic life and cause ecological damage.

Urban flooding stems from various factors, including urbanization, heightened precipitation in urban and upstream areas, overflow from upstream dams and rivers, and the establishment of infrastructure on flood plains or low-lying zones within cities. The phenomenon is exacerbated by urban heat islands, which contribute to increased convective rainfall and subsequent flooding in and around urban areas. The consequences of rapid urbanization encompass expanded paved surfaces, diminished water bodies, decreased groundwater replenishment, and a reduced capacity of urban drainage systems.The influx of rural populations into urban areas, driven by economic opportunities, has further compounded the issue. During monsoon periods, the convergence of sewage and stormwater results in overflow-induced flooding and subsequent outbreaks of epidemics. The swift urban population growth has surpassed the development of sewer systems, leading to untreated discharge of increased wastewater into existing stormwater drains and rivers in numerous cities. This is exacerbated by the shrinking of many aging drainage systems and the incorporation of bridge piers, exacerbating the challenges posed by urban flooding. Due to the poor priority given to the funding for storm drainage, the drains in many communities are either inadequate or non-existent.While funding for 'visible' overground infrastructure is given priority, subsurface drainage is only given consideration when there is catastrophic floods or an epidemic breakout caused by contaminated water. Until recently, there was no specific guidebook for stormwater drainage, thus storm drains were planned using the Sewerage Design guidebook for rainfall intensities of 12 to 20 mm per hour.This is one of the primary causes of the inadequate drains in many Indian cities, which is a substantial contributor to urban floods. There are different types of floods which generally studied while referring to urban floods.

1.2 TYPES OF FLOODS

Floods can be broadly categorized into five types, which are discussed below:

1.2.1 Coastal Flooding:

Coastal flooding occurs when large waves and high tides caused by storms or other weather events exceed the capacity of the coastal defenses to protect the low-lying coastal areas. In India, coastal flooding is a common problem, particularly during the monsoon season. Coastal flooding can cause significant damage to infrastructure, buildings, and agricultural land, and can also cause the displacement of local populations.

1.2.2 Fluvial Floods:

Fluvial floods are caused by the overflow of rivers and their tributaries. They are typically associated with heavy rainfall and can lead to extensive damage to property and infrastructure, as well as the loss of human lives. Fluvial floods are a significant problem in India, particularly in densely populated areas.

India's population density can be broadly categorized into three zones based on the concentration of people per square kilometer. The high-density zone includes the Northern Plains and Kerala, where population density exceeds 500 people per square kilometer. The moderate or medium-density zone encompasses mountainous regions, with a population density ranging between 250 to 500 people per square kilometer. Lastly, the low-density zone is characterized by the plateau regions, where the population density falls below 250 people per square kilometer.

1.2.3 Flash Flooding:

An instance of flash flooding takes place when a sudden and intense rainfall event overwhelms the drainage systems, whether they are natural or man-made. The water rushes down steep slopes in mountainous regions, causing flash floods further downstream. This phenomenon occurs frequently in mountainous regions. There is a potential for flash floods to cause significant damage to property and infrastructure, and they can also be fatal. It is not uncommon for flash floods to occur in the Himalayan region of India. These floods have the potential to cause significant damage to both established communities and infrastructure.

1.2.4 Groundwater Flood:

The phenomenon known as groundwater flooding takes place when the groundwater table rises above the surface as a result of extensive rainfall or other reasons. The contamination of groundwater is another potential consequence of this phenomenon, which can also cause significant damage to buildings, infrastructure, and agricultural land. Flooding caused by groundwater is a problem that occurs frequently in many regions of India, particularly in urban areas where the land has been developed to a significant degree.

1.2.5 Urban floods:

There are a number of factors that contribute to the occurrence of urban floods. These factors include heavy rainfall, drainage systems that are not adequate, and the close proximity of water bodies. In addition to being potentially lethal, urban floods can cause significant damage to both property and building infrastructure. Flooding in urban areas is a significant issue in India, particularly in cities like Mumbai, Kolkata, and Chennai, which are densely populated and are experiencing rapid intensification of urbanization.

1.3 CAUSES OF FLOOD

Floods are caused by various natural and human-made factors. The following are some of the major causes of floods:

1.3.1 Heavy rainfall

Heavy rainfall is one of the primary causes of floods, and its frequency and intensity have increased due to recent climate change. When the amount of rainfall in an area exceeds the capacity of the soil and drainage systems to absorb and transfer it, water accumulates and floods occur. Climate change has led to increased atmospheric moisture, causing an increase in the amount of precipitation in many regions. Additionally, warming temperatures cause more evaporation, leading to more moisture in the atmosphere and increasing the likelihood of heavy rainfall events.When heavy rainfall occurs over a prolonged period, it can result in saturation of the ground, leading to surface runoff that overwhelms the drainagesystem. The excess water flows into streams and rivers, which can rapidly rise and overflow their banks, leading to flooding in nearby areas. This is especially problematic in urban areas where large volumes of water cannot be absorbed by the impervious surfaces such as concrete and asphalt. The situation is compounded when drainage systems are inadequate, clogged or not well maintained, and when constructionis allowed in floodplains.

1.3.2 Deforestation

Deforestation, or the clearance of forests, has a significant impact on the occurrence and severity of floods. Forests play a crucial role in regulating the water cycle, acting as natural sponges that absorb and retain rainfall. When forests are cleared, the soil loses its ability to hold water, leading to rapid runoff and an increase in the volume and velocity of water in rivers and streams.In recent years, climatechange has worsened the consequences of deforestationon flooding. Rising temperatures and changes in precipitation patterns are leading to more frequent and intense rainfall events, exacerbating the effects of deforestation. In addition, the loss of forests reduces the absorption of carbon dioxide, leading to an increase in atmospheric concentrations of this greenhouse gas, which contributes to further warming and more extreme weather events.Deforestation also has indirect effects on flooding, such as the loss of habitats for species that provide ecosystem services, including natural flood control. For example, beavers build dams that slow the flow of water and reduce flooding downstream, but their populations have been decimated due to habitat loss.

1.3.3 Improper agricultural practices

Improper agricultural practices refer to farming activities that contribute to soil erosion and degradation, which can increase the risk of flooding. When land is cleared for agriculture, it can result in the removal of trees and other vegetation that hold soil in place, leading to soil erosion. Additionally, farming practices such as overgrazing, excessive tilling, and leaving fields bare for extended periods of time can also cause soil erosion. As a result, sediment can be deposited in rivers and other waterways, reducing their capacity to hold water and increasing the risk of flooding.Climate change has also impacted agricultural practices, with changing weather patterns and extreme weather events causing disruptions in farming activities. Increased frequency and intensity of rainfall, coupled with longer periods of drought, have made it difficult for farmers to maintain soil health and prevent erosion. As a result, many agricultural areas are at an increased risk of flooding due to improper land management practices.

1.3.4 Inadequate design of drainage channels and structures

Inadequate design of drainage channels and structures can cause floods by impeding the flow of water or redirecting it in unintended ways. Poorly designed or maintained drainage systems can result in standing water or overflowing of rivers, streams, and other water bodies during heavy rainfall events. Additionally, urbanization and development can lead to an increase in impervious surfaces such as roads, parking lots, and buildings, which can exacerbate flooding by preventing water from being absorbed into the ground.Climate change has also had an impact on inadequate drainage design, as more extreme weather events such as heavy rainfall and storms have become more frequent and intense. In many cases, drainage systems have not been able to handle the increased volume of water, leading to flooding and damage.Proper design of drainage channels and structures is essential for preventing flooding. This can involve the construction of retention ponds, installation of culverts and catch basins, and regular maintenance of existing drainage systems. Additionally, incorporating green infrastructure such as bioswales and rain gardens can help to reduce the impact of impervious surfaces and improve the infiltration and absorption of water.

1.3.5 Inadequate maintenance of drainage facilities

Inadequate maintenance of drainage facilities, channels, and structures can also contribute to flooding. When drainage systems are not maintained properly, debris and sediment can accumulate in the channels, reducing their capacity to handle stormwater runoff. This can lead to blockages and backups, causing water to overflow onto streets and properties.In addition, without proper maintenance, the drainage structures such as culverts, stormwater ponds, and retention basins can become damaged or clogged with sediment, reducing their ability to effectively manage stormwater runoff. This can lead to flooding during heavy rainfall events.Climate change can exacerbate the effects of inadequate maintenance, as more frequent and intense rainfall events can overwhelm poorly maintained drainage systems. Proper maintenance of drainage facilities, channels, and structures is therefore essential in reducing the risk of flooding, especially in areas prone to heavy rainfall and severe weather events.

1.3.6 Construction of settlements in flood plains

Construction of settlements in flood plains can cause floods by increasing the amount of impervious surfaces, such as buildings and roads, which prevent water from soaking into the ground. When rain falls on these surfaces, it quickly flows into streams and rivers, overwhelming their capacity and causing flooding downstream. In addition, construction of buildings and other structures in floodplains can change the natural flow of water, redirecting it towards other areas and increasing flood risk. Climate change exacerbates this problem by causing more intense and frequent rainfall events, which can quickly overwhelm the capacity of the drainage systems in these areas. The warming temperatures can also lead to faster snow melt, further contributing to the problem. Furthermore, settlements in flood plains may be more vulnerable to storm surges and coastal flooding due to sea level rise, which is also a consequence of climate change. This can lead to devastating effects on both property and human life, particularly in densely populated areas.

1.4 EFFECTS OF FLOODS

The effects of floods can be devastating, and their impact can be far-reaching. Some of the effects of floods are as follows:

Loss of human lives: Floods can cause the loss of many human lives, especially in areas where people are living in flood-prone areas.

Damage to infrastructure: Floods can cause significant damage to infrastructure, including buildings, bridges, roads, and other structures. This can lead to significant repair costs and can disrupt the functioning of communities and businesses.

Economic losses: Floods can lead to significant economic losses, especially in areas where agriculture and tourism are major contributors to the economy. The loss of crops, livestock, and other property can have a significant impact on the local economy.

Disruption of transportation: Floods can disrupt transportation systems, making it difficult for people to get to work or for emergency services to reach those in need.

Health risks: Floods can lead to health risks such as waterborne diseases, infections, and exposure to toxic substances.

Environmental damage: Floods can lead to environmental damage such as soil erosion, water pollution, and destruction of wildlife habitats.

Displacement of people: Floods can force people to leave their homes and move to safer areas, leading to displacement and social disruption.

Psychological impact: Floods can have a significant psychological impact on people, especially those who have lost loved ones or property.

Interruption of power supply: Floods can cause the interruption of power supply, leading to a lack of access to electricity for days or even weeks.

Damage to cultural heritage: Floods can cause significant damage to cultural heritage sites, leading to the loss of important cultural and historical artifacts.

1.5 MOTIVATION TO STUDY

The motivation to study the challenges of Delhi's urbanization and its impact on the Yamuna River stems from several key factors. Delhi's location along the Yamuna River exposes it to significant flood risks, particularly during the monsoon season, due to disrupted natural drainage patterns caused by unplanned urbanization. As a rapidly expanding urban center and the capital of India, Delhi faces complex challenges related to urbanization, climate change, and water management, making it crucial to address these issues for the city's sustainable development. Low Impact Development (LID) practices, such as permeable pavements and rain gardens, are vital in reducing stormwater runoff, thereby easing the burden on drainage systems and minimizing the impact of floods. Additionally, understanding Land Use and Land Cover (LULC) patterns in Delhi is essential, as different land uses influence water absorption and retention, guiding targeted LID interventions. These practices also enhance climate resilience by improving groundwater recharge, which mitigates water scarcity during periods of intense rainfall and heatwaves. The insights gained from this study are valuable for urban planners, policymakers, and local authorities, aiding in the integration of LID practices into comprehensive urban development strategies.

1.6 OBJECTIVE

Keeping in view the above study and discussion the following objectives are set for present work:

- The main objective of present study is to provide sustainable solution for management of storm water by using Low Impact Development techniques.
- To identify the site of LID's (Low Impact Development)

- To evaluate the performance of LID's
- To compare the effect of pre and post LID Development conditions.

1.7 SCOPE OF THE WORK

The study entails comprehensive flood management analysis in Delhi's Nehru Vihar and Mukherjee Nagar regions, encompassing hydrological modeling, analysis of historical land use and climate trends, identification of flooding attributes, evaluation of Low Impact Development (LID) practices, quantification of their impact, formulation of flood management recommendations, and provision of actionable insights for urban flood resilience enhancement. The scientific rigor is maintained throughout data collection, analysis, and interpretation, ensuring robust findings. This study addresses critical flooding challenges, offering data-driven strategies to foster sustainable urban planning and bolster the areas' resilience against floods and their associated impacts.

1.8 THESIS ORGANIZATION

The organization of the thesis is as follows:

Chapter 1: Introduction

- Provides an overview of the research topic, including the significance and motivation of the study
- States the research objectives and research questions
- Outlines the scope and limitations of the study
- Provides an overview of the thesis structure and the content of each chapter

Chapter 2: Literature Review

- Presents a comprehensive review of the relevant literature related to LID site selection, LULC change, and climate change in the context of urban areas
- Summarizes previous studies, theories, and models related to the research topic
- Identifies the research gaps and highlights the importance of the current study

Chapter 3: Study Area and Data Collection

- Describes the study area, focusing on Delhi city in India.

- Provides background information about the city, including its geographical location, climate, and urbanization patterns
- Explains the data collection methods employed in the study, including the sources of LULC data, climate data, and other relevant data sets
- Describes any fieldwork conducted and the instruments or techniques used for data collection

Chapter 4: Methodology

- Presents the research methodology employed in the study
- Describes the steps involved in LID site selection, including the criteria used, data analysis techniques, and GIS methods
- Explains the process of analyzing LULC change and climate change using appropriate models or tools
- Provides details on any statistical analysis, modeling techniques, or software used in the study

Chapter 5: Results and Discussion

- Presents the findings of the study, including the results of LID site selection, LULC change analysis, and climate change analysis
- Provides a detailed discussion and interpretation of the results, comparing them with previous studies and addressing the research questions
- Highlights the implications and significance of the findings in the context of urban storm water management and LID implementation
- Identifies any limitations or challenges encountered during the study and suggests areas for future research

Chapter 6: Conclusions and Recommendations

- Summarizes the main findings of the study
- Draws conclusions based on the results and their implications

- Provides recommendations for policymakers, urban planners, or practitioners to improve storm water management practices and LID implementation in Delhi city
- Discusses the contributions of the study, its significance, and the potential for future research

Appendices

- Includes any additional information, data, or supplementary materials that support the main content of the thesis

References

- Lists all the references cited throughout the thesis following a specific citation style

CHAPTER 2:LITERATUREREVIEW

Low-impact development (LID) practices, such as green roofs and permeable pavements, mitigate climate change effects by managing stormwater and reducing urban heat, fostering resilience and sustainability in communities."- World Bank (2005)

2.1 BACKGROUND

Inefficient storm drainage networks are one of the leading causes of flooding in urban areas. As cities and towns grow, the amount of impervious surfaces such as roads, buildings, and parking lots increases, which reduces the amount of green space and natural land that can absorb stormwater. This excess water often overwhelms existingdrainage systems, leading to flash floods and damage to infrastructure and property. Additionally, climate change has led to more frequent and severe weather events, exacerbating the problem of flooding.Low Impact Development (LID) techniques offer an alternative to traditional stormwater management approaches. LID aims to manage and treat stormwater at its source, reducing the volume and velocity of runoff and promoting infiltration and natural water cycle processes. By incorporating LID techniques such as rain gardens, green roofs, permeable pavements, and bioretention systems, urban areas can reduce the amount of stormwater runoff that enters traditional drainage systems, reducing the risk of flooding.

Low Impact Development (LID) is an innovative stormwater management approach that aims to manage stormwater at its source, using site-specific techniques that mimic natural hydrology. LID is an alternative to the traditional "end-of-pipe" approach, which focuses on conveying and treating stormwater after it has already caused damage. LID techniques include rain gardens, green roofs, permeable pavements, and other practices that allow stormwater to infiltrate into the ground, evaporate, or be taken up by plants.With the increasing recognition of the importance of LID in managing stormwater, there is a growing need to identify suitable sites for implementing LID practices. Site selection is a critical component of the LID design process, and it requires a thorough understanding of the site's physical characteristics, including the topography, geology, soils, land use/land cover, hydrology, and climate.

In recent years, climate change has become a critical factor in LID site selection. Climate change has the potential to impact the effectiveness of LID practices by altering precipitation patterns, increasing the frequency and severity of extreme weather events, and altering the timing and volume of stream flows. Therefore, it is essential to assess the potential impact of climate change on the site's hydrology and design LID practices that are resilient to these changes.Another critical factor in LID site selection is land use/land cover (LULC) change. Changes in LULC can impact the site's hydrology by altering the surface characteristics that control runoff generation, infiltration, and evapotranspiration. For example, the conversion of natural areas to impervious surfaces, such as roads and parking lots, can increase the volume and rate of runoff, reduce infiltration, and increase the risk of flooding. Therefore, it is essential to understand the existing LULC and how it might change in the future, to identify suitable sites for LID practices.

Performance evaluation of storm water drainage network is a critical component of effective storm water management (Jiang et al. 2015). The goal of performance evaluation is to assess the efficiency and effectiveness of the drainage system in handling excess water from heavy rainfall or snowmelt events (Babaei et al. 2018). With a well-designed and well-functioning storm water drainage network, communities can minimize the risk of property damage, environmental degradation, and public health concerns caused by excessive runoff (Bisht et al. 2016). One of the primary methods used in the performance evaluation of storm water drainage network is hydrologic modeling. Using computational models tosimulate flow of water through the drainage system under different rainfall scenarios (Ahamed and Agarwal 2019, Rabori and Ghazavi 2018, Agarwal and Kumar 2019). The results of these simulations can be used to identify bottlenecks and determine the capacity of the system. By using these models, engineers and planners can evaluate different design options, assess the impact of proposed changes, and predict the performance of the system under various conditions. Another important aspect of performance evaluation is hydraulic modeling (Zhao et al. 2021, Agarwal and Kumar 2020). This involves using computer models to simulate the flow of water through the drainage system, taking into account various factors such as pipe sizes, slopes, and roughness. The results of hydraulic modeling can also be used to assess the impact of proposed changes to the system, such as new development, on the overall performance of the drainage network. Physical inspection is another important component of performance evaluation. This involves visually inspecting the drainage network, including inlets, pipes, and outfalls, to identify any signs of damage, blockages, or other problems that may affect the performance of the system. Regular inspections can help to detect issues early, before they become more serious, and help to prioritize maintenance and repair needs (Vemula et al. 2019, Yang et al. 2022). Extreme rain events, such as heavy storms or flash floods, can have a significant impact on storm water drainage networks. These events can overload the capacity of the system, leading to flooded streets, homes, and businesses, and causing significant damage (Yang et al. 2022, Arisz & Burrell 2006, Fletcher et al. 2013).

In addition to the immediate physical damage, extreme rain events can also result in long-term environmental impacts, such as contaminated water sources and soil erosion. One of the major challenges posed by extreme rain events is the sudden and intense nature of the runoff (Gironás et al. 2010, Goswami et al. 2006, Jain & Kumar 2012). The storm water drainage network may not be designed or built to handle such large volumes of water in a short period of time. This can result in flooding and blockages, as well as damage to pipes, culverts, and other components of the system. Another challenge posed by extreme rain events is the potential for increased runoff to contain pollutants and other harmful substances. For example, heavy rainfall can wash pollutants, such as oil, pesticides, and fertilizers, into the drainage network and out into nearby waterways. This can result in water contamination and harm to aquatic life, as well as drinking water sources for communities (Piro et al. 2019). To mitigate the impact of extreme rain events on storm water drainage networks, communities can take a number of steps, including; Upgrading the capacity, Implementing best, anagement practices, Improving maintenance and inspection, Planning for future events (Deitch & Feirer 2019, Ercolani et al. 2018, Nile et al. 2018, Bai et al. 2018).

2.2 URBANIZATION AND ITS IMPACTS

Urbanization is the process of creating urban areas, such as cities and towns, and is accompanied by various changes in land use, including the conversion of natural areas to impervious surfaces, such as buildings, roads, and pavements as shown in figure 2.1. Urbanization leads to changes in the hydrological cycle, which can result in flooding. Floods can be caused by various factors, including intense rainfall, topography, and the built environment. However, the most significant factor that contributes to flooding in urban areas is the inefficient storm drainage network.In urban areas, the traditional approach to stormwater management has been to collect and convey rainwater as quickly as possible to the nearest river or stream. This approach involves constructing an extensive network of underground pipes and culverts to channel the water away from the city. However, this approach has several drawbacks. First, it increases the flow rate of stormwater, which can lead to downstream flooding. Second, it can cause erosion and stream bank destabilization due to the increased velocity of water. Third, it can cause water pollution due to the transport of sediment, nutrients, and other pollutants.

Low Impact Development (LID) offers an alternative approach to stormwater management. LID is a set of strategies and practices that mimic the natural hydrological cycle by capturing, treating, and infiltrating rainwater where it falls. LID practices include green roofs, rain gardens, bioretention areas, permeable pavements, and infiltration trenches. LID is a cost-effective and environmentally friendly approach to stormwater management that has been proven to reduce the risk of flooding and improve water quality.

The effectiveness of LID in reducing the risk of flooding depends on several factors, including site selection, design, and maintenance. Site selection is critical because LID practices need to be located in areas that receive the most rainfall and where the stormwater runoff is the highest. The design of LID practices should take into account the local climate, soil conditions, and land use. The maintenance of LID practices is essential to ensure their continued effectiveness in reducing the risk of flooding. Regular inspections and cleaning of LID practices are necessary to prevent clogging and ensure proper functioning.

Figure 2.1 Perception of climate change and urban flooding

The world’s urban population has increased by 466% (from 746 million to 4.2 billion) in 69 years, according to data compiled by the Population Division of the United Nations Department of Economic and Social Affairs (UN DESA) (1950 to 2018). In 2018, 55.3% of the world's population lived in cities, a percentage that is expected to increase to 68.4% by 2050, according to the World Urbanization Prospects 2018 research. Since the 1950s, the urban population in the United States has increased significantly; in 1990, 2000, 2005, 2010, and 2018, the proportion of the urban population was 75.3%, 79.1%, 79.9%, 80.8%, and 82.3%, respectively. By 2050, this percentage is expected to increase to 89.2%. Urbanization alters land use through activities such as tree and vegetation clearance, infrastructure construction, stream diversion to supply water for humans, wastewater discharge to stream, and so on (Pielke1997). Because there is less vegetation to slow water down as impermeable areas develop, stormwater runoff increases (White and Greer, 2006; Du et al., 2012). Furthermore, the amount of debris swept into the stream grows, affecting its water quality (Hall et al., 1999; Ren et al., 2003; Tu, 2011) and causing pollution, hurting the ecology and natural habitat of aquatic creatures and plants (Chadwick et al., 2006).The water table lowers when natural landscapes are replaced with impermeable surfaces. (Carlson et al., 2011). Stormwater runoff is becoming increasingly common as natural water-drainage patterns change and infiltration decreases. This extra volume must be managed and sent to streams via a drainage network. Because more water enters the streams more often, the probability of catastrophic flooding increases (Hammer, 1972; Nirupama and Simonovic, 2007; Suriya and Mudgal, 2012; Jinkang et al., 2012). Figure 2.2 contrasts some of the key mechanisms involved in the rainfall-runoff process and indicates a rise in urbanization.

