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Impact of Urbanization on Drainage System: A Case Study of South -West Zone Surat

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***Abstract* - Rapid urbanization has significantly altered the natural hydrological processes of urban areas, leading to increased pressure on existing drainage infrastructure. This study examines the impact of urbanization on the drainage system in the South-West Zone of Surat, a rapidly developing urban region characterized by high population growth and land-use transformation. The research focuses on changes in land use and land cover (LULC), increase in impervious surfaces, and their consequent effects on stormwater runoff and drainage capacity.**

The study integrates geospatial analysis using GIS techniques, rainfall data assessment, and field- based observations to evaluate the efficiency of the existing drainage network. Key parameters such as runoff coefficient, drainage density, and peak discharge were analyzed using methods like the Rational Method. Findings indicate that increased built-up areas and inadequate drainage capacity have intensified surface runoff, resulting in frequent urban flooding and waterlogging, especially during peak monsoon periods. Furthermore, the study identifies critical gaps in stormwater management, including insufficient sewer capacity, poor maintenance, and lack of integrated planning. The results highlight the urgent need for sustainable urban drainage strategies, such as the implementation of green infrastructure, improved stormwater management systems, and policy interventions to mitigate flood risks.

This research provides valuable insights for urban planners and policymakers to enhance the resilience of drainage systems in rapidly urbanizing cities like Surat.

I. INTRODUCTION

1.1 General

Urbanization is a swift and unavoidable process characterized by the rapid growth of economy, population and infrastructure development. Nowadays, many cities across the world continue growing at a faster rate than before. Although urbanization improves the standard of living and offers many job opportunities, it leads to various pressures from human activities and construction on natural and artificial systems. Among the major concerns caused by urbanization, the issue of proper functioning of drainage systems needs to be mentioned.

It is important to emphasize that urban drainage systems play an essential role in the maintenance of environmental cleanliness and reduction of flood risks. However, with increasing urbanization, many cities replace natural soil with non-permeable materials (concrete and asphalt), thus altering land surfaces and making it impossible for excessive water to infiltrate underground layers and decreasing the amount of water runoffs. As a result, such alteration creates pressure on existing drainage systems, which were initially designed to cope with less amount of runoff water.

At present, the South-West Zone of Surat City experiences rapid urbanization as evidenced by its high population density, emerging residential areas, new infrastructure and commercial activities. Originally, the zone possessed a number of natural drainage systems and low-lying zones enabling storm water runoff. Nonetheless, due to encroachment, poor urban planning and lack of maintenance measures, the original natural conditions experienced significant changes.

In view of that, nowadays, the zone suffers from urban flooding, waterlogging and drainage congestion. Those phenomena not only complicate residents' life but also pose threat to people's health and property and undermine the sustainable development of the city. Thus, an urgent need for assessment of the existing drainage system and investigation of the effects urbanization has on it emerged.

The present study focuses on identification of major problems related to the drainage system of South-West Zone of Surat City, assessment of their causes and development of appropriate strategies for improving drainage operations.

1.2 Importance of Urban Drainage Systems

There should be efficient urban drainage systems in Surat due to its geographical location, rapid development and heavy rainfall in the monsoons. Surat lies near the coastal line and Tapi River which increases the chances of flooding and waterlogging.
The main advantage of efficient drainage in Surat would be that it will prevent the floods occurring on a regular basis in Surat. During heavy rainfall, drains often get congested or are not able to cope with the high amount of water thereby causing water accumulation in houses, streets, and markets.
Effective drainage will help in preventing damage to the economic activities and physical structure present in Surat. The damage caused by the flood water includes destruction of roads, bridges, housing structure and the important industrial centers like the textile market. The transport system is likely to get affected.
Furthermore, effective drainage will help in maintaining proper sanitation and public health in the area. Standing water creates an ideal breeding place for mosquitoes causing the prevalence of various diseases such as malaria, dengue fever etc.
On the whole, Surat needs proper drainage systems to prevent floods and protect the economy from being affected along with improving the public health of the area.