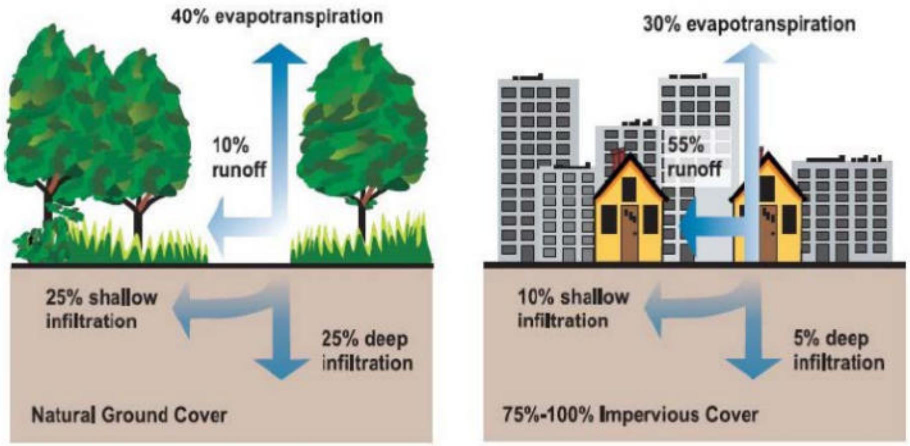


Figure 2.2Natural versus Urban Runoff Response (Source: USEPA, 2003)

2.3 CLIMATE CHANGE AND ITS IMPACT ON FLOOD

Over the past five decades, India has experienced a pronounced escalation in its population, engendering heightened stress on the nation's water resources, as documented by Ahmed et al. (2013) and Liu et al. (2019). This strain is compounded by the climate change, manifesting as augmented precipitation, heightened storm intensity, and elevated sea levels along coastal and low-lying regions, thereby instigating pluvial and urban flooding, as elucidated by Rangari et al. (2019). The altering climatic conditions have significantly elevated the likelihood of flooding in cities situated along riverbanks and in coastal areas. Flood events stand as pivotal contributors to the substantial loss of life and property, exerting profound impacts on the emotional, social, and economic facets of the affected populace. While flooding inherently represents a natural disaster, human interventions within floodplains and catchment areas, exemplified by the construction of bridges, roads, and dwellings, have altered the behavior of these events, amplifying the associated risks and resultant losses in terms of both property and human life, as highlighted by Timbadiya et al. (2011). Consequently, there arises an imperative for precise forecasting of water levels along rivers, necessitating the utilization of dependable hydraulic models for this purpose.

Understanding the impact of climate and land use/land cover (LULC) changes on the hydrologic cycle, particularly on hydrographs, is crucial for effective water resource management. Hydrographs provide valuable insights into the characteristics of river flow, including peak flow and volume of flow. Quantifying the combined effects of climate and LULC on these hydrological variables is essential for assessing water availability, flood risk, and sustainable land use planning. To explore the study of the impact of climate and LULC on the hydrologic cycle, specifically focusing on hydrograph analysis and methods for quantifying the effects on peak flow and volume of flow in rivers.

2.3.1 Impact of Climate on Hydrograph:

Climate variables, such as precipitation, temperature, and evapotranspiration, significantly influence hydrographs. Changes in precipitation patterns, including shifts in intensity, duration, and frequency, directly impact the timing and magnitude of peak flows and overall volume of flow in rivers. Higher temperatures can accelerate evaporation rates, altering the timing and duration of runoff. These climate-induced changes can lead to shifts in hydrograph characteristics, affecting water availability and streamflow dynamics.

2.3.2 Impact of LULC on Hydrograph:

LULC changes, driven by human activities like urbanization, deforestation, and agriculture, also play a crucial role in modifying hydrographs. Alterations in land cover can impact surface runoff, infiltration rates, and water storage within a watershed. For instance, the conversion of natural vegetation to impervious surfaces, such as roads or buildings, reduces infiltration capacity and increases surface runoff, influencing the hydrograph by altering the timing, intensity, and duration of peak flows and overall flow volume.

2.3.3 Quantifying the Impact of Climate and LULC on Peak Flow and Volume of Flow:

To quantify the impact of climate and LULC on peak flow and volume of flow in rivers, researchers employ various methods, including hydrological modeling techniques. These models integrate climate data, LULC information, and hydrological parameters to simulate the hydrograph response under different scenarios. Physically-based models utilize equations representing the processes involved in the hydrologic cycle, while data-driven approaches employ statistical relationships derived from observed data.

By comparing model simulations for different climate and LULC scenarios, researchers can quantify the individual and combined effects of these factors on peak flow and volume of flow. Sensitivity analyses are often conducted to assess the relative importance of climate and LULC variables in driving changes in hydrographs. Additionally, statistical methods such as correlation analysis or regression models can be applied to examine the relationships between climate, LULC, and hydrograph characteristics.Understanding the impact of climate and land use/land cover (LULC) changes on the hydrologic cycle, particularly on hydrographs, is crucial for effective water resource management. This is especially relevant when considering the context of cities and the implementation of Low Impact Development (LID) strategies. Hydrographs provide valuable insights into the characteristics of river flow, including peak flow and volume of flow. Quantifying the combined effects of climate, LULC, and LID on these hydrological variables is essential for assessing water availability, flood risk, and sustainable urban planning. This note aims to explore the study of the impact of climate and LULC on the hydrologic cycle, specifically focusing on hydrograph analysis and methods for quantifying the effects on peak flow and volume of flow in rivers, with a consideration for cities and LID.

2.4 IMAGE ANALYSIS.

There is no error-freeestimation to categorizeland cover and use. There are many different viewpoints on classification, and even when an objective numerical approach is employed, these processes still have a tendency to be subjective. There is no particular reason to believe that a single explanatory inventory should be appropriate for more than a brief classification of the LULC, given how land use and land cover patterns constantly change in response to demands. The kind of classification is designed to meet the user's needs. Generally speaking, there are two subcategories of LULC classification:

2.4.1 Unsupervised Classification

Pixels are categorized based on their reflectance characteristics. Typically, these collections are referred to as clusters. The number of clusters must be determined manually, as must the band that will be utilized. Clusters are produced by image classification using this information. The image cluster algorithm can be applied in various ways, including ISODATA and K-mean. It is necessary to manually identify each cluster with its corresponding land cover classes. A single land cover class is frequently represented by several clusters. A land cover type is created by combining clusters. When there are no sample sites available, the unsupervised classification image classification technique is frequently used.

2.4.2 ISODATA and K-mean

ISODATA (Iterative Self-Organizing Data Analysis Technique) and K-means are both unsupervised clustering algorithms used in data analysis to partition a set of data points into distinct clusters based on their similarities.

K-means is a simpler, widely-used algorithm that partitions the data into a predefined number of clusters (K) by minimizing the variance within each cluster. It starts with K initial centroids, assigns each data point to the nearest centroid, and then recalculates the centroids based on the mean of the assigned points. This process is repeated iteratively until the centroids stabilize, and the clusters do not change.

ISODATA, on the other hand, is a more advanced variant of K-means that improves flexibility by allowing the number of clusters to change dynamically during the iteration process. It not only splits clusters that are too large and merges clusters that are too close but also removes clusters that have too few data points, making it particularly useful for handling complex and heterogeneous datasets. ISODATA requires more parameters and computational resources but offers greater adaptability in cluster formation compared to the fixed structure of K-means.

2.4.3 Supervised Classification

Manually samples are collected for every land cover class in the digital image. The term "training sites" refers to these exemplary land cover classes. Different kinds of software are available for classifying images. To identify the land cover classes throughout the entire image, this software makes use of the training sites. Based on the spectral signature defined in the training set, land cover is classified. Based on the training set's similarities, the digital image classification software establishes each class. The most widely used supervised classification algorithms are minimum-distance classification and maximum likelihood classification. The maximum likelihood technique is used for the LULC classification in this study.

2.5 Maximum Likelihood Classification

The two guiding principles of the Maximum Likelihood Classification tool are:

- Each class sample's cells are distributed normally in the multidimensional space.
- Bailey's decision-making theorem.

When assigning each cell to one of the classes represented in the signature file—that is, maximizing the likelihood function—the Maximum Likelihood Classification tool takes into account both the variances and covariances of the class signatures, assuming that the distribution of a class sample is normal. Each of a predetermined set of classes has its probability of a pixel belonging determined; the pixel is then assigned to the class for which the probability is highest.

$$P(x/w_i) = \frac{1}{(2\pi)^{\frac{1}{2}}\sigma_i} e^{\left[-\frac{1}{2}\frac{(x-\mu_i)^2}{\sigma_i{}^2}\right]} \qquad (2.1)$$

The above formula is used to calculate the probability density function for class wi (forest, for example), where e is the base of the natural logarithms, x is a brightness value, μi is the estimated mean of all the values in the forest training class, and χi is the estimated variance of all the measurements in this class. Table 2.1 below lists the LANDSAT's sensors along with the corresponding images' image resolution.

The downloaded images are available in the 7 bands, al the bands are composited and mosaicked to for the single image of the study area and processed for the further analysis, which is explained in the subsequent sections.

2.5.1 IMAGE CLASSIFICATION USING ARCGIS

GIS can be used to store geographic data, make maps and analysis spatial data. The identification and computation of the land use and land cover types from these images were accomplished by ArcGIS (software used for processing and analyzing the geospatial imagery). The land use and land cover classification system presented in the report includes generalized first and second class level classes. The system classifies the three major attributes to the classification process as outlined by Grigg (1965)

- It gives names to the categories by simply using accepted terminology ;
- It enables the information to be transmitted ; and
- It allows inductive generalizations to be made.

Table 4.2 outlines the classification system adopted for the study. Level I and level II classes are given in the table. Classification tool used for supervised classification in ArcGIS is Maximum Likelihood Classification. This type of classification requires pixel marking for each class. A signature file was created for all the five classes. The signature file contains all the pixels marked under the same class.

2.6 CONVENTIONAL STORMWATER MANAGEMENT

Efficient and prompt removal of stormwater runoff is imperative for ensuring proper drainage on a site. The design of an efficient stormwater runoff conveyance system is a priority in every community, aiming to deliver runoff systematically and promptly to a centrally located management device and, subsequently, to a nearby stream, as depicted in Figure 2.3 (Stahre, 2006). In traditional stormwater management systems, the emphasis is typically on reducing runoff volume and frequency to safeguard human health and property, with comparatively lower consideration for ecosystem preservation and water quality concerns linked to stream degradation (Roy et al., 2008). Notably, there is limited attention given to enhancing water reusability, minimizing travel times, and retaining or infiltrating runoff, as indicated in the Prince George's County report (2006).Additionally, concerns about the long-term effectiveness and sustainability of conventional drainage systems have been raised in previous studies (Wilderer, 2004; Zevenbergen et al., 2008; Burns et al., 2012), with a particular focus on the associated costs and time demands for installation and maintenance. The conjunction of these factors, compounded by the escalating trends of urbanization and the impacts of climate change, underscores the imperative for the development of a new, improved, and cost-effective drainage system. Such a system should not only mitigate stormwater volume but also replicate predevelopment hydrological functions and safeguard aquatic biodiversity (Zahmatkesh et al., 2014; Zhou, 2014).

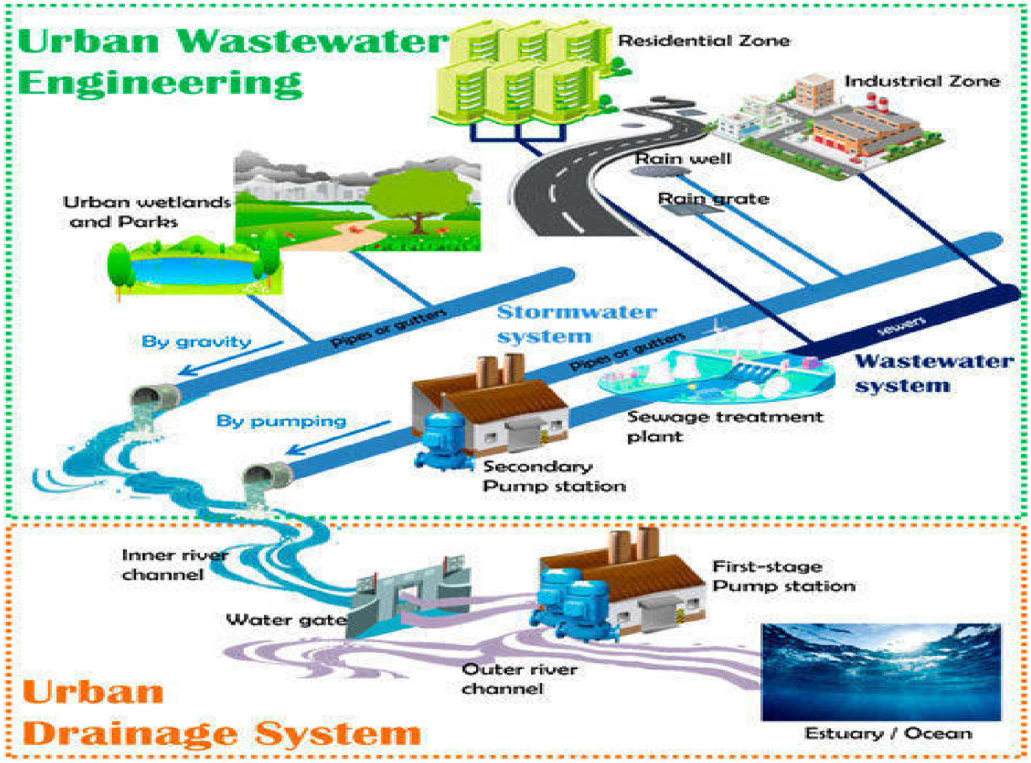


Figure 2.3. Diagram of urban stormwater system and drainage system (Source: Zhou, 2014)

2.7 LOW IMPACT DEVELOPMENT TECHNIQUES

A ground-breaking approach aimed at ensuring that the hydrology of a site after development closely mirrors its natural state is known as Low Impact Development (LID) (USEPA, 1999a). In order to protect water quality and related aquatic habitats, the U.S. Environmental Protection Agency (USEPA) defines LID as the use of systems and practices that either replicate or employ natural processes that lead to the infiltration, evapotranspiration, or beneficial use of rainwater. LID reduces effective imperviousness, encourages natural water flow within a watershed, and sees stormwater as an asset rather than a waste product that should be thrown away. According to USEPA, when applied on a broad scale, LID has the potential to uphold or restore the hydrologic and ecological functions of a watershed.While terminologies for LID may vary across regions, the underlying objectives remain largely consistent. The detailed planning and design techniques also differ for each region, aligning with their specific county, state, and federal regulations. Nonetheless, the primary objectives of these techniques are to integrate key elements that fulfil the functions of aordinary drainage system while concurrently preserving the environment and reducing the construction and maintenance costs associated with stormwater infrastructure (see Figure 2.2).

2.7.1 LID practices

There are different LID practises used across the world, each with its own set of functions and stormwater management approaches. According to USEPA 2000, the type of LID practices used depend on site conditions such soil type, impermeable terrain, slope, and the deepness of the ground water level. LID controls such as porous/pervious pavements, bioretention areas/rain gardens, rain barrels, grass swales, and vegetative roofs, among others. Previous studies have shown promising results for both individual and combination of these LID controls. For instance, porous/pervious pavements have been found effective in reducing stormwater runoff in studies conducted by Legret and Colandini in 1999 and Ahiablame and Shakya in 2016. Bioretention areas/rain gardens have also shown promising results in studies conducted by Dietz and Clausen in 2005 and Davis in 2008. Similarly, rain barrels have been found to be effective in reducing stormwater runoff in studies conducted by Abi Aad et al. in 2009 and Jones and Hunt in 2010. Grass swales have also shown promising results in reducing stormwater runoff in studies conducted by Abida and Sabourin in 2006 and Stagge et al. in 2012. Vegetative roofs have been found effective in reducing stormwater runoff in studies conducted by Carter and Todd in 2006 and Carter and Jackson in 2007. These LID controls are designed to capture and temporarily retain stormwater (rain barrels), infiltrate stormwater (rain gardens, porous pavement), and promote evapotranspiration (vegetative roofs, rain gardens) according to USEPA (2000). Table 2.1 briefly describes the LID control and usage in the past.Low Impact Development (LID) controls along with their promising outcomes as documented in past studies. Among the featured controls are Porous/Pervious Pavements, which have been explored by Legret and Colandini in 1999 and Ahiablame and Shakya in 2016. Bioretention Areas and Rain Gardens have also garnered attention, with studies conducted by Dietz and Clausen in 2005 and Davis in 2008. Rain Barrels, investigated by Abi Aad et. al. in 2009 and Jones and Hunt in 2010, showcase another avenue of LID control. Grass Swales, examined by Abida and Sabourin in 2006 and Stagge et. al. in

2012, contribute to the array of sustainable practices. Lastly, Vegetative Roofs, as studied by Carter and Todd in 2006 and Carter and Jackson in 2007, round out the list. These LID controls, identified through prior research, demonstrate promising results in managing stormwater runoff and offer potential solutions for sustainable urban development and environmental conservation.

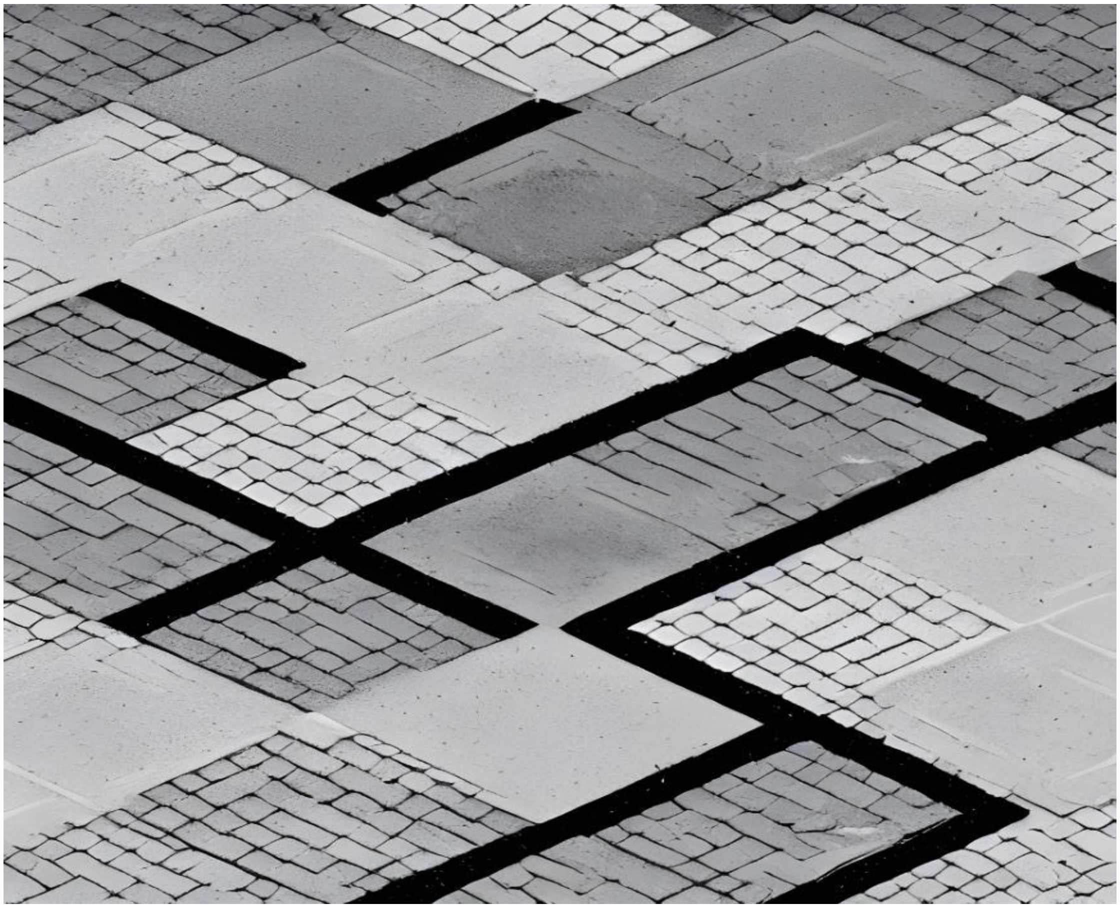


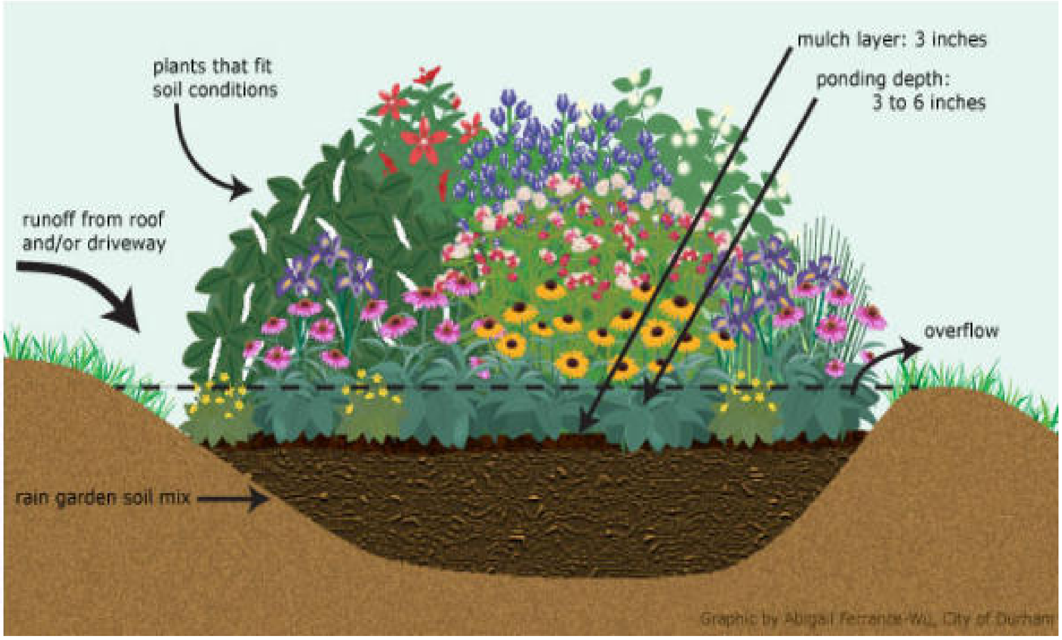
Figure 2.4 Porous Pavements

2.7.2 Porous/Pervious Pavements

Porous or pervious pavements are a type of LID control designed to reduce stormwater runoff and increase groundwater recharge. They are an alternative to traditional impervious pavements that do not allow water to pass through and instead generate large amounts of surface runoff during storms. Porous pavements are made of porous materials such as pervious concrete, asphalt, or interlocking pavers that allow water to percolate through the pavement surface and infiltrate into the underlying soil.The primary benefits of porous pavement as an LID control are that it helps to reduce stormwater runoff and promote infiltration, which helps to recharge groundwater aquifers. By capturing and infiltrating stormwater on-site, it reduces the need for large, costly infrastructure projects such as storm sewers, retention basins, and detention ponds. Moreover, porous pavements can also reduce the urban heat island effect and improve the aesthetics of urban landscapes.One of the challenges of porous pavements is that they require maintenance to ensure that they remain permeable over time. Accumulation of sediment and debris can clog the pores in the pavement, reducing its effectiveness. However, regular maintenance such as vacuum sweeping, power washing, or occasional resurfacing can help to ensure the longevity and effectiveness of porous pavement as an LID control.

2.7.3 Rain Garden

A rain garden is a low area that collects rainwater from impermeable surfaces, such as parking lots, private residences, and small businesses, and lets it seep into the ground (USEPA 2000). It also improves the quality of water by filtering out impurities and reduces runoff by increasing infiltration. Additionally, it is made up of three or more native plant species that enhance the aesthetics of the area around it, transpire runoff, and serve as a habitat for butterflies and other wildlife (Figure 2.3). In technical terms, a rain garden that incorporates an underdrain system is referred to as a bioretention area. Nonetheless, those two terms are frequently used interchangeably.



Graphic by Abigail Ferrance-Wu, City of Durham

Figure 2.5: Rain garden and its components

2.7.4 Rain Barrel

The United States Environmental Protection Agency (USEPA, 2000) defines a rain barrel as a specialized cistern designed to "capture water from a roof and hold it for later use, such as on lawns, gardens, or indoor plants." The fundamental concept behind a rain barrel is straightforward: by collecting runoff from the roof, it diminishes the volume of water flowing across a property and delays the peak runoff. Furthermore, the stored water can be reused, it represents a sustainable approach to stormwater management. The rooftop's surface area and the intended amount of rainfall storage determine the rain barrel's size. As an illustration, a 42-gallon barrel can provide 0.5 inches of runoff storage for a rooftop area of approximately 133 square feet (Prince George's County, 1999a). Gutter and downspout systems are used to transfer water from the roofs to the barrel (refer to Figure 2.4). Overflow and drain outlets are commonly found on rain barrels. You can use the drain outlet to use the water for irrigation by connecting it to a garden hose. However, due to possible contaminants and germs from roof materials, care should be taken to prevent putting this water on edible plants. Regular maintenance of rain barrels is essential for optimal efficiency, with gutters equipped with filtration screens to prevent debris clogging.

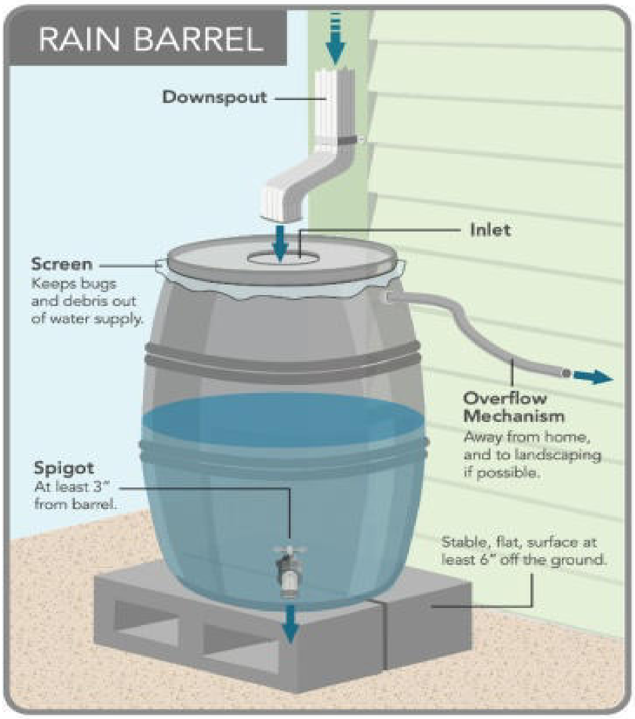


Figure 2.6: Rain Barrel and its components (Source: Abigail Wu, Durham)

2.7.5 Grass swales

Grass swales are another LID technique that helps manage stormwater runoff. They are designed as shallow channels that are filled with vegetation, typically grass or other plants, which help to slow down and filter runoff. As stormwater flows through the swale, the vegetation helps to remove pollutants and sediment, while the swale itself provides storage capacity for excess runoff during storms.Grass swales can be incorporated into a variety of landscapes, including along roadways, in parking lots, and in residential areas. They are particularly effective in areas with moderate to low slopes and can be designed to accommodate larger volumes of runoff by increasing their width or depth.In addition to their stormwater management benefits, grass swales also have aesthetic and ecological benefits. They provide habitat for wildlife, promote biodiversity, and can contribute to improved air quality.

Figure 2.7 Swales example

2.7.6 Vegetative roofs

Vegetative roofs are an important LID technique that can help to reduce the negative impacts of urbanization on the natural water cycle. Vegetative roofs are designed to replicate natural vegetation in urban environments, providing a range of ecological, social, and economic benefits. These green roofs are essentially a layer of vegetation that is installed on top of a waterproof membrane or other substrate.Vegetative roofs have become increasingly popular in recent years due to their potential to reduce stormwater runoff, reduce the urban heat island effect, and improve the aesthetic appeal of buildings. These green roofs can also improve air quality, reduce energy consumption, and increase the lifespan of roofing materials.One of the most significant benefits of vegetative roofs is their ability to manage stormwater. The vegetation and growing medium of a vegetative roof can absorb and store rainwater, reducing the amount of runoff that enters the stormwater system. This can help to prevent flooding and erosion, improve water quality, and reduce the strain on existing stormwater infrastructure. In addition, the vegetation on a vegetative roof can help to remove pollutants from the air and water, further improving water quality.

Figure 2.8: Vegetated Roof as LID

Vegetative roofs can be installed on a range of building types, including residential, commercial, and industrial structures. They are typically installed on flat or low-sloped roofs, although they can also be installed on steeper roofs with additional structural support. There are several different types of vegetative roofs, including extensive green roofs, which have a thin layer of soil and support hardy plant species, and intensive green roofs, which have a deeper growing medium and can support a wider range of plant species.The installation of vegetative roofs can be a significant investment, but over time, they can provide a range of economic benefits. Vegetative roofs can reduce energy consumption by insulating buildings and reducing the need for air conditioning during hot summer months. They can also increase the lifespan of roofing materials, reducing the need for costly repairs and replacements. In addition, vegetative roofs can increase property values, improve the aesthetic appeal of buildings, and provide additional usable space for outdoor activities.

2.7.6 Effectiveness and limitations of LID controls

Numerous studies have systematically assessed the temporal performance of Low Impact Development (LID), examining its immediate post-installation behavior and maintenance requirements. Evaluation criteria include the extent of runoff detention, the nature and magnitude of removed pollutants, and the sustained effectiveness of LID. Notable investigations into LID efficacy concerning both water quantity and quality metrics have been conducted. Davis (2008), Line and Hunt (2009), Chapman and Horner (2010), and DeBusk and Wynn (2011) observed reductions in runoff ranging from 58%, 49%, 74%, to 97%, respectively, following the implementation of bioretention areas.

Further more, comprehensive analyses by DeBusk and Wynn (2011), Davis (2008), Rusciano and Obropta (2007), Hunt et al. (2006), Hsieh and Davis (2005), and Roseen et al. (2006) underscored the success of bioretention systems in enhancing water quality. However, skepticism regarding the performance and feasibility of LID controls arises, especially in the absence of regular maintenance. Instances of efficiency decline due to clogging issues have been noted (Hsieh and Davis, 2005; Hsieh et al., 2007; Bergman et al., 2011). Asleson et al. (2009) encountered challenges in achieving anticipated reductions in rain garden drain time due to soil restrictions. Concerns have been raised about the winter performance of infiltration-based LID systems and potential groundwater contamination resulting from impurity absorption (Dietz, 2007). Some studies reveal that the reduction in runoff volume following LID implementation may be lower than anticipated in extreme events, emphasizing the high sensitivity of such reduction to local conditions (Nascimento et al., 1999; Holman-Dodds et al., 2003).

2.8 ADVANCEMENT ON STORM WATER MANAGEMENT

Arisz and Burrell (2006) emphasized the importance of incorporating climate change considerations into the planning and design of drainage infrastructure. Over time, the cumulative effects of climate change are expected to impact the hydrology, influencing the volume and frequency of peak flows. This could lead to more frequent flooding and surcharging of drainage systems due to increased rainfall intensity.

Bisht et al. (2016) addressed urban stormwater management by analyzing rainfall trends using Mann-Kendall and Sen's slope tests and conducting frequency analysis for a small urban area in West Bengal, India. They used MIKE URBAN and SWMM models to design an efficient drainage system for the region. Similarly, Rabori and Ghazavi (2018) applied the SWMM model to predict urban flooding in Zanjan, Iran, highlighting the need for assessing drainage system performance under extreme events. The study emphasizes the importance of regular evaluations of stormwater drainage networks to prepare for and mitigate the impact of extreme rainfall.

Peter et al. (2014) discussed the challenges of integrating urban drainage, water supply, and simulation models within broader urban water systems. They reflected on 30 years of research in urban drainage modeling, advocating for pragmatic, user-friendly approaches that address the interplay between social, economic, and technical factors. Despite some obstacles, they highlighted the potential of integrated models to serve as effective communication platforms and tools for exploring uncertainties in urban water systems, guiding future research and practice.

Peilin and Minghong (2012) highlight that water scarcity is a significant challenge in China's rapid urbanization, particularly in the eastern coastal regions where it has become a common constraint. Their case study of Shandong illustrates the urbanization process over recent decades, noting how rapid urban growth has increased urban water demand, particularly for domestic use, leading to strained water supplies. The study also documents significant environmental impacts, including groundwater depletion, river and spring dryness, seawater intrusion, and declining water quality. To address these issues and achieve sustainable urbanization in Shandong and similar regions, the authors recommend comprehensive measures such as developing inter-city water networks, planning urbanization based on local water availability, adjusting industrial structures, and innovating water management practices, with a focus on ecological restoration. They conclude that the water shortages and environmental degradation linked to urbanization in China pose serious risks to the sustainability of urban growth, necessitating integrated approaches to urban planning and water resource management.

Sher, Bruce, and Asaad (2013) investigated how the placement of Floating Treatment Wetlands (FTWs) in rainwater reservoirs affects hydraulic performance. Their study, which was the first of its kind, found that the size, orientation, and arrangement of FTWs significantly influence their effectiveness. The research demonstrated that FTWs, when positioned centrally in the reservoir, can enhance hydraulic performance by improving water flow and treatment efficiency.

Anna and Ilaria (2015) explored the implementation of Low Impact Development (LID) systems in urban catchments, focusing on how green roofs and permeable pavements affect hydrological responses. Using the EPA SWMM model, they simulated various land use scenarios and found that LID measures improved stormwater management by restoring natural flow regimes and reducing runoff. Their study highlighted the need for detailed land use analysis to effectively implement LID solutions.

David and Michael (2015) compared stormwater runoff and nutrient output from LID and traditional control watersheds using the Stormwater Management Model (SWMM). Their results showed that, with calibration, the models for LID and traditional watersheds predicted runoff within 12% and 5% of observed values, respectively. This study underscored the importance of calibration in improving the accuracy of runoff predictions and noted that nutrient output predictions were less accurate compared to runoff predictions.

Uzair (2010) discussed the benefits of LID for sustainable rainwater management, presenting case studies and modelling techniques for rainwater LID measures. The study demonstrated that LID technologies, such as rainwater gardens and bio-retention systems, offer significant advantages over traditional methods. It emphasized the need for updated models that incorporate LID-specific functions to better support sustainable urban development.

Maya et al. (2010) addressed the problems caused by excess rainwater runoff from impervious surfaces, such as sewer system overflows and groundwater depletion. Their research focused on controlling runoff at its source using specialized techniques. By modeling various Best Management Practices (BMPs) with EPA SWMM-5, they assessed the effectiveness of different runoff reduction strategies, highlighting the importance of source control in managing stormwater and reducing peak flows.

Haifeng (2012) assessed Low Impact Development (LID) practices for urban runoff control using a case study of Beijing Olympic Village (BOV). The study utilized the

BMPDSS model to evaluate the original stormwater management system and to propose improvements for optimizing runoff control. The SWMM-BMPDSS framework was used to analyze peak flow and runoff reductions based on 2008 rainfall data. The findings informed recommendations for enhancing BOV's stormwater management system to better handle urbanization effects.

Aysha and Shoukat (2015) evaluated the potential of a Rainwater Harvesting (RWH) system in South Al-Abad, Chittagong, using the Analytic Hierarchy Process (AHP) to analyze factors such as roof area and drainage density. The HEC-HMS model was employed to simulate precipitation-runoff processes and assess the effectiveness of RWH in addressing water shortages and urban flooding.

Elliott and Trowsdale (2007) reviewed ten existing rainwater models, focusing on their capabilities to model Low Impact Development (LID) systems. They found that while many models incorporate various LID devices and components, there is still a need for further development in areas such as pollutant transport, base flow, and automated calibration. The review concluded that current models are useful for preliminary planning but require improvements for comprehensive LID applications.

Shouhong and Yiping (2015) evaluated the SWMM LID module's performance in modeling permeable pavement systems. They identified limitations in the module's ability to accurately simulate infiltration through pavement layers and proposed an alternative method of representing permeable pavements as conventional sub-catchments. This method can be used as a temporary solution until improvements are made to the LID module.

Gabriele et al. (2010) compared various urban stormwater management techniques, including distributed and centralized systems, to determine their effectiveness in mitigating rainwater impacts. Using a custom model, the study assessed the impact of different best management practices (BMPs) on water quantity and quality. The results highlighted the need for integrated BMP approaches and maintenance plans to enhance urban drainage systems.

Obaid et al. (2014) investigated sewerage overflow and flooding in Karbala city using SWMM. They found that the western part of the residential area is particularly vulnerable due to sewer overflow exacerbated by inadequate drainage, gaps in manholes, and the presence of broken covers. Recommendations include rehabilitating the drainage systems, sealing gaps, and using lift pumps to manage high water volumes.

Liong et al. (1991) developed a knowledge-based system to automate the calibration of the SWMM runoff model. Their system focuses on sensitivity studies of calibration parameters, parameter selection, and knowledge representation. It effectively discriminates prediction errors and adjusts parameters to improve model accuracy.

Ellis et al. (2012) introduced a coupled 1D/2D modeling approach to analyze surface flow paths, flood depths, and velocities during extreme storm events. This method helps in flood risk assessment and planning but is less suitable for real-time forecasting due to high sensitivity to data quality and computational demands.

Harshal Pathak et al. (2015) examined BMPs using SWMM to mitigate urban flooding. They found that rain garden systems significantly reduced peak flow and runoff volume, offering a more sustainable solution compared to conventional methods. A new design approach focusing on risk assessment and resilience is proposed.

Warwick et al. (1990) applied SWMM to a residential area with varying parameters and calibration events. Their study assessed the model's effectiveness at different spatial scales and calibration scenarios, focusing on forecasting accuracy.

Lei Jiang et al. (2014) used SWMM to simulate urban flooding in Dongguan City, China. The study demonstrated the model’s potential for predicting urban flooding but noted limitations due to its lack of surface runoff routing.

Chien-Lin H. (2015) employed SWMM for rainwater harvesting system design, using simulation optimization to determine the optimal tank capacity and quantity. The study utilized fuzzy C-means clustering and statistical analysis to improve flood mitigation designs.

Shouhong Z. and Yiping G. (2015) evaluated the SWMM LID module’s performance for modeling permeable pavements. They found limitations in the module’s ability to accurately simulate infiltration when pavement depth is less than 120 mm and suggested an alternative approach using conventional sub-catchments.

2.9 Literature on Application of HECRAS for LID

Alexander et al. (2010): This study developed three hydraulic models using HEC-RAS for the Hoje catchment to simulate flood events: (i) a 1D model for river and floodplain, (ii) a 2D model for both, and (iii) a 1D-2D coupled model with a 1D river and 2D floodplain. All three models effectively recreated a historic flood event. The 2D model was particularly noted for its accuracy in simulating flood wave propagation and flow velocity. The 2D mesh analysis showed sensitivity to mesh alignment towards barriers.

Abdulaziz et al. (2016): This study compared 1D and 2D hydraulic models for water level simulation in channels and floodplain inundation. Two methods were described: (1) a 1D model that discretized floodplain units into storage regions and (2) a 2D model for channel and floodplain surface. The models were tested on Bear Creek and the Great Miami River and evaluated by comparing simulated flood extents to actual measurements. The study also explored the theoretical foundations of floodplain flow modeling using 2D analysis.

Timbadiya et al. (2012): This research highlighted the sensitivity of channel roughness in developing hydraulic models for flood inundation mapping and forecasting. Manning's roughness coefficients were calibrated using flood data from 1998 and 2003 through HEC-RAS. The calibrated model was then used to simulate the 2006 flood, emphasizing the importance of accurate roughness parameterization in flood modeling.

Eldho et al. (2014): Focused on the spatial and temporal LULC changes in the Mithi River catchment in Mumbai, India, between 1966 and 2009. The study reported a significant increase in built-up areas (59.66%), leading to higher runoff peaks. The flood hydrographs for different land use scenarios were derived using HEC-HMS, and floodplain and hazard maps were developed by integrating HEC-HMS, HEC-RAS, HEC-GeoHMS, and HEC-GeoRAS. The combined modeling approach proved effective in estimating floods and mapping floodplains and hazards.

Praveen et al. (2016): This study assessed LULC changes in the Lower Tapi Basin from 2001 to 2015, highlighting the impact of urbanization and deforestation on flood peaks. HEC-HMS was used to estimate peak flows, revealing a positive correlation between urbanization and increased surface runoff. The study concluded that urbanization significantly affected hydrological processes, resulting in higher peak flows due to reduced forest cover.

Varun Narayan Mishra et al. (2014): This study focused on Muzaffarpur city, Bihar, analyzing LULC changes using Landsat images from 1988 and 2010. The Land Change Modeler (LCM) was used to predict future LULC changes for 2025 and 2035. The study utilized Erdas Imagine software for image processing and reported an accuracy of 72.28% for LULC change predictions.

Singh et al. (2015): This study used the CA-MC model, combined with MCE technique, to identify temporal and spatial changes in Allahabad district, Uttar Pradesh. The study calibrated and validated the model using Landsat imagery from 1990 to 2000 and projected LULC changes for 2020. The findings highlighted the influence of socio-economic and biophysical factors on agricultural lands and settlements.

Sundara Kumar et al. (2015): This research analyzed and predicted LULC changes in Vijayawada city, Andhra Pradesh, using Landsat images from 1973, 2001, and 2014. The study area covered 85,515.75 hectares, and the LCM software was used to predict future LULC changes for 2030 and 2040. The study required supplementary inputs, including an elevation map from SRTM imagery and a dynamic road network from Survey of India topo sheets. The accuracy across all phases exceeded 80%.

Dhruva et al. (2015): This study developed a deforestation model using LCM, analyzing land cover maps from 1996 and 2001 to predict deforestation. Inputs included proximity to roads, slopes, and towns. The model's predictions for 2006 were validated against actual classified images, showing the model’s effectiveness in predicting deforestation.

Jain et al. (2017): This study analyzed and predicted urban growth in Gurgaon city using satellite images from 1995, 2009, and 2016. The Land Change Modeler was used to predict future land use scenarios for 2020 and 2025, helping to anticipate the impacts of urbanization on land use patterns.

CONCLUSIONS

"In conclusion, the adoption of Low-Impact Development (LID) techniques presents a promising avenue for mitigating climate change impacts by managing stormwater, reducing urban heat, and promoting sustainability. However, effective implementation requires careful site selection, considering factors like soil type and land use patterns. Additionally, studies assessing the influence of climate change on LID effectiveness are imperative for enhancing resilience and adapting strategies accordingly. Addressing urban heat island effects through novel approaches within LID frameworks further underscores the importance of innovative solutions in mitigating climate challenges and fostering resilient, livable cities."

CHAPTER 3: STUDY AREA AND DATA COLLECTION

3.1 STUDY AREA

Delhi is situated between the latitudes of 28° 24′ 17″ and 28° 53′ 00″ North and the longitudes of 76° 50′ 24″ and 77° 20′ 37″ East in the northern part of the Indian subcontinent (Fig. 1). Uttar Pradesh and Haryana have borders with the territory of Delhi. Delhi spans 1.483 square kilometres. The line's maximum length and width are 51.90 km and 48.48 km, respectively. along the Gangetic Plains' periphery. It is located somewhat west of 78E longitude and slightly north of 28N latitude. The vast Indian desert of Rajasthan, historically known as Rajputana province, is to the west and south-west, while the Yamuna River, across which the modern-day larger Delhi has extended, is to the east. To the west of the city, the ridges of the Aravalli hills stretch all the way into Delhi itself, giving some areas of the city an undulating appearance. Delhi, the capital city of India, has a semi-arid climate with high variation in temperature. The city experiences hot summers and cold winters, with temperatures ranging from about 4°C (39°F) in the winter to about 46°C (115°F) in the summer. The average temperature in Delhi is around 25°C (77°F). Delhi receives most of its rainfall during the monsoon season, which lasts from June to September. During this time, the city gets an average of about 714 millimeters (28 inches) of rain. The rest of the year is relatively dry, with only a few millimeters of rain per month. The city is prone to drought during the dry season and to flooding during the monsoon season. Overall, the climate of Delhi is characterized by extreme temperatures and variable rainfall.

3.2 DATA COLLECTION

IRS-P6, LISS-3 and Landsat 8 Imaged were used which are freely available on the Indian GIS website Bhuvan and USGS website earth explorer respectively for the year 2020. Satellite information is given in table 1 and 2 for LISS 3 and Landsat 8 and satellite respectively. Details of band informationis given in the thesis, Rainfall data was collected from the India Meteorological Department (IMD). Layout of existing drainage network of Mukhrjee Nagar was collected from Delhi municipal corporation.

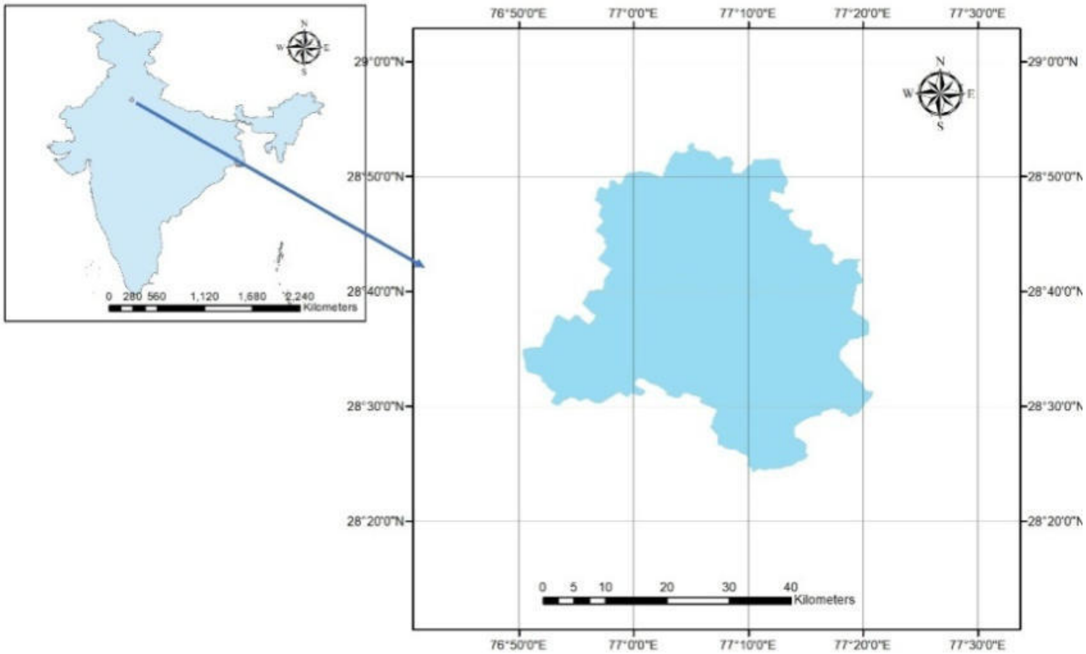


Figure 3.1 Study area.