1.3 Problems Statement

The drainage system has been adversely impacted due to the speedy urbanization of surat, particularly its south-west zone. With the rising number of people, an increasing number of constructions have been made within the area, leading to concreting over the land area, resulting in less absorption of water and increased runoff water.
The drainage network is not designed to accommodate excessive rainwater due to haphazard construction, obstruction in the natural course of drainage systems, and poorly constructed facilities. Therefore, floods, blockages, and waterlogging are common events that occur often during monsoon.
Furthermore, the drainage system has become worse due to improper maintenance of the drainage network, dumping of solid waste, and lack of proper planning. These factors contribute to making the lives of the people miserable, deteriorating property worth, worsening traffic congestion, and causing health hazards.
Therefore, the most pressing issue is determining the rate and pace of unplanned urbanization and its impact on the drainage system of surat's south-west zone.

1.4 Aim

To improve impact of of urbanization on the drainage system in the South-West Zone of Surat City, Gujarat and to access its implications for flood risk and stormwater management.

1.5 Objective

- To Study the effects of urbanization on efficiency of the drainage system in South-West Zone, Surat City.
- To identify areas prone to Issue due to changes in land use and impervious surface growth.
- To provide recommendations for improving drainage System and prepare relevant planning proposal.

1.6 Scope and Limitations

Scope of study

This West Zone of Surat. This involves analyzing the present drainage capacity of the sewer and stormwater network, the maximum rainfall capacity, and flood-prone locations. The zone is well-developed, highly populated, and features an existing drainage system with adequate treatment facilities and pump stations.
Furthermore, the research considers changes in land use, impervious coverage increase, and the absence of natural drainage systems. Urbanization leads to more development, paving, and elimination of natural drainage channels. This increases the impermeability of urban areas, leading to runoff rather than absorption. This has put pressure on the existing drainage system.
Moreover, the research considers the causes of flooding due to high-intensity rainfall. Common issues such as overflows, channel blockage, inadequate drainage capacity, among others, are considered. Also, the applicability of various software such as Storm Water Management Model (SWMM) for assessment and optimization of drainage networks is highlighted.

Limitation of study

The research is confined to the South-West Zone and excludes some parts of Surat, meaning that the findings might not be generalizable to regions with varying circumstances.

It draws most of its data from readily available sources such as precipitation figures, drainage plans, and population counts. Given the dynamic nature of the city, the data might be out-of-date.

Furthermore, estimating the impact of Climate Change and adverse climatic events on drainage systems is difficult.