3.2.1 Data CollectionGIS and RS data

IRS-P6, LISS-3 and Landsat 8 Imaged were being used which are freely available on the Indian GIS website Bhuvan for the year 2000, 2005, 2010, 2015, 2020. Satellite information is given in table 3.1 and 3.2 for LISS 3.3 and Landsat 8 and satellite respectively. Table 3.3 gives the acquired dates of the images.

3.2.2 Drainage Network Data

Designing an effective storm water drainage network requires a variety of data and information to ensure that the system is properly sized, located, and constructed to meet the needs of the community. Some of the data required for the design of a storm water drainage network include:

1 Hydrologic data: This includes information on the quantity and distribution of precipitation in the area, including the frequency and intensity of rain events. This data is used to determine the amount of runoff that will need to be managed by the drainage network. Rainfall data was obtained from the Indian Meteorological department (IMD) from 1970 to 2020.

2 Topographic data: This includes information on the land surface elevation, slope, contours and other physical features of the area. This data is used to determine the location and alignment of the drainage network and to ensure that it will effectively convey runoff from the catchment to the discharge point. In the present study contour map was obtained from the Delhi Municipal Corporation from which slope and elevation information were derived.

3 Soil and geotechnical data: This includes information on the physical and mechanical properties of the soil, including its permeability. This data is used to determine the design of the drainage infrastructure, including the type and size of pipes, the slope of channels, and other design considerations. Soil information was also obtained from the Delhi Municipal Corporation.

Table 3.1 LISS 3 Images specification

Specification	LISS-3
No. of Bands	4
Spectral Bands(μ)	B2 0.52-0.59; B3 0.62-0.98 B4 0.77-0.86; B5 1.55-1.70
Resolutions	23.5 m
Swath	140 km
Revisit	24 days
Data Rate (Mbs per Stream)	105
Quantisation	10-bit
Gains	100% Albedo no gain setting

4 Land use and land cover data: This includes information on the type and extent of development in the catchment, including residential, commercial, and industrial areas. This data is used to determine the potential sources of pollutants and to ensure that the drainage network is designed to minimize the risk of water quality degradation. LULC maps were developed using LISS 3 satellite image.

Table 3.2 Landsat 8 Images specification.

Band # and Type	Bandwidth (µm)	Resolution (m)
Band 1 Coastal	0.43 - 0.45	30
Band 2 Blue	0.45 - 0.51	30
Band 3 Green	0.53 - 0.59	30
Band 4 Red	0.63 - 0.67	30
Band 5 NIR	0.85 - 0.88	30
Band 6 SWIR 1	1.57 - 1.65	30
Band 7 SWIR 2	2.11 - 2.29	30
Band 8 Pan	0.50 - 0.68	15
Band 9 Cirrus	1.36 - 1.38	30
Band 10 TIRS 1	10.6 - 11.19	30 (100)
Band 11 TIRS 2	11.5 - 12.51	30 (100)

5 Existing infrastructure data: This includes information on the location and condition of existing drainage infrastructure, including pipes, channels, and other components of the network. This data is used to determine the catchments and sub catchment by relating to the contour map. Existing network and sub catchment information was obtained from Delhi Municipal Corporation.

Table 3.3 Image Acquired Date of Images from the satellite

Image Year	Acquired Date	Satellite
2000	14 July 2000	Landsat 8
2005	11 Jun 2005	
2010	28 Oct 2010	
2015	09 Oct 2015	LISS 3
2020	08 Sept 2020	

CHAPTER 4: METHODOLOGY

"Agriculture's strength lies in its ability to adapt. Let us cultivate hope and crops that flourish in a water-scarce world."- Agro World

4.1 BACKGROUND

A significant portion of earth's landscape has undergone alterations due to increasing human environmental interventions, placing immense pressure on terrestrial ecosystems. Land cover encompasses elements like plants, rocks, and buildings on the surface, distinct from land use, which defines the activities on a parcel of land, such as agriculture, habitation, or industry (Lillesand et al., 2003). The study of land use and land cover (LULC) has become indispensable for managing natural resources and understanding the diverse impacts of human activities on the environment. The accelerated pace of urbanization stands out as a major driver of LULC transformation, with urbanized societies predominantly emerging in the 19th and 20th centuries. The shift from rural to urban habitats, propelled by economic growth, has led to the conversion of rural areas into urban centers, altering the urban-to-rural ratio (Davis, 1955). Rapid urbanization, at times, has contributed more significantly to stream degradation than other forms of land use (Hoffman et al., 2000).Research by Jain et al. (2016) in Delhi revealed notable changes in LULC from 1977 to 2014, including a +30.61% increase in built-up areas, -22.75% decrease in agricultural areas, -5.31% reduction in dense forest, -2.76% decline in wasteland, and +2.41% growth in the road/rail network. Notably, open forest, scrubs/degraded forest, plantations, and rivers/water bodies showed no significant net percent change. In the period from 1990 to 2018, Delhi witnessed a constant rise in built-up area and open/fallow land, coupled with a decrease in agricultural land and vegetation. Specifically, open/fallow land increased by 44%, built-up area surged by approximately 326%, while agricultural land and vegetation cover decreased by 12% and 34%, respectively (Naiko et al., 2020).Variable Source Area (VSA) hydrology, a process-based concept identifying areas prone to saturated overland runoff and increased potential for pollutant transport, informs recent Low-Impact Development (LID) siting techniques targeting non-point source (NPS) pollutants from smaller sub-catchments of watersheds (Hewlett & Hibbert, 1967; Qiu, 2009). Hydrologically Sensitive Areas (HSAs), a related concept predicting pollution transmission, have been utilized for constructing conservation buffers but have not been applied to prioritize specific locations for LID in urban watersheds.This study introduces a Geographic Information System (GIS)-based framework to assist landscape architects, urban planners, and watershed managers in making informed decisions regarding LID placement. The framework prioritizes locations for LID based on the identification of HSAs using a multi-variable topographic index and the assessment of suitability for LID application considering land use, spatial scale, location within the stream network, and efficiency in impervious areas. The chapter demonstrates the adaptability and broad application of this method by addressing various methodologies, including climate and LULC changes over time, carrying capacity of existing storm drainage networks, and finding solutions through flood susceptibility maps and identifying optimal sites for LID.

Table 4.1 LANDSAT sensors and Image Resolution

YEAR	SENSOR	RESOLUTION(m)
2001	LANDSAT- 5 Thematic Mapper	30×30
2010	LANDSAT -7 Enhanced Thematic Mapper Plus	30×30
2015	LANDSAT-8 Operational Land Imager and Thermal Infrared Sensor	30×30

4.2 COMPREHENSIVE APPROACH

Comprehensive approach to Low Impact Development (LID) site selection for stormwater management is very important for sustainable development of the city. Present design approach considers various factors that affect stormwater management, including climate change and land use/land cover change analysis, and analyses the existing storm network design to identify areas that require improvement. Furthermore, it identifies flood susceptibility areas and suggests suitable sites for LID implementation. The methodology emphasizes the importance of using a variety of data sources, including GIS data and local knowledge, to make informed decisions about site selection. Figure 4.1 gives the comprehensive approach to Low Impact Development (LID). The methodology for LID site selection for stormwater management starts with an analysis of climate change and LULC change, which can have a significant impact on the hydrology of a region. This analysis can be conducted using various models and tools, including Land Change Modeler in ArcGIS or

QGIS. The outputs of this analysis will provide valuable information on how changes in precipitation patterns and land use may affect stormwater runoff in the region. The next step is to analyze the existing stormwater network design and identify any potential lacunas. This analysis can be conducted by reviewing existing stormwater infrastructure maps and conducting site visits to identify areas with high potential for flooding or other stormwater-related issues. Once the areas of concern have been identified, flood susceptibility maps can be developed using tools such as the Hydrology and Hydraulic Analysis (H&H) parameters. These maps can then be used to identify sites that are suitable for LID installation. The selection of suitable LID sites can be done using various criteria, such as land use/land cover, slope, soil type, wetness index, and drainage density. These criteria can be weighted using the AHP method to determine the relative importance of each criterion. The weighted criteria can then be combined using overlay analysis in ArcGIS to create a suitability map for LID installation. Once the suitability map is generated, the final step is to prioritize the potential LID sites based on their suitability and other factors such as community priorities, project budget, and available resources. This prioritization can be done using a multi-criteria decision analysis (MCDA) approach, which considers multiple criteria simultaneously to determine the best sites for LID installation. Every step presented in these methodologies are briefly described in the subsequent sections.

The figure provides a comprehensive approach to Low Impact Development (LID) site selection for stormwater management. The methodology begins with Data Collection, which is essential for understanding the existing conditions and includes gathering information on the existing storm drainage network, meteorological data, satellite images, and soil data.

The Data Collection phase is crucial as it forms the basis for the subsequent analysis. This step involves gathering detailed information about the storm drainage network, such as the layout, size of conduits, and elevation data. Additionally, meteorological data like temperature and rainfall, satellite images for multispectral analysis and Digital Elevation Models (DEM), and soil data for understanding soil type and infiltration rates are collected.

Next, the figure highlights the Temporal Change Study, where two key analyses are conducted:

Quantification of Changes in Rainfall: This includes studying trends in rainfall and updating Intensity-Duration-Frequency (IDF) curves to reflect climate change impacts.

LULC Change Analysis: Quantification of Land Use and Land Cover (LULC) changes, which are crucial as they significantly affect hydrological processes, such as runoff and infiltration.

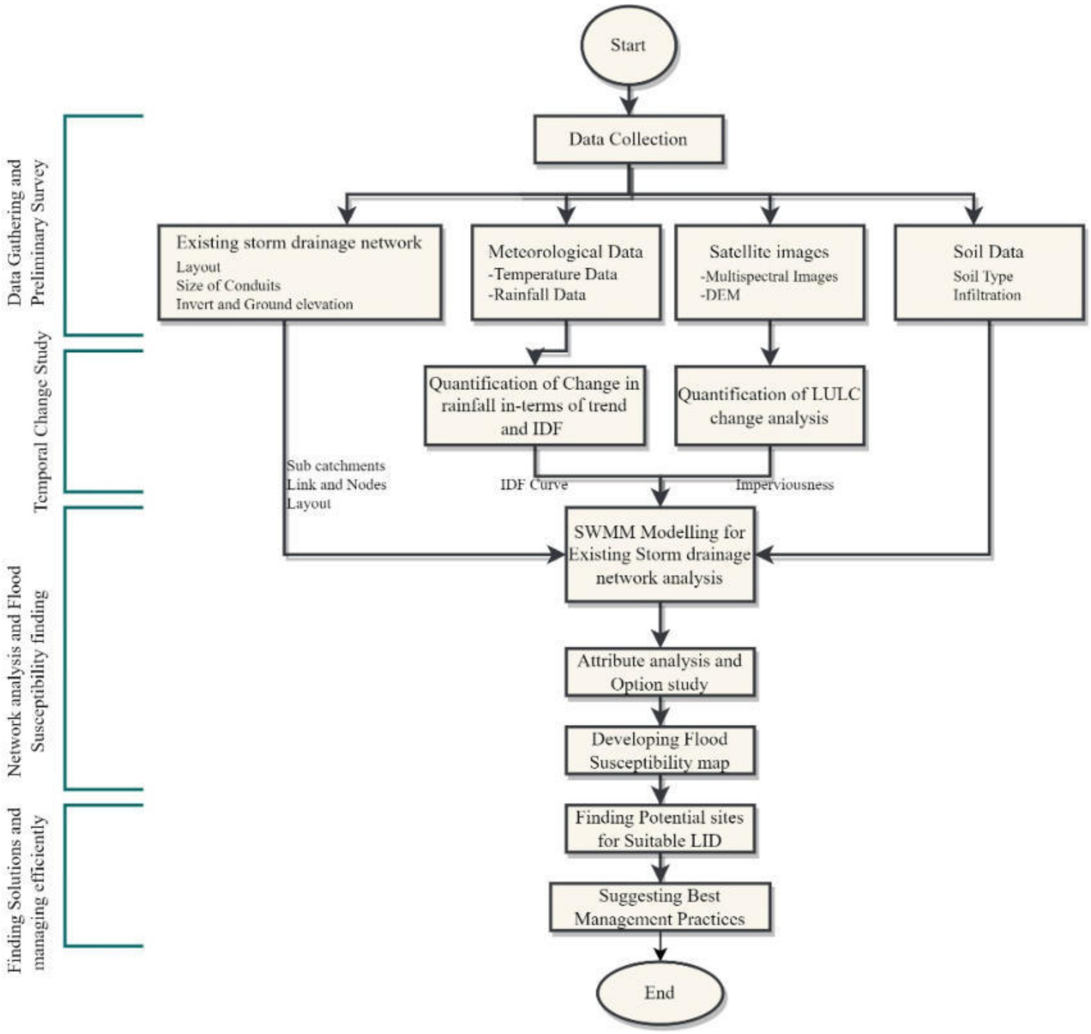


Figure 4.1 Comprehensive approach to Low Impact Development (LID)

These analyses feed into SWMM (Storm Water Management Model) Modelling for the existing storm drainage network, allowing for a detailed understanding of how changes in rainfall patterns and land use affect the network's performance.

Following this, the Network Analysis and Flood Susceptibility Finding phase is undertaken. This includes attribute analysis and option studies that help identify potential issues and solutions within the stormwater system. A Flood Susceptibility Map is developed based on this analysis, which helps in identifying areas at risk of flooding.

Finally, the figure outlines the step of Finding Solutions and Managing Effectively. Here, potential sites for implementing LID are identified. The goal is to manage stormwater runoff effectively through practices that mimic natural hydrology. This phase concludes with the Suggestion of Best Management Practices (BMPs), ensuring that the most suitable and sustainable methods are employed for stormwater management.

4.3 QUANTITATIVE ASSESSMENT OF LAND USE LAND COVER CHANGE

LULC trends and the climate crisis are both dynamic. Natural events and anthropogenic actions dominate the overall process (Getachew et al. 2021; Mas, 1999). The term "land use" describes how people use land, encompassing forestry, urban planning, and agriculture. The term "land cover" describes the natural and artificial coverings of the land, such as flora, water sources, and man-made architecture (Prakasam, 2010). Additionally, the rising human demand on the planet's finite natural resources contributes to changes in land surface cover. Some potential impacts of LULC change include: Loss of biodiversity, Soil erosion, and degradation, Changes in the water cycle, Changes in climate, and Social and economic impacts(Jokar Arsanjani et al. 2013; Rindfuss et al. 2004; Dong et al. 2009).

Reports on LULC changes are essential for managing and using natural resources (Wang et al., 2009, Kafi et al., 2014). Modifications in land coverage and land use can be caused by several variables (LULC). Some of the main drivers of LULC change include 1) Population growth: As the population grows, there may be a need for more housing, infrastructure, and other development, which can result in changes in LULC (Lambin et al., 2001). 2) Economic development: Changes in the economy, such as the growth of new industries or the decline of traditional industries, can also drive changes in LULC. For example, developing a new mine or factory may change the surrounding land (Kaliraj et al., 2017). 3)Natural disasters: Earthquakes, floods, etc., can also drive changes in LULC. For example, a flood may destroy buildings and infrastructure, leading to changes in the use of the land (Aansen et al., 2014). 4)Climate change: Changes in rainfall and temperature patterns due to climate change can also affect LULC. For example, increased droughts or extreme weather events may change the types of vegetation that can survive in a particular area (Lambin et al., 2001; Estoque & Murayama, 2015). 5) ‘Human activities: Activities, such as farming, forestry, and urban development, can also drive changes in LULC’. For example, expanding a city or converting forestry to cultivated land may result in noteworthy changes to the territory (Lambin et al., 2001; Dash et al., 2015). There are two methods generally fallowed for LULC classification as explained in the previous chapter. In this study Supervised image classification method was fallowed which is recommended in the various studies in the past. In the Supervised classification method present study considers the Maximum likelihood classification (MLC). Brief description and mathematical expression is given the subsequent section.

4.4 MAXIMUM LIKELIHOOD CLASSIFICATION

Maximum likelihood LULC classification is a supervised classification technique that uses statistical models to assign labels to data points based on the probability that each data point belongs to a particular class. This method develops a statistical model for each class based on the training data. The model that gives the highest probability for a given data point is chosen as the label for that data point. To perform maximum likelihood classification, you first need to select the statistical model that will be used to represent each class. This can be done using various techniques, such as fitting a Gaussian distribution to the data or using a more complex model such as a neural network. Once the models have been developed, you can apply the maximum likelihood criterion to classify new data points by selecting the model with the highest probability for each data point shown in Eq. 1.

$$P(x/w_i) = \frac{1}{(2\pi)^{\frac{1}{2}}\sigma_i} e^{\left[-\frac{1}{2}\frac{(x-\mu_i)^2}{\sigma_i^2}\right]} ..(4.1)$$

Where x is the class label (e.g., "urban," "forest," etc.), wi is the data point being classified, and $P(x/w_i)$ is the probability that x belongs to class wi. *e* is the base of the natural logarithms, $\mu_i$is estimated mean, $\sigma_i$is the estimated variance of all the measurements in this class. After the image classification it is recommended to test the accuracy of resulted LUCL by referring ground truth data, which can be done by accuracy assessment. Different aspects of accuracy assessment is given below.

4.5 ACCURACY ASSESSMENT

These measures can be used to assess the quality of a classified image and identify any errors or inaccuracies in the classification. Generally, the following statistics are used for LULC image accuracy assessment.

Commission error refers to the percentage of pixels misclassified as a specific land cover type.

Omission error, on the other hand, refers to the percentage of pixels that have been missed or not classified as a specific type of land cover.

Producer accuracy The proportion of pixels successfully categorized by the classification algorithm is a proxy for the classification's overall accuracy.

User accuracy is a measure of the accuracy of the classification as perceived by the user or analyst, calculated as the percentage of pixels that were correctly classified according to the reference map or other ground truth data.

The kappa coefficient An inter-rater agreement metric known as the kappa coefficient is frequently used to assess how well a LULC classification algorithm works. It measures the level of agreement between the predicted labels for a dataset (generated by the classification algorithm) and the true labels. It takes into account the possibility of a chance agreement.

The kappa coefficient is calculated as follows:

$$kappa = \frac{\left(P(a) - P(e)\right)}{\left(1 - P(e)\right)} \,..(4.2)$$

Where P(a) is the ground truth agreement between the predicted and true labels, and P(e) is the expected agreement between the predicted and true labels based on chance alone.

A kappa coefficient of 1 indicates perfect agreement and 0 indicates no agreement between true and predicted labels.

Overall accuracy is a measure of the overall accuracy of the classification, calculated as the percentage of pixels that were correctly classified according to the reference map or ground truth data. It is a useful measure of the overall quality of the classification and can be used to compare different classifications or to assess the performance of different classification algorithms.

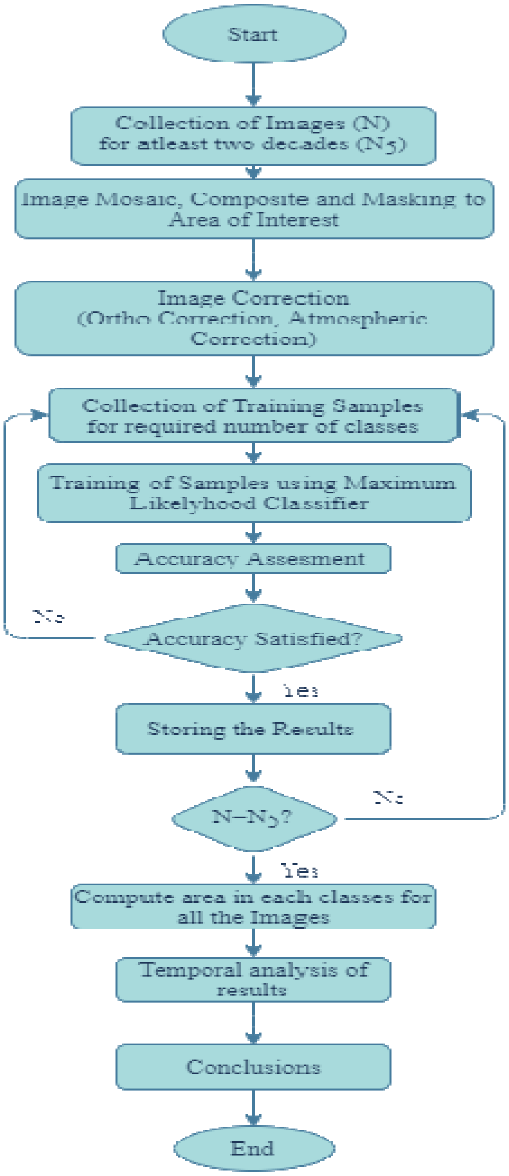


Figure 4.2 Flow diagram of the methodology adopted

4.6 QUANTITATIVE ASSESSMENT VARIATION OF RAINFALL

The watershed saw lower trends in precipitation with increasing rainfall variability, according to Parida et al. (2006)'s study of rainfall patterns and their consequences on the stream flow of the Limpopo headstream in Botswana. Even after aggregation of current research on precipitation analysis, the primary input into the hydrologic system, there is indisputable proof that rainfall is falling, notably across Southern Africa, with consequences for water distribution and availability (Christensen et al., 2007; Meehl et al., 2007). Thus, it is becoming more evident that analyzing rainfall trends is crucial when researching the effects of climate change on the planning and management of water resources (Haigh, 2004).

Precipitation trend analysis considers both the temporal and geographical axes. The homogeneity of the region must thus be assessed in order to account for the spatial variation in the trends estimated using temporal time-series data at a station. According to Buonomo et al. (2007), variations in extreme rainfall values increase when both the return period of the rainfall and the length that is taken into account get shorter. Accordingly, the rise in 24-hour precipitation for the European region during a return period of 20 years will be 18% by the end of the twenty-first century, compared to just 13% for a return period of two years. The increases are lower when more extended than 24 hours are taken into account. More intense rainfall is recorded as opposed to less yearly precipitation. Generally variation of rainfall found by Trend analysis (Explained in 4.4.1).Trend analysis is a powerful tool that can be used to estimate changes in the intensity of rainfall over time. By providing insights into long-term trends, predicting future patterns, and quantifying the magnitude of change, trend analysis is useful for decision-making in a range of applications.

4.7 TREND ANALYSIS.

Trend analysis is a statistical method that is used to analyze data over time to identify trends or patterns. In the context of rainfall, trend analysis can be used to identify long-term trends in the amount of rainfall that is received in a particular location (Merabtene et al., 2016; Barana, 2017; Radeny et al., 2019).

There are several methods that can be used to conduct trend analysis of rainfall data, including:

Linear regression: This method involves fitting a straight line to the data and using it to predict future values based on the slope of the line.

- Pros: Simple and easy to implement; provides a clear relationship for prediction.
- Cons: Assumes linearity; sensitive to outliers; may not capture complex trends.

The Mann-Kendall test: This is a statistical test that is used to determine if there is a significant trend in the data.

- Pros: Non-parametric; does not assume any specific distribution; robust to outliers.

- Cons: Only identifies the presence of a trend; does not provide a predictive model.

Seasonal decomposition: This method involves breaking down the data into its seasonal components (such as annual, monthly, and daily cycles) and analyzing the trends within each component.

- Pros: Handles multiple seasonal components; effective for data with strong seasonal patterns.
- Cons: Complex; may overlook non-seasonal trends; requires a larger dataset.

Time series analysis: This method involves examining the data in the context of the period in which it was collected to identify trends or patterns that may be related to seasonal or other periodic factors.

- Pros: Captures temporal dynamics; flexible in identifying trends, cycles, and irregular patterns.
- Cons: Computationally intensive; requires large datasets; more complex to implement.

Moving average: This method involves calculating the average of a set of data points over a specified period and then plotting the average values over time. This can help to smooth out short-term fluctuations in the data and highlight long-term trends.

- Pros: Simple to implement; smooths data to highlight long-term trends.
- Cons: May oversimplify data; can miss short-term variations; introduces a lag in responsiveness.

In the present study, the Mankendall Trend test was used to identify trends In Delhi city.

4.8 MANN KENDALL TREND TEST

The Mann-Kendall test is a nonparametric statistical test used to assess whether or not there is a monotonic trend in time series data. It can be used to test for trends over time in the mean level of a variable, as well as the slope of the trend.The Mann-Kendall test is based on the statistic "S", which is calculated as follows:

$$S = \sum(si)$$

Where si is calculated as:

$$si = +1 \, if \, y(i) > y(j)$$

$$si = -1 \, if \, y(i) < y(j)$$

$$si = 0 \, if \, y(i) = y(j)$$

Here, $y(i)$ and $y(j)$ are values in the time series data, and the sum is taken over all pairs of values i and j in the data. The Mann-Kendall test statistic is then calculated as:

$$Z = \frac{S - \left(\frac{n(n-1)}{2}\right)}{\sqrt{\frac{n(n-1)(2n+5)}{18}}} \, ..(4.3)$$

Where n is the number of values in the time series data.

The null hypothesis for the Mann-Kendall test is that there is no trend in the data. If the calculated value of Z is greater than the critical value for the given level of significance, then the null hypothesis is rejected and there is evidence of a trend in the data.

4.9 STANDARDIZED ANOMALY INDEX (SAI) FOR RAINFALL

The Standardized Anomaly Index (SAI) is a statistical measure that is used to quantify the deviation of a value (such as rainfall) from its long-term average (Koudahe et al. 2017; Obubu et al. 2021, Belay et al. 2021). It is calculated by subtracting the long-term average value from the observed value and then dividing this difference by the standard deviation of the long-term average. This index is often used to identify unusual or anomalous values, such as unusually high or low levels of rainfall. It can help detect and track changes in climate patterns, and for identifying areas that may be at risk for drought or flooding.The equation for the Standardized Anomaly Index (SAI) for rainfall is as follows:

$$SAI = \frac{(Observed \, Rainfall - Average \, Rainfall)}{Standard \, Deviation} \, ..(4.4)$$

Positive anomalies may indicate drought conditions, while negative anomalies may indicate flood conditions. Here is a table showing the interpretation of the SAI values based on the criteria proposed by McKee et al. (1993):

Table 4.2. SAI values based on the criteria

SAI Value	Condition
< -1.0	Severe drought
-1.0 to -0.5	Moderate drought
-0.5 to 0.5	Near normal
0.5 to 1.0	Moderate wetness
> 1.0	Severe wetness

Note that these values are just a general guide and may vary depending on the specific location and context. When interpreting the SAI values, it is essential to consider other meteorological data and factors.

LULC and climate change studies can provide valuable information for designing storm drainage networks that are better able to handle changes in precipitation patterns and reduce the risk of flooding and water pollution. In the present study performance of existing storm drainage of Delhi city was found by evaluating the complete drainage network with the present climate and LULC scenario. Subsequent section explains the methodology for evaluating the Storm Water Drainage Network (SWDN).

4.10 PERFORMANCE EVALUATION OF STORM WATER DRAINAGE NETWORK (SWDN)

Performance evaluation of storm water drainage network is a critical component of effective storm water management (Jiang et al. 2015). The goal of performance evaluation is to assess the efficiency and effectiveness of the drainage system in handling excess water from heavy rainfall or snowmelt events (Babaei et al. 2018). With a well-designed and well-functioning storm water drainage network, communities can minimize the risk of property damage, environmental degradation, and public health concerns caused by excessive runoff (Bisht et al. 2016). One of the primary methods used in the performance evaluation of storm water drainage network is hydrologic modeling. This involves using computer models to simulate the flow of water through the drainage system under different rainfall scenarios (Ahamed and Agarwal 2019, Rabori and Ghazavi 2018, Agarwal and Kumar 2019). The results of these simulations can be used to identify bottlenecks and determine the capacity of the system. By using these models, engineers and planners can evaluate different design options, assess the impact of proposed changes, and predict the performance of the system under various conditions. Another important aspect of performance evaluation is hydraulic modeling (Zhao et al. 2021, Agarwal and Kumar 2020). This involves using computer models to simulate the flow of water through the drainage system, taking into account various factors such as pipe sizes, slopes, and roughness. This helps to identify areas of the system that may be prone to flooding or where water velocities are too high (Yang et al. 2020, Barreiro et al. 2022). The results of hydraulic modelinge.g Discharge, Velocity, Water depth, turbulence, etc. can also be used to assess the impact of proposed changes to the system, such as new development, on the overall performance of the drainage network. Physical inspection is another important component of performance evaluation. This involves visually inspecting the drainage network, including inlets, pipes, and outfalls, to identify any signs of damage, blockages, or other problems that may affect the performance of the system. Regular inspections can help to detect issues before they become more serious, and help to prioritize maintenance and repair needs (Vemula et al. 2019, Yang et al. 2022). Extreme rain events, such as heavy storms or flash floods, can have a significant impact on storm water drainage networks. These events can overload the capacity of the system, leading to flooded streets, homes, and businesses, and causing significant damage (Yang et al. 2022, Arisz& Burrell 2006, Fletcher et al. 2013).

4.11 ASSESMENT OF DRAINAGE NETWORK

SWMMis a widely used computer software tool for the design and analysis of storm water drainage networks. SWMM can be used to simulate the flow of runoff through a drainage network and to assess the performance of the system under various rainfall conditions (Zhao et al. 2021, Agarwal and Kumar 2020, Yang et al. 2020, Barreiro et al. 2022, Vemula et al. 2019, Yang et al. 2022, Taji and Regulwar 2021). In recent years, the impact of climate change on storm water management has become a major concern for communities and engineers. Climate change is causing changes in precipitation patterns and intensities, leading to an increase in the frequency and severity of extreme rainfall events. To address these challenges, SWMM can be used to model the effects of climate change on the performance of a storm water drainage network. The software can incorporate climate change scenarios into the simulation, allowing engineers to assess the potential impacts of these changes on the system and to design the network accordingly (Fletcher et al. 2013, Gironás et al. 2010, Goswami et al. 2006). Figure 2 shows the detailed methodology for simulating the storm through the drainage network using SWMM tool.

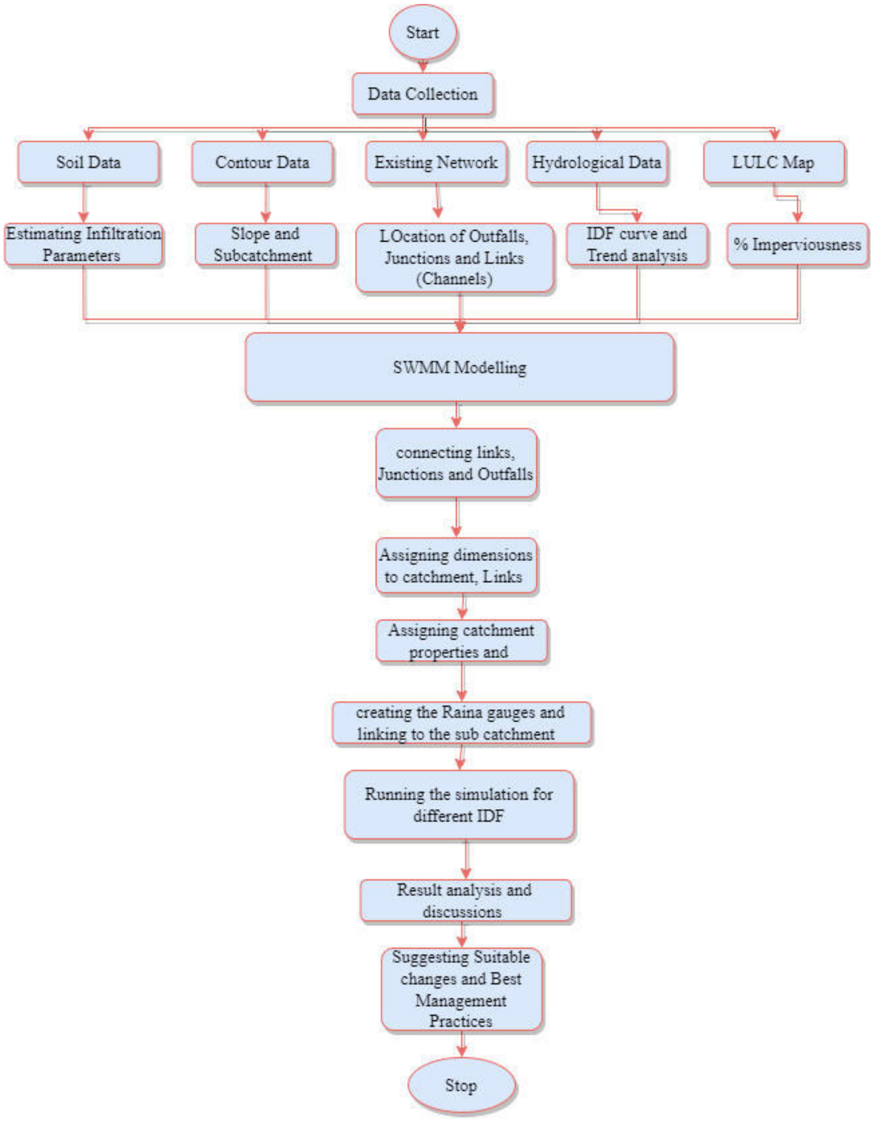


Figure 4.3. Detailed methodology for storm water drainage network modelling using SWMM

The design of a storm water drainage network using SWMM involves several steps, including the selection of appropriate Intensity-Duration-Frequency (IDF) curves, the creation of a digital terrain model, the definition of the drainage network components, and the simulation of runoff flow through the network. Detail steps can be found in the literature (Bibi 2022, Kong et al. 2017) however, The following steps outline the general process for designing a storm water drainage network using SWMM with different IDF curves:

Selection of IDF curves: The first step in the design process is to select the appropriate IDF curves for the location. These curves describe the relationship between rainfall intensity, duration, and frequency for a given location. The selection of the appropriate IDF curves should be based on the available rainfall data for the location and the design criteria for the drainage network.

Creation of a digital terrain model: The next step is to create a digital terrain model of the area. This can be done using GIS software, aerial imagery, or other data sources. The digital terrain model provides the necessary information on the topography of the area and is used to define the catchment area and to determine the location of the drainage network components.

Definition of drainage network components: The third step is to define the components of the drainage network, including the inlets, pipes, and outfalls. The size, location, and configuration of these components are based on the design criteria and the digital terrain model.

Simulation of runoff flow: The final step is to simulate the flow of runoff through the drainage network using SWMM. This simulation takes into account the selected IDF curves and the defined drainage network components to estimate the flow rates, velocities, and volumes of runoff. The simulation results can be used to evaluate the performance of the drainage network and to make necessary design modifications.

Assessment of results: The results of the simulation should be assessed to determine the effectiveness of the drainage network design. The results can be used to evaluate the capacity of the network, identify potential problem areas, and make necessary design modifications.

By using SWMM with different IDF curves, engineers and planners can design storm water drainage networks that are more effective and resilient in the face of changing rainfall patterns and intensities associated with climate change.

After understanding the lacunas in the existing SWDN its important to carryout Flood susceptibility mapping which can provide valuable information for better managing stormwater drainage networks. By identifying areas that are vulnerable to flooding, targeted improvements can be made, emergency response plans can be developed, land-use planning decisions can be informed, and opportunities for green infrastructure can be identified. This can help reduce the risk of flooding and improve the overall health of the ecosystem. Fallowing section explain the methodology for flood susceptibility mapping.

4.12 FLOOD SUSCEPTIBILITY MAPPING

Flood susceptibility mapping involves analyzing various factors that contribute to the likelihood of flooding in a particular area. This includes factors such as topography, land use, soil type, and rainfall intensity, among others. The output of flood susceptibility mapping is a map that shows the areas that are more likely to experience flooding. On the other hand, flood vulnerability mapping focuses on the exposure and sensitivity of elements at risk to flooding. This includes people, buildings, infrastructure, and other assets that may be affected by flooding. Flood vulnerability mapping takes into consideration the characteristics of these elements, such as their age, construction materials, and accessibility, to determine their level of vulnerability to flooding. In summary, flood susceptibility mapping assesses the likelihood of flooding in a given area, while flood vulnerability mapping assesses the potential impact of flooding on the elements at risk in that area. Both approaches are essential for developing effective flood risk management strategies. Flood susceptibility mapping is the process of identifying areas that are likely to be flooded based on various factors such as topography, land use, soil type, and rainfall intensity. This mapping technique is essential for flood risk assessment and management, as it helps to identify areas that are most at risk of flooding, allowing for the development of effective flood risk management strategies.

4.13 DEVELOPMENT OF FSM

The Analytical Hierarchy Process (AHP) is a multi-criteria decision-making method that can be used in flood susceptibility mapping to prioritize the importance of the different parameters. Here are the steps to use AHP in flood susceptibility mapping with the above parameters:

Identify the criteria: Determine the different parameters that are important in flood susceptibility mapping, such as elevation, slope, precipitation, LULC, NDVI, distance from river, distance from road, drainage density, and soil type.

Define the scale: Create a scale for each parameter based on its relative importance in flood susceptibility mapping. For example, you might use a scale of 1-5, where 1 is very low importance and 5 is very high importance.

Pairwise comparison: Compare each parameter against every other parameter and assign a score to indicate its relative importance. For example, you might compare elevation against slope and assign a score of 5 to indicate that elevation is more important than slope in flood susceptibility mapping.

Consistency check: Check the consistency of the scores assigned by comparing the scores against each other. If there are inconsistencies, adjust the scores until they are consistent.

Weight determination: Calculate the weights of each parameter by summing the scores assigned to each parameter and dividing by the total number of parameters.

Overlay analysis: Use the weights assigned to each parameter to perform an overlay analysis in a GIS environment to develop a flood susceptibility map. This map will show areas that are more susceptible to flooding based on the different parameters and their weights.

Validation: Validate the flood susceptibility map by comparing it to historical flood events or other sources of flood susceptibility data.

By using AHP to prioritize the importance of different parameters in flood susceptibility mapping, resources can be allocated more effectively to areas that are at higher risk of flooding. Additionally, the resulting flood susceptibility map can help identify areas that require targeted flood risk management strategies.

4.14 SITE SELECTION METHODOLOGY FOR THE LID

When identifying potential sites for Low Impact Development (LID) projects in the context of flood reduction, it's important to consider several factors related to hydrology, topography, and land use.

1 Hydrology: Look for sites that are located in areas with high flood risk, such as low-lying areas or near rivers and streams. Identify areas where surface water runoff is concentrated, and where the soil has low permeability.

2 Topography: Look for sites that are relatively flat or have a gentle slope, as steeper slopes can increase the risk of flooding. Consider the direction of surface water flow and identify areas where water tends to collect or pond.

3 Land use: Look for sites that are currently developed or are planned for development, as these are more likely to benefit from LID projects. Identify areas where the existing land use is likely to contribute to increased runoff, such as areas with a lot of impervious surfaces

like buildings, roads, and parking lots. Identify areas that can act as a natural retention and detention basins, such as wetlands, parks, and open spaces. Identify potential sites for LID features such as green roofs, rain gardens, permeable pavements, and bio-retention basins that can be used to reduce runoff and improve water quality. selection of LID sites may also involve consultation with local government agencies, community groups, and other stakeholders to ensure that the projects are feasible, cost-effective, and acceptable to the community.

4.14.1 LOCATING PRIORITY SITES FOR LOW IMPACT DEVELOPMENT

To locate priority sites for Low Impact Development (LID) using slope, soil, wetness index, and Land Use and Land Cover (LULC) data, the following steps can be taken:

- Collect data on slope, soil type, and LULC. This information can be obtained from topographic maps, aerial photos, and remote sensing data.
- Calculate the wetness index for each location in the study area. The wetness index is typically calculated as the natural logarithm of the ratio of the specific catchment area (the area of the catchment draining to a specific point) to the tangent of the slope.
- Use GIS (Geographic Information System) software to combine the data on slope, soil, and wetness index with the LULC data to create a map of the study area.
- Identify areas that have a high wetness index, a gentle slope, and a soil type that is conducive to infiltration. These areas are likely to be the most suitable for LID projects.
- Evaluate the suitability of these areas for LID projects based on the LULC data. Look for areas that are currently developed or are planned for development, as these are more likely to benefit from LID projects.

4.14.2 WETNESS INDEX

The wetness index is a measure of the degree of wetness of an area, based on the topography and the distribution of water bodies. It is commonly used in GIS (Geographic Information System) and remote sensing to assess the hydrological characteristics of an area and to identify areas that are prone to flooding or erosion. The wetness index can be calculated using digital elevation data and a hydrological model. It is typically calculated using the following equation:

$$Wetness\ Index = ln\left(\frac{a}{tan(slope)}\right)..(4.5)$$

where "a" is the specific catchment area (the area of the catchment draining to a specific point) and "slope" is the slope of the land.

The wetness index can be used to identify areas that have a higher likelihood of flooding or erosion, as well as areas that are more likely to have wetland or aquatic habitats. It can also be used to identify areas that may be suitable for the implementation of erosion control or flood prevention measures. In GIS and remote sensing, the wetness index is often calculated using digital elevation data and a hydrological model, and the results are displayed on a map. This can help visualize the distribution of wetness across the landscape and identify areas that may be at higher risk of flooding or erosion.

4.14.3 SELECT OF SITES FOR LID USING WETNESS INDEX IN GIS AND RS

To select sites for Low Impact Development (LID) using the wetness index in GIS (Geographic Information System) and remote sensing, you can follow these steps:

- Define the goals and objectives of the LID project. This will help you determine the factors that need to be considered when selecting sites for LID.
- Collect data on the physical, social, and economic characteristics of the area. This can include data on land use, hydrology, soil type, slope, and other factors that may affect the feasibility of LID.
- Use GIS to map the data and calculate the wetness index for each location in the study area. The wetness index is a measure of the degree of wetness of an area based on the topography and the distribution of water bodies. It is calculated using the equation 1:
- Use remote sensing techniques, such as aerial photography or satellite imagery, to verify the suitability of the identified sites and to identify additional potential sites.
- Evaluate the potential impacts of the LID projects on the environment, including the potential for water quality improvements and flood reduction.

- Prioritize the sites based on their wetness index and their potential benefits and feasibility. Sites with a higher wetness index may be more suitable for LID projects that aim to manage stormwater runoff and reduce flooding.

- Develop a plan for implementing LID at the identified sites. This may include designing and constructing LID features, such as green roofs, permeable pavement, and rain gardens, and implementing management practices, such as properly maintaining the LID features and educating the community about their benefits.

4.14.4 COMMON LID TECHNIQUES

Low Impact Development (LID) techniques are designed to mimic the natural hydrology of a site and reduce the amount of runoff that is generated during rainfall events. The suitability of a site for a particular LID technique depends on several factors, including the site's physical characteristics, such as slope, soil type, and hydrology, as well as its intended land use and existing development patterns. LID techniques can be grouped into several categories based on their generalized site suitability:

- Rain Gardens: Rain gardens are shallow depressions filled with soil and plants that are designed to capture and infiltrate runoff from impervious surfaces, such as roofs and paved areas. Rain gardens are well-suited for sites with gentle slopes, well-drained soils, and low-volume runoff.

- Green Roofs: Green roofs are vegetated roofs that are designed to reduce runoff and improve the energy efficiency of buildings. Green roofs are well-suited for flat or gently sloping roofs, especially in urban areas where space is limited.

- Infiltration Trenches: Infiltration trenches are shallow trenches filled with gravel and surrounded by soil that are designed to infiltrate runoff from impervious surfaces. Infiltration trenches are well-suited for sites with well-drained soils and low-volume runoff.

- Permeable Pavement: Permeable pavement is a type of pavement that allows water to penetrate through its surface and into the soil below. Permeable pavement is well-suited for sites with gentle slopes, well-drained soils, and low-volume runoff.

- Bioretention Systems: Bioretention systems are shallow basins filled with soil and plants that are designed to capture and infiltrate runoff from impervious surfaces. Bioretention systems are well-suited for sites with gentle slopes, well-drained soils, and moderate- to high-volume runoff.
- Swales: Swales are shallow channels that are lined with vegetation and designed to convey runoff from impervious surfaces. Swales are well-suited for sites with gentle slopes, well-drained soils, and moderate- to high-volume runoff.

These are just a few examples of the many LID techniques that are available. The specific suitability of a site for a particular LID technique will depend on the specific goals of the project, the local climate and hydrology, the existing land use and development patterns, and the social and economic characteristics of the area. Table 4.4shows the relative amount of area required for LID implementation

Table 4.3. LID techniques and the amount of area required for each

LID Technique	Amount of Area Required
Rain Gardens	Small to medium (10-200 square meters)
Green Roofs	Depends on the size of the building
Infiltration Trenches	Small to medium (10-200 square meters)
Permeable Pavement	Depends on the size of the impervious surface being replaced
Bioretention Systems	Medium to large (100-200 square meters)
Swales	Medium to large(100-200 square meters)

4.14.5 Overlay Analysis with The Physical Criteria to Generate Suitable Sites For LID

parameters that can be considered for site selection of LID:

- Land use/land cover map
- Wetness index
- Soil map

- Slope map
- Drainage density
- Impervious surface percentage
- Precipitation intensity and duration
- Stream proximity and watershed area
- Groundwater depth and recharge rate
- Climate change projections and historical trends

Land use/land cover map, wetness index, soil map, slope map, and drainage density are all important parameters to consider for site selection of LID due to their direct influence on stormwater runoff and infiltration. The land use/land cover map provides information on the types of surfaces present in the area, which can affect how much runoff is generated and how easily infiltration can occur. Areas with more impervious surfaces such as roads and buildings will generate more runoff, while areas with more vegetation will allow for more infiltration. The wetness index provides information on the potential for surface saturation and soil moisture, which can impact infiltration rates and the potential for standing water. Areas with high wetness indices may have a lower potential for infiltration and may require additional LID measures to manage stormwater. The soil map provides information on the type and composition of soils present in the area, which can affect infiltration rates and the potential for runoff. Soils with high clay content, for example, may have a lower potential for infiltration and may require additional LID measures. The slope map provides information on the gradient of the land, which can affect the speed and direction of stormwater runoff. Areas with steeper slopes will generate more runoff and may require additional LID measures to manage stormwater. The drainage density provides information on the density of the stream network in the area, which can affect the potential for flooding and the need for additional stormwater management measures. Areas with high drainage densities may have a higher potential for flooding and may require additional LID measures to manage stormwater.

While the remaining parameters such as impervious surface percentage, precipitation intensity and duration, stream proximity and watershed area, groundwater depth and recharge rate, and climate change projections and historical trends are also important factors to consider, they may not have as direct of an impact on stormwater runoff and infiltration as the first five parameters listed above.

4.14.6 Land Cover

The most significant physical attribute to consider while locating LIDs is land cover. Land cover has a direct impact on a watershed's hydrologic features by boosting runoff volume and pace while lowering infiltration and groundwater recharge (Goonetilleke et al. 2005; Guo 2008; Roy and Schuster 2009). According to Liu et al. (2004), intensively built urban areas produce the majority of surface runoff volume during significant occurrences. Densely developed metropolitan areas contributed the most to surface runoff, followed by croplands and grasslands. Other land use types (forest and woods) were shown to improve total depression storage capacity, which tends to decrease runoff volume. The existence of a certain land cover can influence the type of LID utilised at a location, as well as whether LID approaches should be used at all. For example, heavily developed metropolitan areas may have insufficient open space to enable the installation of some types of LIDs, such as wet and dry ponds and artificial wetlands, which require enormous area extents (U.S. EPA 2004). High density urban areas modify hydrologic properties the most (Liu et al. 2004) and, as such, should be prioritised for LID installation. As a result, the SSM technique rates the land cover classes appropriately. Classification and Rank of Significance indicates the land cover classes for the research region, as defined by the literature, and their order of importance. Land cover classes with similar ranks in the table reflect equal importance. The highest coefficient is assigned to the most significant class. The literature review suggestions are used to rank the land cover classes, and the importance inferred in the literature is converted into coefficients using AHP.

Table 4.4: Land Cover Classification and Rank of Importance as per literature

LULC Class	Rank
Open Water	1
Woody Wetlands	2
Emergent Herbaceous	3
Grassland/Herbaceous	4
Deciduous Forest	5
Evergreen Forest	6
Shrub/Scrub	7

Barren Land	8
Developed, Open Space	9
Cultivated Crops	10
Developed, Low Intensity	11
Developed, Medium Intensity	12
Developed, High Intensity	13

4.14.7 IMPERVIOUSNESS

When it comes to LID setting, imperviousness is the most essential aspect of land cover. Impervious land coverage is a key feature of urban and suburban regions. Impervious surfaces are any surface covers that restrict or greatly decrease water penetration into the soil. Increasing urbanisation changes the natural terrain, increasing imperviousness. Rooftops, highways, parking lots, and other urban surfaces frequently cover soils that, prior to development, enabled precipitation and runoff to permeate into the soils, recharging aquifers and providing base flow for surface waterways (BASMAA 1999; Yang et al. 2000). The U.S. EPA's Low-impact Development Design Strategies manual (1999) from Prince George's County, Maryland's Department of Environmental Resources Programs and Planning Division (DERPPD) promotes LID in areas where continuous impervious areas exist as a way to disrupt the connectivity of these areas. This manual served as the foundation for the DERPPD's LID guidelines. Under Section C.3.f of its regional NPDES permit, the SFRWQB oversees hydromodification caused by increasing imperviousness.

4.14.8 SLOPE GRADIENT

Slope considerations are critical for LID project scale and placement. Slope gradient is required to compute runoff volumes required for LID size, and it is utilised in terrain preprocessing models to determine flow pathways required for LID deployment. A DEM, which is easily available for the whole United States from the USGS Data Warehouse, may be used to properly calculate slope gradient (Gesch 2007). There are several DEM resolutions available. 1/3 arc second DEMs span the whole conterminous United States. For several places, finer resolution 1/9 arc second DEMs are also available. Recently, 1/9 arc DEMs are not currently available for all regions of the United States, therefore they were not used, even though higher resolution is not necessary for LID siting at the watershed scale. Furthermore, additional preprocessing steps would be required due to the higher resolution of these models. In 1/9 arc second DEMs, for instance, structures like highway overpasses may appear as damlike barriers, which will have an impact on flow route predictions. Although using a stream vector layer during terrain preprocessing can prevent this, the extra manipulation needed to avoid it slows down and increases the cost of modeling. Because the advantage of a finer resolution is lost, using the 1/9 arc second model is not recommended.

The average slope gradient of a region is an essential characteristic to consider since it influences the overland flow rate. The stormwater runoff volume and erosion potential of a specific site are determined by this rate in conjunction with precipitation intensity and soil hydraulic parameters. Because the primary goal of LID is to compensate for changing runoff volumes, appropriate LID placement must take slope gradient into account (Liu et al. 2004). Ha and Stenstrom (2008), on the other hand, use a slightly modified slope gradient-suitability scale that incorporates three percent slope categories from a DEM. The slopes are classified as 0-2%, 2-6%, and >6%. The BAHM, on the other hand, employs four slope classes: 0-5%, 5-10%, 10- 20%, and higher than 20%. In the SSM, a three-tiered slope categorization identical to the BAHM was used (BASMAA 1999). It was chosen because it enabled finer resolution ranking during site appropriateness calculations and offered a threshold comparable with the SUSTAIN model (Lai et al. 2007). This system classified slopes as 0-5%, 5-15%, and higher than 15%. Table 2: Slope Gradient Classifications compares the classifications used in various models and studies to the classification method utilised in the SSM. AHP was used to assign a coefficient to each tier. This method's slope categorization attempts to give priority to places with a low slope gradient. For some LID types to work, a precise slope gradient is necessary. As an illustration, consider the slope gradient needed for infiltration trenches to operate as intended. For these kinds of LIDs, the US EPA (2004) suggests a gradient of less than 15%.

Slope Category	Ha and Stenstrom (2008)	BAHM	SSM
0-2%	Suitable	Suitable	Suitable
2-6%	Suitable	Suitable	Suitable
5-10%	Moderately suitable	Suitable	Suitable
>15%	Not suitable	Not suitable	Suitable

4.14.9 SOIL

The kind of soil determines the LID technology to be used as well as the installation locations. Dietz (2007), for example, emphasises that soils with poor infiltration rates or hydraulic conductivity may not be suitable for LID methods such as porous pavements, infiltration trenches, and infiltration basins. Because they rely on water penetration into the soil substrate, these LID measurements are often confined to soils with strong hydraulic conductivity. These aforementioned approaches cannot function properly without appropriate penetration. Soils with high infiltration rates and a short depth to the water table, on the other hand, may be unsuitable (Winogradoff 2002). This is because contaminated runoff may enter groundwater without first being filtered by slow percolation through the soil, which traps contaminants through cation/anion exchange (U.S. EPA 2000, 2004, 2009b). Extremely porous soils that lay atop a shallow water table may not filter contaminants out of the water before it enters the aquifer. Hence, in soils with high hydraulic conductivity ratings, the usage of porous pavements, infiltration trenches, and infiltration basins may be undesirable (U.S. EPA 2000).

The hydrologic response of a watershed is heavily influenced by soil. Different soil types have distinct qualities that influence the volume of overland flow within a watershed, the quantity of interflow, and the amount of groundwater recharge. Moreover, soils affect surface erosion susceptibility rates and consequently sedimentation. availability. Most hydrologic models are thus built on soil data (Whittemore and Beebe 2000; WSDE 2005; Bicknell, Beyerlein, and Feng 2006; U.S. EPA 2009b, 2010). All of the previously stated models use soil maps to reflect variance in infiltration rates. LID implantation requires knowledge of infiltration rates or hydraulic conductivity.

Various types of LID projects need distinct physical site features. Stormwater BMPs in the past concentrated on detention ponds, infiltration trenches, and bioswales, all of which were meant to allow collected runoff to percolate into and through the soils. These procedures replenish groundwater while also cleaning it by trapping bigger sediment sizes within the LID installation. Other approaches, including as hydrodynamic storage devices, green roofs, bio-retention features, and rain barrels that do not rely on soils, have been created. Yet, because many LID procedures incorporate water/soil interaction, soil data is an essential component of any LID siting process (Lai et al. 2007).

The infiltration rate is the most important soil attribute for LID design and siting. Soil maps for the United States are provided by the Natural Resource and Conservation Service (NRCS). For each soil, the NRCS rates its hydraulic conductivity on a scale of A to D. These classes represent the conductivity rates of saturated soils and are based on the standard SCS

(Soil Conservation Service) categorization system (USDA 2007). (Table 3). Class A soils are largely sand and aggregated silts with high saturation infiltration rates (>0.45 inches per hour), whereas class D soils, primarily clays, swell greatly when wet. The saturation infiltration rates are minimal, ranging from 0.0 to 0.05 inches per hour (USDA 2007).

4.15 ESTIMATING THE WEIGHTAGES FOR THE PARAMETERS

Analytic Hierarchy Process (AHP) is a widely used decision-making method that helps in prioritizing and ranking multiple criteria based on their relative importance. It is commonly used in environmental management, engineering, and other fields where complex decision-making is required. AHP uses a hierarchical structure to break down a complex problem into smaller, more manageable sub-problems.

The AHP process involves the following steps:

- Identification of the problem and the decision-makers involved.
- Determination of criteria and sub-criteria to be used in decision-making.
- Construction of a decision hierarchy to organize the criteria and sub-criteria.
- Pairwise comparison of criteria and sub-criteria to derive priority weights.
- Calculation of consistency ratios to ensure the validity of the pairwise comparisons.
- Aggregation of the priority weights to obtain an overall ranking of the criteria.

The AHP method can be used to rank the importance of the 10 parameters used in LID site selection. In this case, the criteria hierarchy would be structured with the 10 parameters at the lowest level, grouped under broader categories such as physical, environmental, and socioeconomic factors at higher levels. Decision-makers would then be asked to make pairwise comparisons between the parameters in each group to derive priority weights. The pairwise comparisons are done using a scale from 1 to 9, with 1 indicating equal importance, and 9 indicating extreme importance. These comparisons are then transformed into a matrix of priority weights. The matrix is then processed using mathematical formulas to calculate the eigenvalues and eigenvectors of the matrix, which are then used to obtain the priority weights for each criterion. To ensure the validity of the pairwise comparisons, consistency ratios are calculated. Consistency ratios are a measure of how consistent the pairwise comparisons are.

If the consistency ratio is greater than 0.1, it means that the pairwise comparisons are inconsistent and need to be reviewed and adjusted. Once the priority weights have been obtained, they are aggregated to obtain an overall ranking of the criteria. The criteria with the highest priority weights are considered to be the most important for LID site selection. Parameters and their priority is given below.

Table 4.5. AHP weights for LID Site Selection

1		Weights	+/-
1	TWI	13.8%	5.7%
2	Elevation	12.1%	2.7%
3	Slope	9.9%	4.1%
4	Precipitation	13.5%	5.5%
5	LULC	6.6%	3.7%
6	NDVI	5.9%	2.4%
7	Distance from river	14.1%	6.2%
8	Distance from road	5.6%	2.4%
9	Drainage density	9.3%	3.0%
10	Soil type	9.3%	3.0%

Matrix 1. AHP relative weightages

Matrix		TWI	Elevation	Slope	Precipitation	LULC	NDVI	Distance from river	Distance from road	Drainage density	Soil type	normalized principal Eigenvector
		1	2	3	4	5	6	7	8	9	10	
TWI	1	1	1	1	1	3	5	1	3	1	1	13.78%
Elevation	2	1	1	1	1	2	3	1	3	1	1	12.07%
Slope	3	1	1	1	1	3	1	1/2	1	1	1	9.90%
Precipitation	4	1	1	1	1	3	2	2	3	1	1	13.45%
LULC	5	1/3	1/2	1/3	1/3	1	1	1/3	3	1	1	6.62%
NDVI	6	1/5	1/3	1	1/2	1	1	1/5	1	1	1	5.87%
Distance from river	7	1	1	2	1/2	3	5	1	3	1	1	14.08%
Distance from road	8	1/3	1/3	1	1/3	1/3	1	1/3	1	1	1	5.59%
Drainage density	9	1	1	1	1	1	1	1	1	1	1	9.32%
Soil type	10	1	1	1	1	1	1	1	1	1	1	9.32%

There are two types of LID techniques are suggested: Intermediate-scale LID and Catchment-scale LID. Intermediate-scale LID refers to the implementation of LID techniques at a neighborhood or sub-watershed scale. The goal of intermediate-scale LID is to reduce the amount of runoff generated by impervious surfaces and direct it to more permeable areas for infiltration and treatment. Intermediate-scale LID is typically implemented through a combination of various LID techniques, such as rain gardens, green roofs, infiltration trenches, permeable pavement, bioretention systems, and swales. These techniques can be selected based on site-specific factors, such as the type and slope of the soil, the existing land use and development patterns, the local climate and hydrology, and the social and economic characteristics of the area. Catchment-scale LID refers to the implementation of LID techniques at a larger scale, encompassing an entire watershed or drainage area. The goal of catchment-scale LID is to reduce runoff and improve water quality throughout the entire watershed. This is achieved through the implementation of various LID techniques, as well as through the integration of LID principles into land use and development policies and regulations. Catchment-scale LID selection typically involves a comprehensive analysis of the entire watershed, including the evaluation of the existing land use and development patterns, the local climate and hydrology, and the social and economic characteristics of the area. Based on this analysis, LID techniques can be selected and prioritized based on their potential to reduce runoff and improve water quality, as well as their feasibility and cost-effectiveness.

4.16 CONCLUSIONS

Effective management of stormwater drainage networks requires consideration of various factors such as climate, land use/land cover (LULC), cost, flood susceptibility, and the use of low-impact development (LID) sites. Climate and LULC studies are crucial in designing and managing stormwater drainage networks as they provide vital information on changes in precipitation patterns and land use changes, which can inform better design decisions. Flood susceptibility mapping can help identify areas that are at risk of flooding, and targeted improvements can be made in those areas to reduce the risk of flooding. LID techniques, such as green roofs, permeable pavement, and rain gardens, can be incorporated to manage stormwater at the source, reducing the amount of runoff that enters the drainage system. Cost considerations are also important in implementing stormwater management strategies that are effective and sustainable in the long run. By considering these factors, stormwater drainage networks can be managed more effectively, reducing the risk of flooding and improving water quality while also promoting sustainable development.

CHAPTER 5: RESULTS AND DISCUSSIONS

"The future of agriculture lies in innovation, sustainability, and adaptability, as we cultivate the seeds of progress to feed a growing world."

5.1 Background

The study begins with an analysis of historical LULC changes in the study area to identify areas that have undergone significant land use and land cover changes. This information is then used to predict future land use and land cover changes, which can have a significant impact on the hydrological regime of the study area. In the second phase, trend detection analysis is conducted to identify climate change trends that are likely to affect the study area. This information is then used to model the potential impact of climate change on flooding in the study area. Finally, flood susceptibility mapping is carried out to identify areas at risk of flooding and to assess the suitability of different types of LID controls. This involves identifying the characteristics of the study area that influence flood susceptibility, such as topography, soil types, and land use. The results of the flood susceptibility mapping are then used to assess the suitability of different types of LID controls, such as porous pavement, bioretention areas, and rain barrels. Overall, the study aims to identify the most appropriate sites for implementing LID controls in the context of LULC change and climate change, with the ultimate goal of reducing the risk of flooding in the study area.

5.2 LULC Change Analysis

Spatial-temporal analysis of LULC images involves using techniques and methods to analyze and interpret the spatial and temporal patterns and changes in LULC over a specific area. The spatial analysis involves studying the patterns, relationships, and characteristics of LULC within a specific area or region. Spatial analysis can be used to identify trends, patterns, and relationships in LULC and to understand the factors that influence LULC change. The temporal analysis involves studying the changes in LULC over time, either within a specific area or region or across multiple areas or regions. This can be done using a series of images obtained at different periods or by comparing the results of different analyses performed at different times. Temporal analysis can be used to identify trends and patterns in LULC change and to understand the drivers and impacts of this change. Both spatial and temporal analysis of LULC images can be helpful in various applications, resource management, ecological monitoring, and disaster response. The table, labeled as Table 5.1, illustrates the percentage (also presented in Figure 5.1) changes in land use and land cover (LULC) over four distinct time intervals from 2000 to 2020. Each row corresponds to a specific land use type, and the columns represent the percentage change during the periods 2000-2005, 2005-2010, 2010-2015, and 2015-2020. Positive values denote an increase inthe area of the respective land use type , while negative values indicate a reduction. Notably, the "Built Area" experienced consistent growth over the entire timeframe, with a substantial 74.56% increase from 2005 to 2010. Conversely, "Barren Land" exhibited a varied pattern, with a notable decrease of -70.37% from 2005 to 2010, followed by subsequent increases. "Vegetation" underwent fluctuations, showing reductions in 2000-2005 and 2010-2015 but an increase in 2005-2010. Lastly, "Water" demonstrated an overall increase, particularly in the initial and 2010-2015 periods, while experiencing a significant reduction of -22.44% from 2015 to 2020. These trends provide fallwoing insights into the dynamic changes in land use patterns over the specified time intervals.

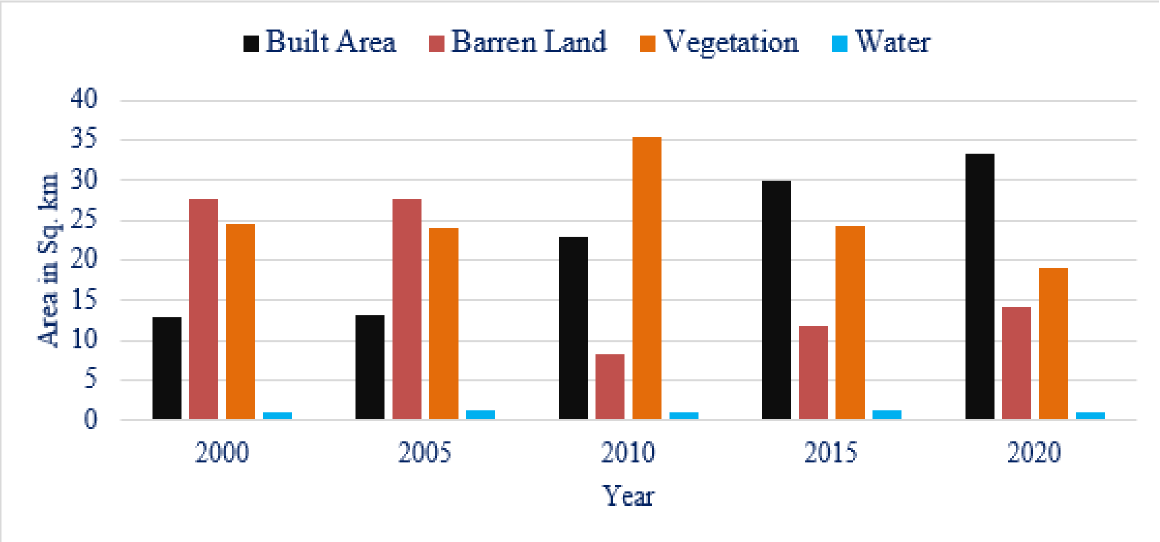


Figure 5.1 Temporal change of LULC over Delhi City from 2000 to 2020

The Land Use Land Cover (LULC) trend of Delhi city, as shown in the graph, reveals the following insights:

- Increase in Built Area: There is a consistent increase in the built-up area from 2000 to 2020, indicating rapid urbanization. The built area nearly doubles during this period, reflecting the city's expansion and population growth.

- Decline in Vegetation: The area covered by vegetation decreases significantly between 2000 and 2020. This suggests a loss of green spaces due to urban development, which could have implications for the city's ecosystem and climate.
- Fluctuations in Barren Land: Barren land initially decreases from 2000 to 2005, then shows a significant increase in 2010 before gradually declining again by 2020. This fluctuation may indicate land being cleared for development and later being utilized for urban purposes.
- Stable Water Coverage: The area under water remains relatively constant over the two decades, showing minimal change. This stability might suggest effective management of water bodies or limitations in expanding or reducing water-covered areas.

Table 5.1 Statistics of AHP results

Consistency Ratio	0.37
GCI:	0.20
CR:	5.5%
Lambda:	10.730
MRE:	40.4%

Table 5.2. Percentage area change for the LULC from 2000 to 2020 (-ve value indicates the %reduction in the area)

Land Use Type	% Change in the Land Use Type			
	2000-2005	2005-2010	2010-2015	2015-2020
Built Area	2.61	74.56	31.38	10.73
Barren Land	-0.43	-70.37	46.56	18.01
Vegetation	-1.62	47.45	-31.42	-21.04
Water	18.69	-7.03	12.51	-22.44

5.3 Accuracy Assessment of Classified Images

5.3.1 Confusion Matrix

A confusion matrix (Matrix 1) is a technique for evaluating a classifier's or model's precision. It is a table that lists the amount of accurate predictions the classifier made, including true positives, true negatives, false positives, and false negatives. In the context of classified images, a confusion matrix can be used to evaluate the accuracy of a classifier that has been used to assign labels or classes to different pixels in the image. For example, a classifier might identify different land cover types in a satellite image, such as forest, grassland, or urban. The confusion Matrix of GLIM is shown in Matrix 1 for the LISS III image for 2020. Moreover, it is assumed to remain the same for any period under consideration. Omission error and commissions error were also obtained for LISS III image for the year 2020 and results are presented in Table 5.1. from the table it can be observed that errors are high in case of Builtup area and least error is found in water body classification.

$$\begin{matrix} 386 & 14 & 06 & 12 \\ 0 & 803 & 265 & 50 \\ 0 & 322 & 192 & 10 \\ 0 & 3 & 42 & 870 \end{matrix}$$

Matrix 1 for supervised classification (GLIM)

Table 5.3.Omission and commission error for GLIM

Methods -	GLIM	
Classes	Omission Error	Commission Error
Water	0.085308	0
Built-up	0.286856	0.297463
Barren	0.641791	0.623529
Vegetation	0.105858	0.391608

In the context of Delhi, research has shown that built-up areas exhibit high omission and commission errors compared to other land cover types. For instance, a study assessing the classification accuracy of different LULC classes revealed that the omission error for built-up areas was approximately 28.69%, while the commission error was around 29.75% . These errors indicate that a substantial portion of actual built-up areas were either misclassified or omitted from the classification process, resulting in less reliable data for urban planning and resource management.

Conversely, water body classifications generally displayed low errors, with an omission error of about 8.53% and no commission error. This suggests a higher accuracy in distinguishing water bodies compared to urban areas, which is crucial as such classifications are fundamental for effective urban ecology and water resource management . The lower errors in water classifications can be attributed to their distinct spectral characteristics and less variability compared to urban landscapes.

The increased complexity and dynamic nature of urban growth in Delhi, attributed to rapid urbanization and infrastructural developments, further complicate accurate LULC mapping. Studies have indicated a notable shift in land use from agricultural areas to built-up regions as Delhi's population and economic activities have expanded. The errors encountered in LULC classifications reside not only in the inherent difficulties of detecting fine-scale changes within urban areas but also in the methodologies applied during classification

5.3.2 Overall accuracy and Kappa coefficient

1. Accuracy Metrics

Overall accuracy represents the proportion of correctly classified instances in a classification model, typically expressed as a percentage. In the context of the present study on LULC classification, values for overall accuracy typically range from 76.84% to 85.33% across different years and models14. This percentage reflects the reliability of the mapping process and indicates the classifier's effectiveness in distinguishing between various land cover types.

2. Kappa Coefficient Calculation

The Kappa coefficient serves as an indicator of agreement between the observed classifications and those expected by chance alone. Its value ranges from -1 to 1, where 1 indicates perfect agreement and values close to 0 suggest that the classification is no better than random guessing710. In the current context, Kappa coefficients reported have varied between 0.722 and 0.805, implying substantial to strong agreement between classified data and ground truth48.

3. Relationship between Overall Accuracy and Kappa

While both metrics indicate classification quality, they embody different aspects of accuracy assessment. Overall accuracy measures the percentage of correctly classified pixels, while the Kappa coefficient accounts for agreement beyond chance, offering a more nuanced view of classification strength. As classifications become more complex and nuanced, specifically in heterogeneous landscapes, the Kappa coefficient becomes increasingly critical for understanding classifier performance under varied conditions912.

4. Implications for LULC Applications

For policy-making, environmental monitoring, and urban planning, reliable LULC information derived from accurate classification is paramount. High overall accuracy and substantial Kappa coefficients not only establish confidence in the mapped data but also enhance the understanding of land use dynamics critical for strategic planning8. As such, continued emphasis on accuracy assessment will strengthen the integrity of geospatial analyses in diverse applications.

Overall accuracy and Kappa coefficient results are 0.66 and 0.57, respectively. The adopted method has moderately performed well, which indicates that the employed method has a good capability for image classification.

5.3.3 Spatial-Temporal analysis

LULC area for the periods 2000, 2005, 2010, 2015, and 2020 is given in table 5.1 and the figure 5.1 below. Figure 5.1 shows that the built-up area has exponentially increased, as Vegetation cover has reduced by nearly half from the base period of 2000. Barren land is also reduced and has the same pattern as Vegetation since the water body is the river that flows across the Delhi City. It is clearly evident that the built-up area has increased 1.6 times in the last two decades. A negative value indicates the reduction in the table below. Barren land has been reduced by almost 50%. Vegetation is also reduced to 18% since 2000.

5.3.4 Quantitative Assessment of Climate Change

As previously mentioned, the Mann-Kendall test was used to examine trends. The results are given in Table 5.3. The estimated Z statistics were found to be indicating that there was an indication of significant trends in the annual rainfall at the 0.05 significance level for any of the individual locations mentioned in the Delhi city. Out of Four stations, three indicate an increasing trend, and one shows a downward trend.

Table 5.4 . Mann-Kendall test statistics

Points	Lat/lon	N (Sample size)	M-K Statistic	Z Value	Alpha
	19	18263	1.67E+08	202.6916	0.05
P1	77.25	At a 0.05 significance level, there is a significant **Upward Trend.**			
		N	M-K Statistic	Z Value	Alpha
	19	18263	-2425486	-3.85379	0.05
P2	77.5	at 0.05 significance level, there is a significant **Downward Trend**.			
		N	M-K Statistic	Z Value	Alpha
	19.25 77.25	18263	1.67E+08	202.6028	0.05
P3		at 0.05 significance level, there is a significant **Upward Trend.**			
		N	M-K Statistic	Z Value	Alpha
	19.25	18263	1.67E+08	202.6028	0.05
P4	77.5	at 0.05 significance level, there is a significant **Upward Trend**.			

The SAI is used to identify anomalies or deviations from the average, which can be either positive (above average) or negative (below average). Positive anomalies may indicate drought conditions, while negative anomalies may indicate flood conditions. The SAI is typically used with other meteorological data to better understand and predict weather patterns and trends. Figure 5.2 shows the rainfall anomalies from 1970 to 2020. From the figure 5.2, it is clear that there are many normal and wet years as compared to dry years. Table 5.4. shows the Wet and dry year over Delhi city.

5.4 Development of IDF Curve for the Delhi city

The IDF curve is a graphical representation of the relationship between rainfall intensity, duration, and frequency. It is an important tool for stormwater management and design of drainage systems. The IDF curve for a specific location can be developed using historical rainfall data and statistical analysis. To develop the IDF curve for Delhi city using maximum rainfall data for the period between 1971 to 2020, the first step is to identify the maximum rainfall intensity for different durations (5, 10, 15, 30, 60, 120, 180, and 240 minutes) for each year. This data can be obtained from the Indian Meteorological Department

(IMD) or otherdrainage systems. The IDF curve for a specific location can be developed using historical rainfall data and statistical analysis. To develop the IDF curve for Delhi city using maximum rainfall data for the period between 1971 to 2020, the first step is to identify the maximum rainfall intensity for different durations (5, 10, 15, 30, 60, 120, 180, and 240 minutes) for each year.This data can be obtained from the Indian Meteorological Department (IMD) or other relevant sources. Once the maximum rainfall intensity data is collected, the next step is to calculate the frequency factor for each duration. After calculating the frequency factor for each duration, the next step is to plot the maximum rainfall intensity data against the frequency factor on a logarithmic scale. The resulted graph can be used to represent the relationship between rainfall intensity,duration, and frequency. The resulting IDF curve can be used for designing stormwater management systems and drainage structures that can handle different levels of rainfall intensity and frequency. It can also be used to estimate the expected rainfall intensity and frequency for different return periods, which is useful for assessing the flood risk and designing appropriate flood mitigation measures. Figure 5.3 shows the IDF curve for the Delhi city.

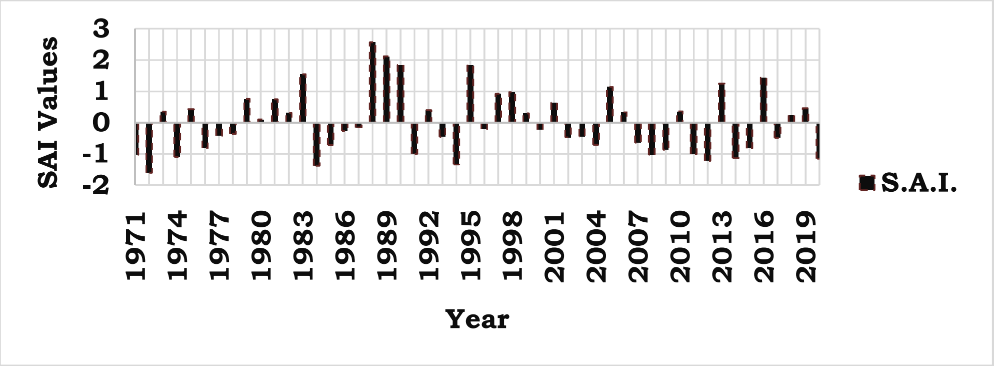
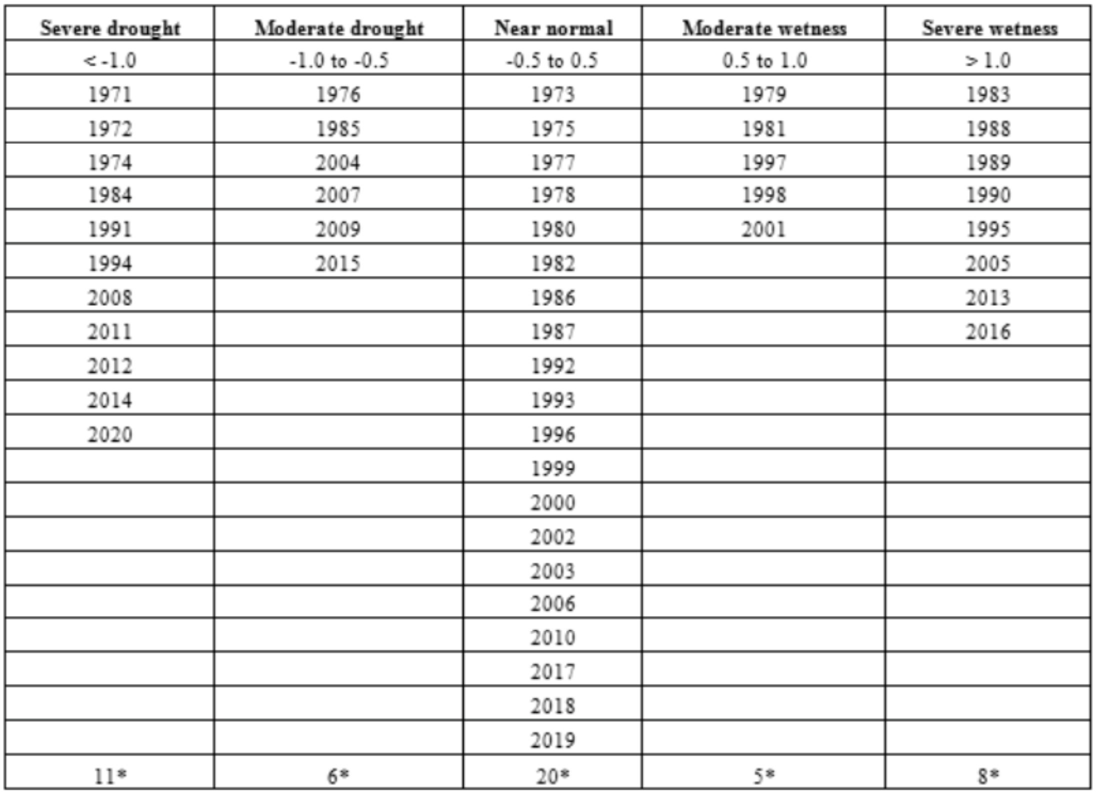


Figure 5.2 SAI for Delhi City

Table 5.5 Wet and Dry Year over Delhi City



Severe drought	Moderate drought	Near normal	Moderate wetness	Severe wetness
< -1.0	-1.0 to -0.5	-0.5 to 0.5	0.5 to 1.0	> 1.0
1971	1976	1973	1979	1983
1972	1985	1975	1981	1988
1974	2004	1977	1997	1989
1984	2007	1978	1998	1990
1991	2009	1980	2001	1995
1994	2015	1982		2005
2008		1986		2013
2011		1987		2016
2012		1992		
2014		1993		
2020		1996		
		1999		
		2000		
		2002		
		2003		
		2006		
		2010		
		2017		
		2018		
		2019		
11*	6*	20*	5*	8*

The maximum intensity is about 115cm/hr, 153 cm/hr and 177cm/hr for 2-, 5- and 10-year return period rainfall. Average intensity is about 100cm/hr for each year. The network is analysed for 10year return period rainfall intensity as shown in Figure 5.3.

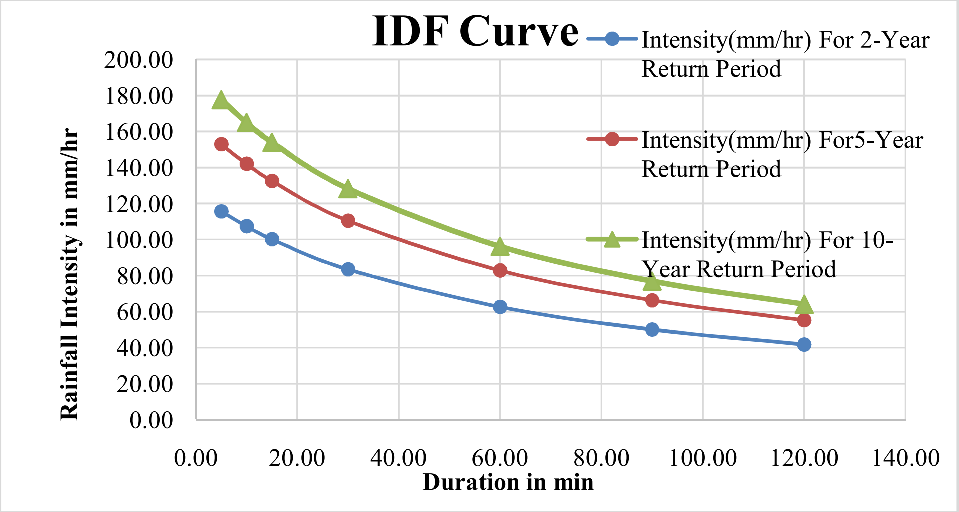


Figure 5.3 IDF curve of Delhi city

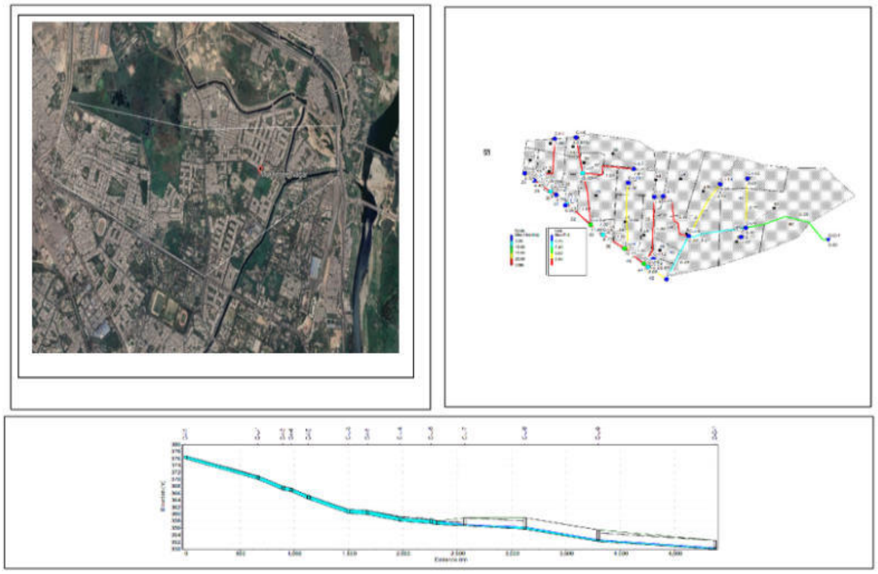


Figure 5.4 SWMM model results for Mukharjee Nagar

5.5 Flood Susceptibility Mapping

In this study, Landsat 8 satellite data have been used in order to investigate the UHI. LANDSAT 8 image with the input of the fourth (Green Band),third band (red wavelength/micrometres, 0.64–0.67), fifth (near infrared (NIR) wavelength/micrometres, 085–0.88), and tenth (thermal infrared sensor (TIRS) wavelength/micrometres, 10.60–11.19) bands and sixth band(SWIR).

5.6 RESULTS AND DISCUSSIONS OF UHI

MatLab code was generated as per algorithm shown in Fig. 4.2 and results are presented using ARCMAP 10.3

5.6.1 NDVI and MNDWI Map

NDVI and MNDWI maps were computed in MatLab and exported as tiff file in the ARCMAP as shown figure 5.5 and 5.6 respectively.

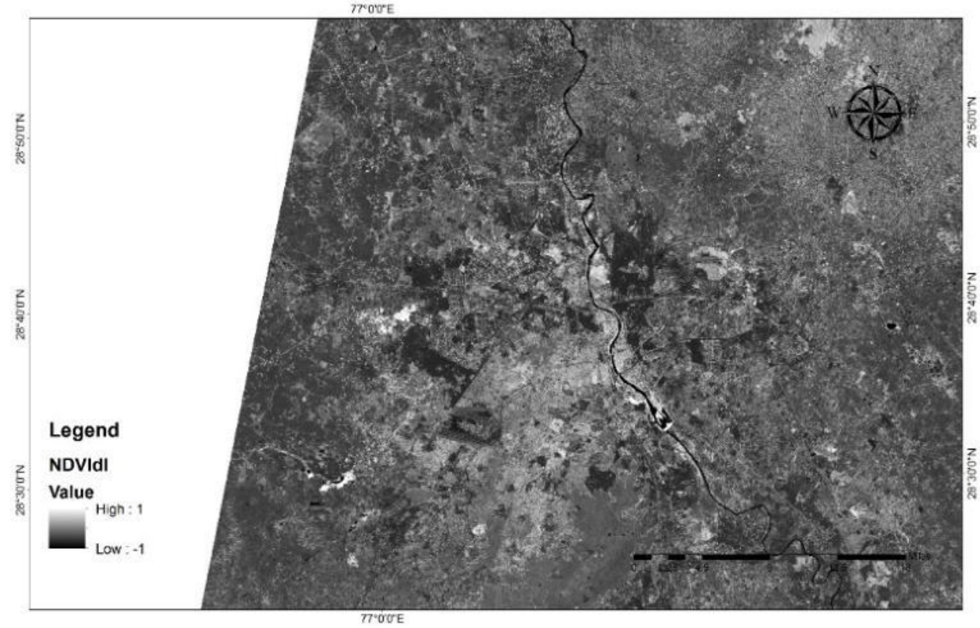


Figure 5.5 NDVI map

It can be seen that NDVI value is ranging from -1 to +1. Bright pixels shows the high vegetation and dim pixels shows the low vegetation. MNDWI values are ranging from -1 to +1. Bright pixels shows the water body and dim pixels shows the low moisture

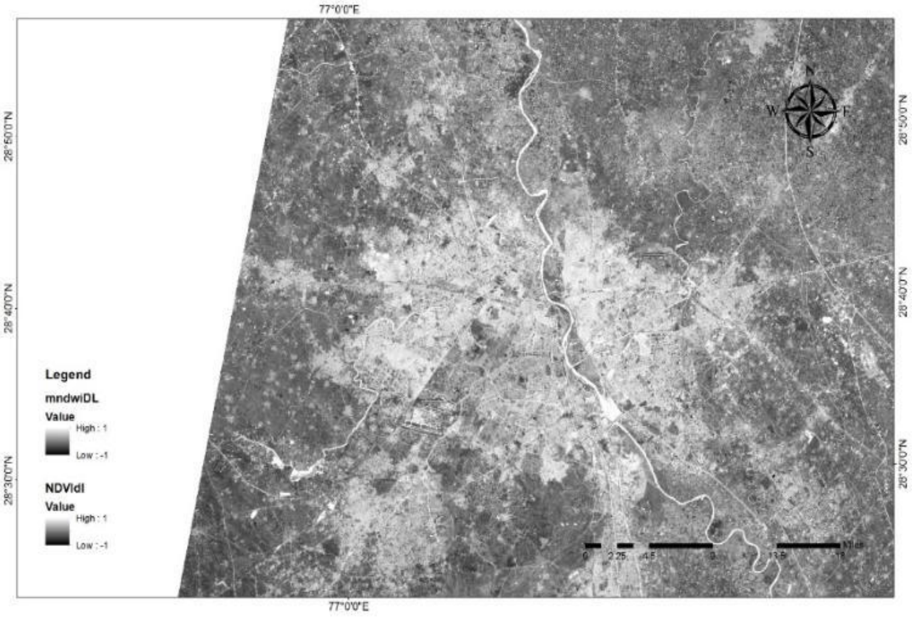


Figure 5.6 MNDWI map

5.6.2 Land Surface Temperature Map

Land Surface Temperature raster was computed from the Tb and L. NaN values in the Map indicates the no pixel value, This type of pixel values get assigned when particular portion of matrix has no values in it. From the figure 5.7 it can be seen that temperature values varies from 37.72^{0}C -48.37^{0}C

5.6.3 Actual Surface Temperature Map

Actual Surface Temperature Map was obtained using IDW analysis using the temperature data of GCM model. In the Present study GCM model (GFDL2.0) was used for the comparing with Land Surface Temperature raster obtained from the Thermal image analysis From the figure 5.8 it can be seen that temperature values varies from $37,72^{0}$C - 44.5^{0}C.

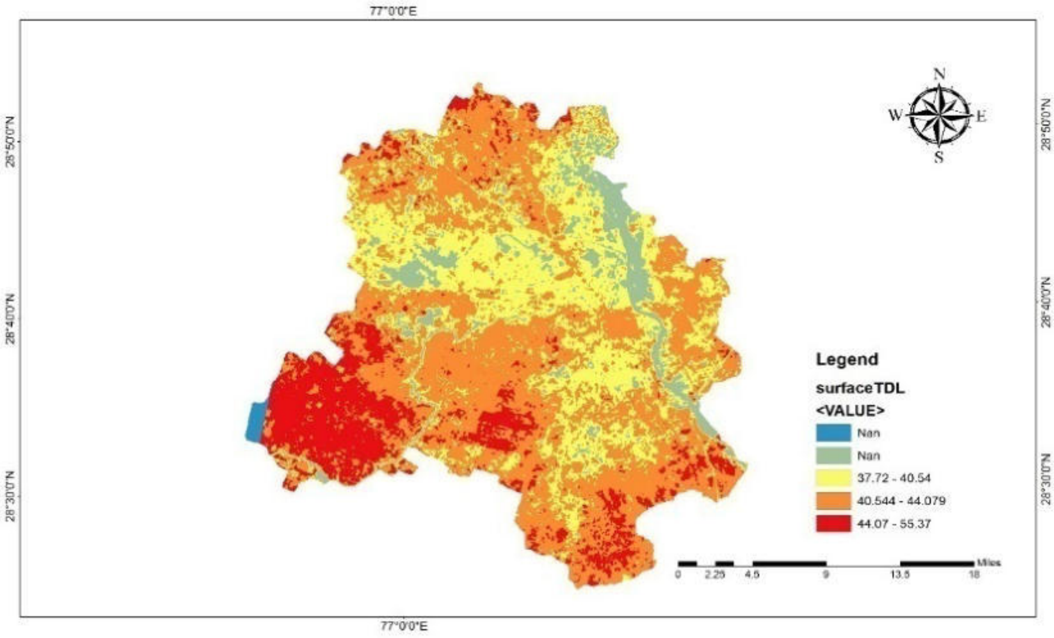


Figure 5.7 **Land Surface Temperature Map of Delhi**

From both the raster it can be observed that minimum temperature matches very well but there is discrepancy in the maximum temperature. Discrepancy is may be due to predictive capability of GCM model.

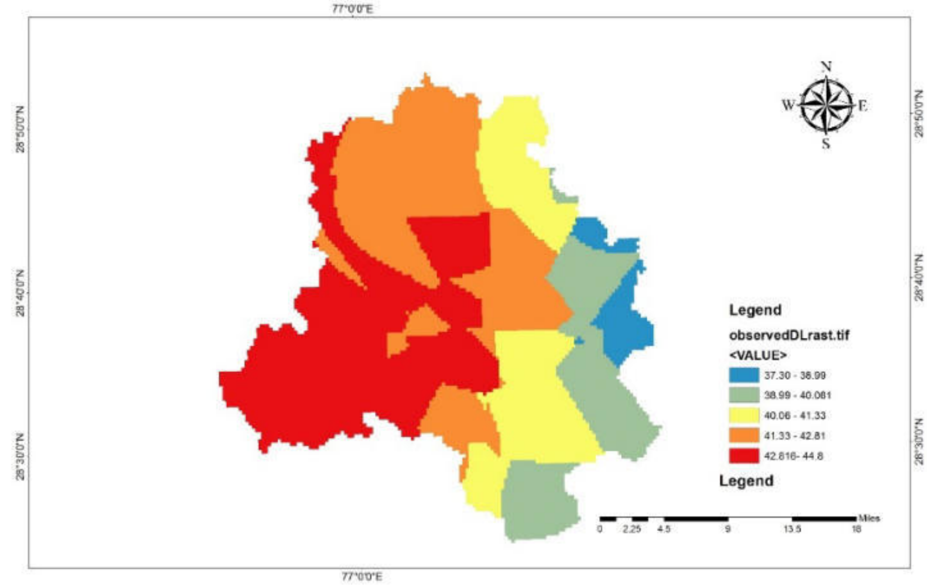


Figure 5.8 Land Surface Temperature Map of Delhi

5.6.4 Generation of UHII

UHII was generated as explained earlier. It can be seen that areas which are more warmer are showing bright pixels and low values for water covered areas as shown in Figure 5.9.

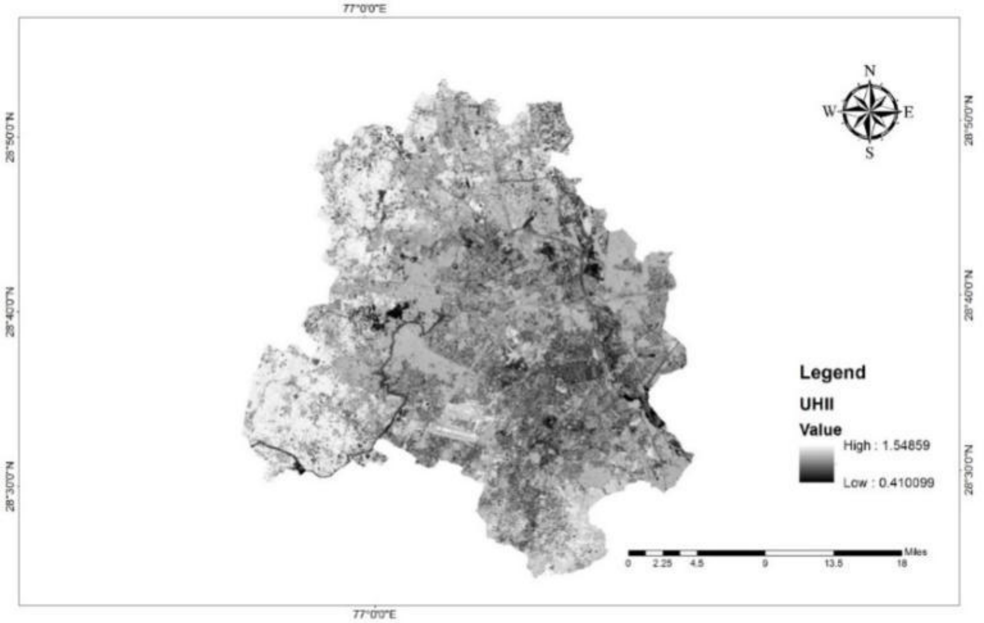


Figure 5.9Scaled UHII Map of Delhi

Hence it can be concluded that developed methodology extracts the UHI very well in consistent to the land surface temperature.

5.7 Deriving LID Using GIS and RS

There are two types of LID techniques are suggested: Intermediate-scale LID and Catchment-scale LID. Intermediate-scale LID refers to the implementation of LID techniques at a neighborhood or sub-watershed scale. The goal of intermediate-scale LID is to reduce the amount of runoff generated by impervious surfaces and direct it to more permeable areas for infiltration and treatment. Intermediate-scale LID is typically implemented through a combination of various LID techniques, such as rain gardens, green roofs, infiltration trenches, permeable pavement, bioretention systems, and swales. These techniques can be selected based on site-specific factors, such as the type and slope of the soil, the existing land use and development patterns, the local climate and hydrology, and the social and economic characteristics of the area. Catchment-scale LID refers to the implementation of LID techniques at a larger scale, encompassing an entire watershed or drainage area. The goal of catchment-scale LID is to reduce runoff and improve water quality throughout the entire watershed. This is achieved through the implementation of various LID techniques, as well as through the integration of LID principles into land use and development policies and regulations. Catchment-scale LID selection typically involves a comprehensive analysis of the entire watershed, including the evaluation of the existing land use and development patterns, the local climate and hydrology, and the social and economic characteristics of the area. Based on this analysis, LID techniques can be selected and prioritized based on their potential to reduce runoff and improve water quality, as well as their feasibility and cost-effectiveness.

5.7.1 Deriving LULC for LID

LULC is an important factor in the selection and implementation of Low Impact Development (LID) techniques. The type of land use and land cover can have a significant impact on the hydrological and ecological conditions of a landscape, and can therefore affect the suitability of different LID techniques for a given site. For example, urban and densely populated areas often have high amounts of impervious surfaces, such as buildings, roads, and parking lots, which can increase the amount of runoff generated during a storm event. In these areas, LID techniques that reduce runoff, such as green roofs or rain gardens, can be more effective and appropriate than other techniques. LULC map of Delhi is shown in the Figure 5.10.

5.7.2 Deriving the Wetness Index using GIS and RS.

The Wetness Index is a measure of the hydrological and ecological conditions of a landscape, and it can be derived from a Digital Elevation Model (DEM) as shown in Figure 5.11. The first step in calculating the Wetness Index is to determine the flow direction of water on the surface of the landscape. This can be done by using the slope information derived from the DEM to determine the direction of water flow based on the steepest descent principle. Once the flow direction has been determined, the next step is to calculate the flow accumulation, which is a measure of the amount of water flowing into each cell in the grid. This can be done by tracing the flow direction from each cell to its neighbors, summing the flow from each neighbor cell, and repeating the process until all cells have been processed Figure 5.12 shows the flow accumulation raster.The Wetness Index can then be calculated by taking the natural logarithm of the flow accumulation divided by the slope as shown in Figure 5.13. The formula for the Topographic Wetness Index (TWI) is: TWI = ln(A/S), where A is the flow accumulation and S is the slope. The Wetness Index is typically normalized by dividing the result of the calculation by thenatural logarithm of the maximum flow accumulation in the grid. This normalization step ensures that the Wetness Index has a consistent range across different landscapes and provides a meaningful comparison between different locations. The final step is to create a map of the Wetness Index by using the values calculated in step 4 to color-code the cells in the grid. The resulting map can then be used to identify areas with high and low Wetness Index values, which can be useful for site selection for Low Impact Development (LID) and other applications. Figure 5.15 represents the LID suitable sites for new delhi.

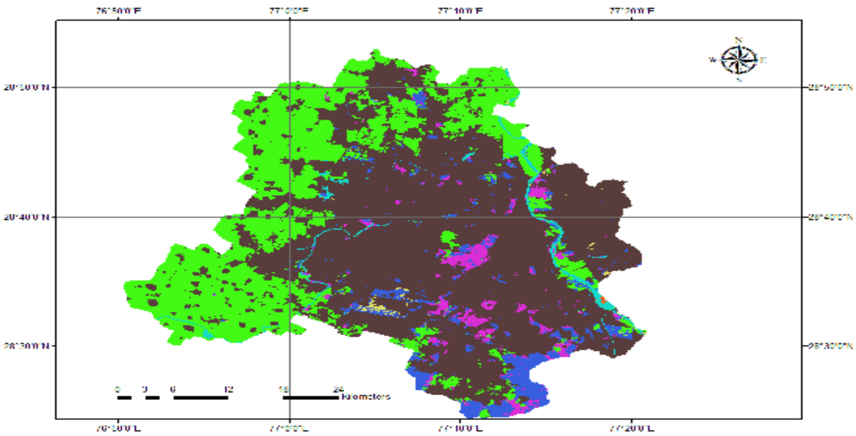


Figure 5.10 LULC map of New Delhi

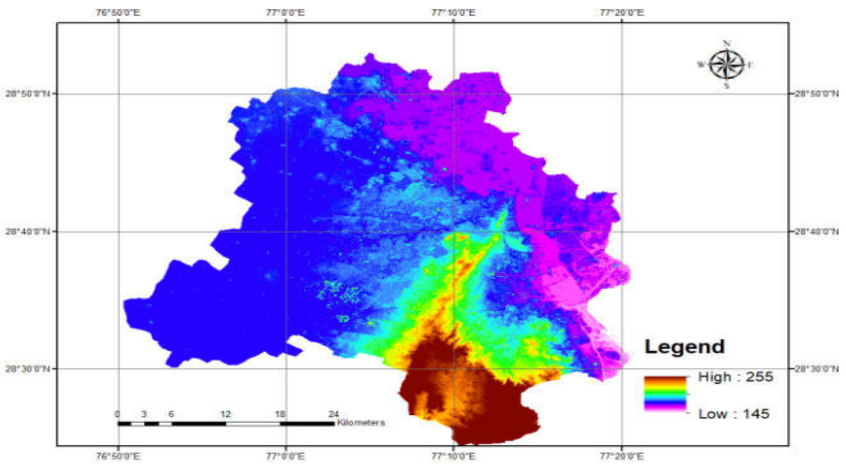


Figure 5.11 Digital Elevation Model (DEM) of New Delhi

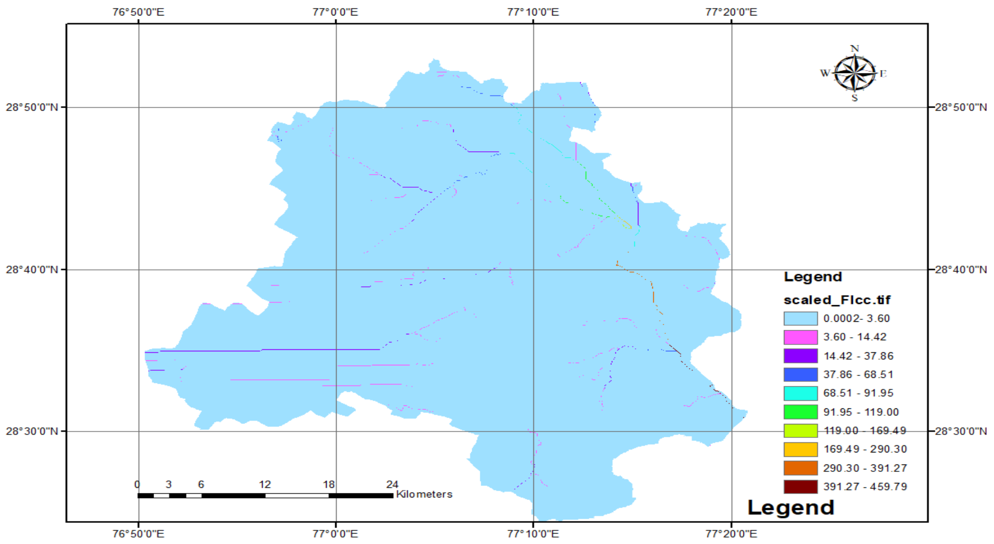


Figure 5.12 Flow accumulation raster

Mapping: The final step is to create a map of the Wetness Index by using the values calculated in step 4 to color-code the cells in the grid. The resulting map can then be used to identify areas with high and low Wetness Index values, which can be useful for site selection for Low Impact Development (LID) and other applications.

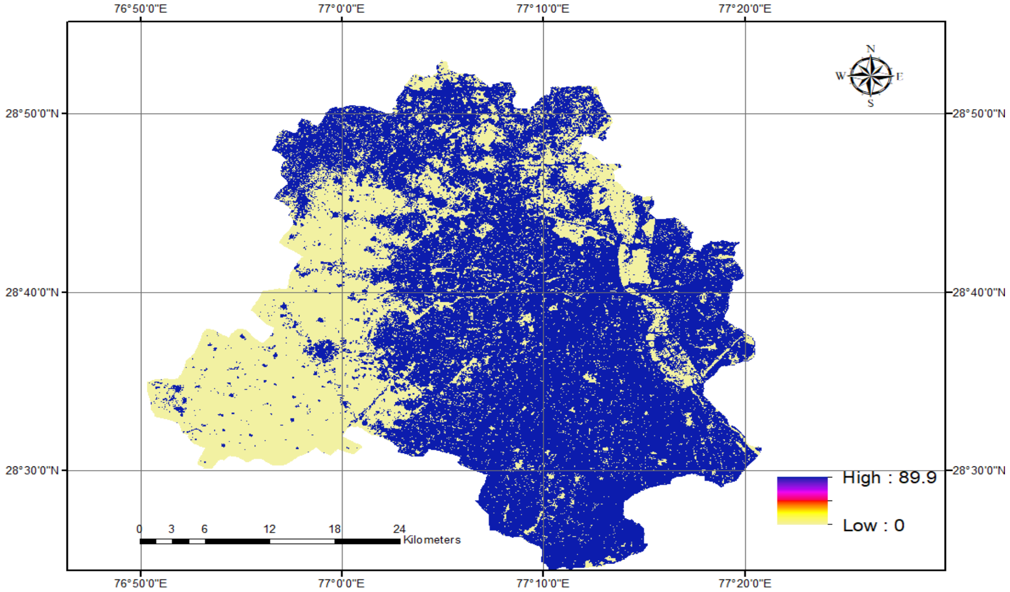


Figure 5.13 Slope raster

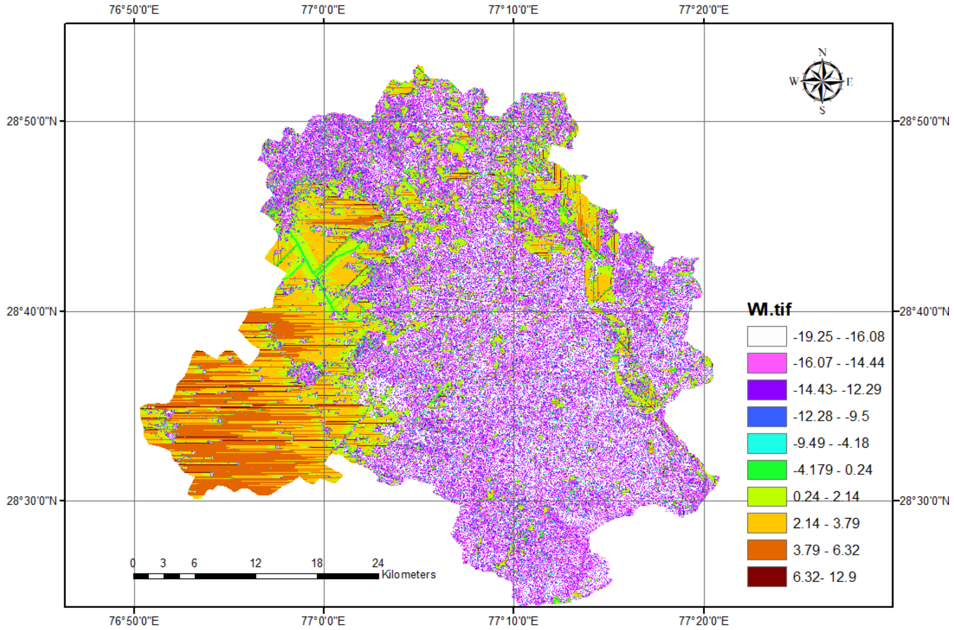


Figure 5.14Wetness Index of New Delhi

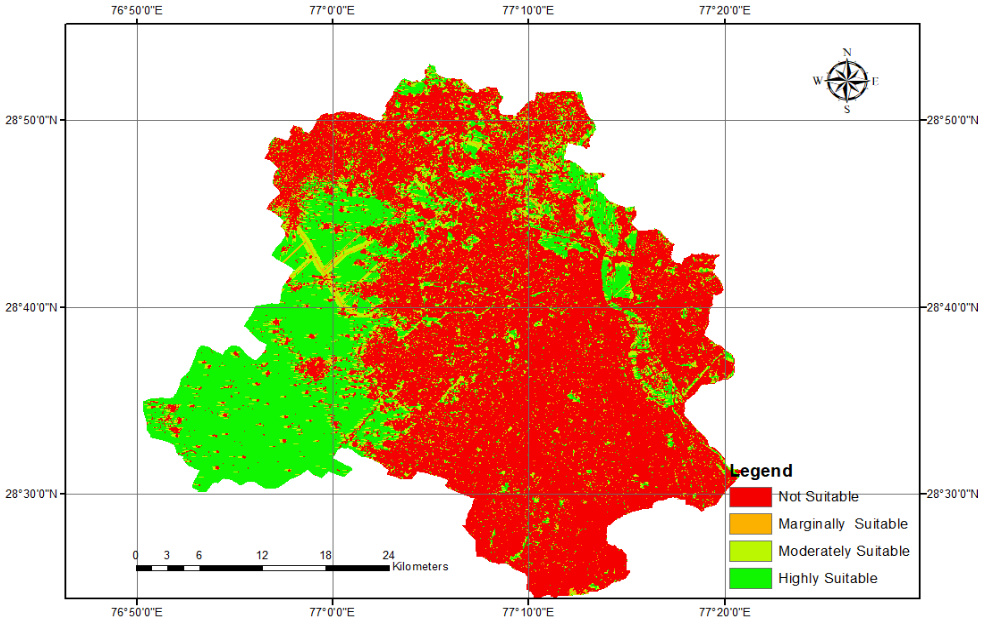


Figure 5.15LID Suitability Map of New Delhi

5.8 LID Performance

The performance of each LID (Low Impact Development) technique at the outfall can be assessed based on the percentage reduction in flow depth and volume for each LID case. Figure below shows the reduction in flow depth with each of the LID cases. It clearly evident that LID has the great influence on reducing the flow depth in drainage network which intern help in reducing the flood due to storm. Table 5.5. suitability of different Low-Impact Development (LID) practices in the Indian context and Figure 5.16 presents the performance of LID under different conditions.

Table 5.6. Suitability of different Low-Impact Development (LID) practices in the Indian context:

LID Practice	Suitability	Explanation
Rain Gardens	High	Effective for capturing runoff during intense monsoon rainfall.
Green Roofs	Moderate	Suitable where structural capacity and plant adaptability permit.
Infiltration Trenches	Low	Limited suitability due to high groundwater and clay soils.
Permeable Pavement	Moderate	Appropriate in well-drained areas with moderate rainfall.

Bioretention Systems	High	Effective in treating stormwater and improving water quality.
Swales	High	Effective for stormwater conveyance and treatment.

These LID practices vary in their suitability based on factors like rainfall intensity, soil types, and urban development conditions in different regions of India.

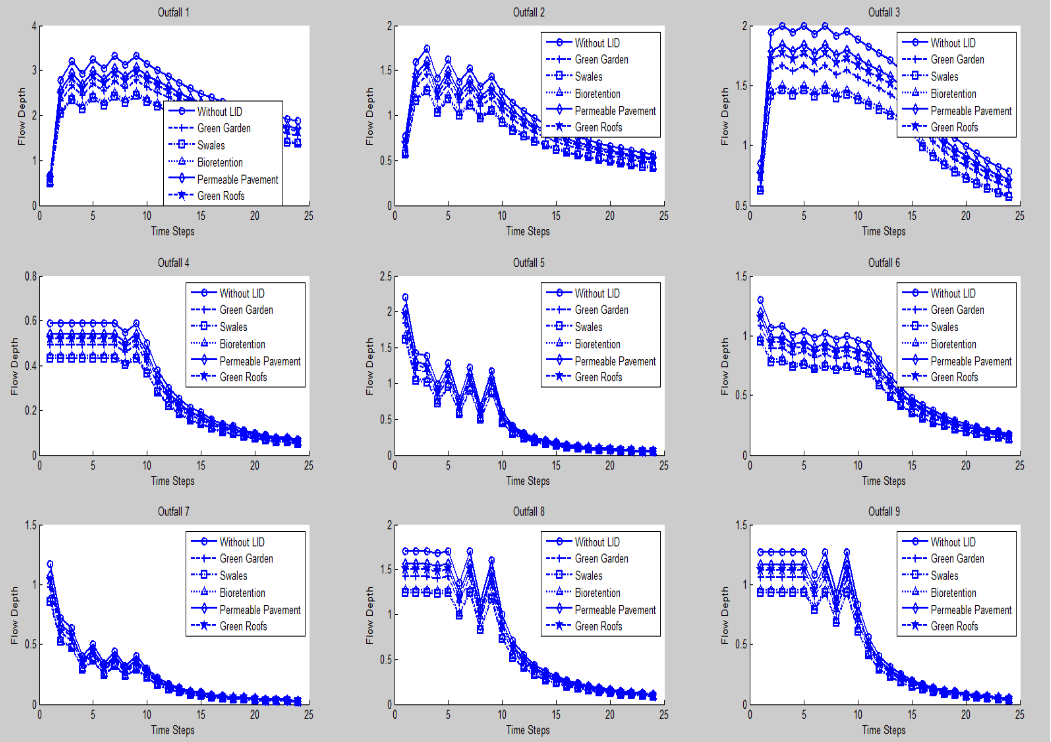


Figure 5.16LID performance

The data provided shows the percentage reduction in volume for each LID technique: Green Garden, Swales, Bioretention, Permeable Pavement, and Green Roofs.Table 5.6 illustrates the effectiveness of different LID techniques in reducing stormwater volume, with swales showing the highest reduction percentage, followed by bioretention, green garden, permeable pavement, and potentially green roofs. These techniques play a crucial role in sustainable urban water management by mitigating the impact of urbanization on stormwater runoff and water quality.

Table 5.7.The table presents the percentage reduction in stormwater volume achieved by various Low-Impact Development (LID) techniques.

LID	%Reduction Volume
Green Garden	16.6
Swales	26.86
Bioretention	24.92
Permeable Pavement	8.12

CHAPTER 6:CONCLUSIONS

6.1 Introduction

Objective 1: Provide Sustainable Stormwater Management

The study extensively delves into Low-Impact Development (LID) practices, exploring their potential applicability across diverse urban contexts. It highlights the transformative potential of LID in revolutionizing stormwater management, emphasizing how these practices can enhance urban resilience and mitigate the adverse effects of urbanization. By focusing on sustainable methods like LID, the research underscores the importance of adopting innovative approaches to manage stormwater effectively in rapidly urbanizing areas, ultimately contributing to more sustainable and livable cities.

Objective 2: Site Identification for LID Implementation

In the context of Delhi's unique challenges, particularly its vulnerability to flooding risks along the Yamuna River during the monsoon season, the research emphasizes the critical importance of this study. The study identifies indiscriminate urbanization and increased impervious surfaces as major disruptors of natural drainage patterns, exacerbating the threat of urban flooding. Through the application of the Analytical Hierarchy Process (AHP) with inputs from GIS and remote sensing (RS) data, the research successfully locates suitable sites for LID implementation. These identified sites are pivotal in mitigating flooding risks and restoring the natural hydrological balance within the urban landscape.

Objective 3: Performance Evaluation of LID Techniques

The study's findings and recommendations form a cornerstone in the development of strategies aimed at making Delhi more resilient to flooding and water-related challenges. It highlights specific LID practices, such as permeable pavements, rain gardens, and green roofs, as effective measures for mitigating stormwater runoff. These techniques are shown to alleviate strain on drainage systems and reduce the impact of floods significantly. Notably, the study finds that swales, in particular, perform exceptionally well in reducing flood risks, showcasing their potential as a key component in sustainable urban stormwater management.

Objective 4: Comparison of Pre and Post LID Development Conditions

The study integrates Land Use/Land Cover (LULC) analysis and climate trends into the assessment of LID suitability, acknowledging the undeniable correlation between LULC and hydrological behavior. This integration emphasizes the necessity of tailoring LID interventions based on the existing landscape to maximize their effectiveness. The research reveals that the implementation of the suggested LID techniques could reduce flooding by up to 25%, demonstrating a significant improvement over pre-LID conditions. This comparison underscores the potential of LID in enhancing urban resilience and provides a compelling case for widespread adoption of these practices.

Additional Insights:

The study anticipates the impending challenges posed by climate change, effectively addressing the dynamic relationship between changing climate variables and flood occurrences. By closely examining how shifts in temperature, precipitation patterns, and extreme weather events influence flood risks, the research provides a comprehensive understanding of the multifaceted impacts of climate change on urban stormwater management. Furthermore, the co-benefits of LID practices, such as enhanced air quality and the mitigation of the urban heat island effect, are critically analyzed, highlighting their contribution to creating a more habitable and aesthetically pleasing urban environment. These additional benefits not only improve environmental quality but also enhance the overall well-being of urban residents, reinforcing the importance of LID practices in sustainable urban planning.

Research Gaps and Future Directions:

Despite the promising potential of LID practices, the study identifies several critical research gaps that need to be addressed. One major gap is the limited availability of localized studies that consider the unique characteristics of specific urban areas. For instance, regions like Nehru Vihar and Mukherjee Nagar in Delhi have not been extensively studied in the context of flood management, highlighting an urgent need for targeted research in these areas. The study also emphasizes the need for more sophisticated modeling techniques that can incorporate a broader range of variables, such as social and economic factors, to provide a more accurate representation of real-world scenarios.

Moreover, the research calls for tailored recommendations that align with the specific needs and challenges of different urban areas. This involves moving beyond generic solutions and developing strategies that resonate with the nuances of the study area. By bridging the gap between theoretical models and practical implementation, the study advocates for a more grounded approach to flood management, ensuring that the proposed solutions are both effective and feasible in real-world settings.

In extending these sections, the study would benefit from a deeper critical analysis of the current methodologies and the potential for integrating emerging technologies, such as machine learning and advanced GIS modeling, to enhance the precision and applicability of LID strategies. Additionally, the research could explore the role of community engagement and public awareness in the successful implementation of LID practices, recognizing the importance of social factors in achieving sustainable urban water management.

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