1.7 Methodology

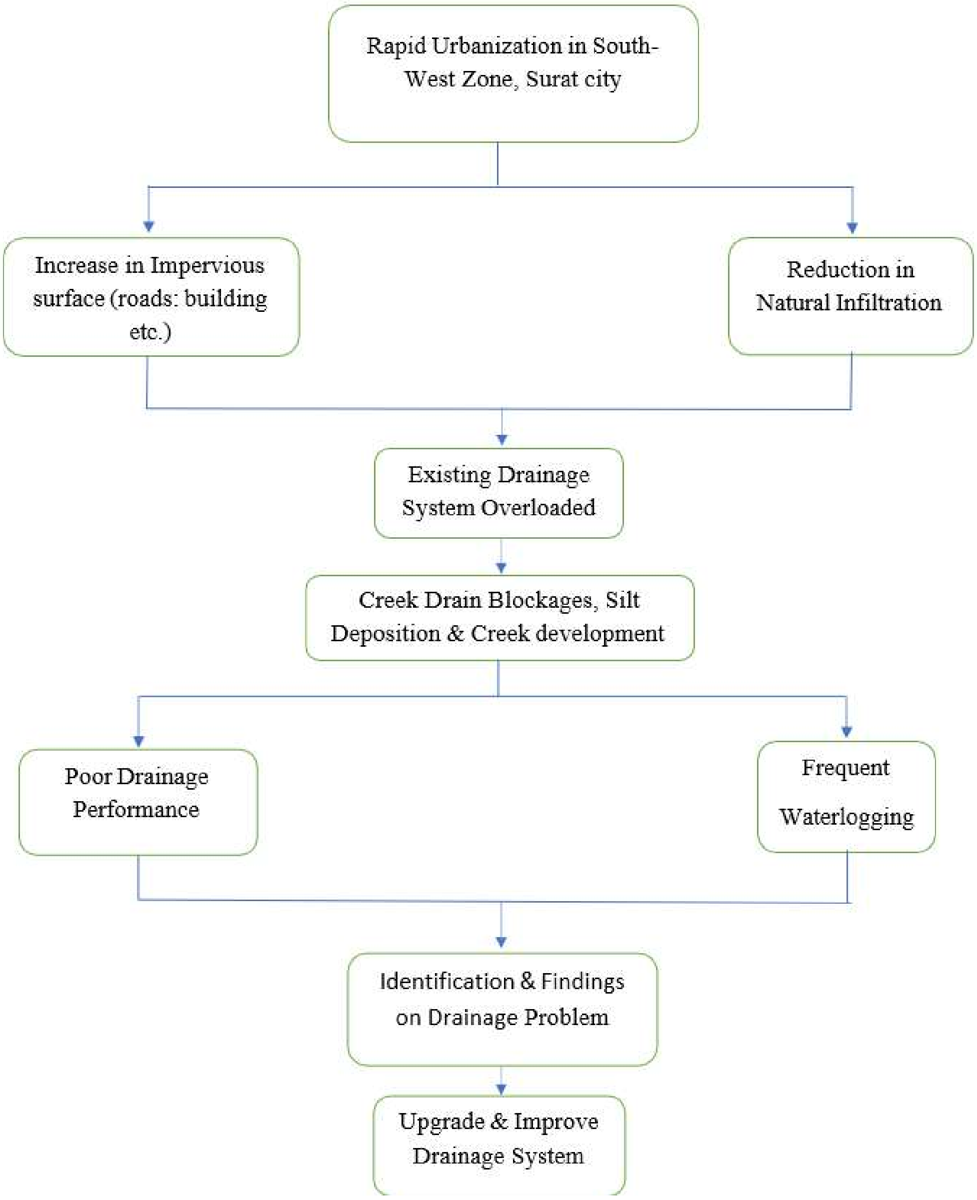


Fig 1.1 Flow Diagram of Urbanization in South-West Zone, Surat

II. BACKGROUND AND LITERATURE REVIEW

2.1 Background

The rate of urbanization across the globe is increasing rapidly. It is affecting the natural landscape and water drainage systems. Rapid urbanization has led to changes in drainage systems in most developing nations such as India. For instance, concrete and asphalt pavements replace vegetation, leading to a reduction in infiltration capacity. Such urban structures are not conducive to the efficient operation of drainage systems.

Surat is an emerging port city located in Gujarat. It is situated along the banks of the river Tapi. It is among the fastest growing cities in the country. Besides, it is considered one of the vital economic centers due to its role in trade. Being located in a low-lying zone adjacent to the Arabian Sea, it is prone to flooding. Surat city experienced several flash floods in the recent past, the most devastating occurring in 2006. The 2006 floods proved the inadequacy of the drainage system.

Drainage channels including khadis have been reclaimed to accommodate more urban infrastructure development. Illegal encroachments have increased over the years. These have made it difficult for natural drainage channels to retain excess water, hence increasing the possibility of flooding. On the other hand, the rapid urbanization has resulted in the creation of impermeable surfaces. Consequently, there is limited infiltration leading to high runoff. Additionally, the increase in paved surfaces affects the capacity of stormwater drainage networks.

South West Zone of Surat City is among the rapidly developing areas. There are numerous residential buildings in addition to the population density in this region. Drainage and sewer networks exist in some areas. However, they are yet to be fully constructed. Wastewater is discharged directly to the stormwater drains or adjacent water bodies. The discharges increase the burden on drainage facilities while posing environmental pollution threats.

Climate change has affected the drainage network adversely. Most drainage infrastructures were designed using historical data. Therefore, they are not capable of coping with extreme weather conditions such as torrential rains. As a result, many areas experience frequent flooding. Similarly, some regions experience waterlogging during rainy seasons.

Human activities have contributed immensely to drainage problems. Blocked drains, unregulated construction, and improper disposal of solid waste limit the efficiency of drainage networks.Moreover, encroachments on natural drainage channels increase their vulnerability during the rainy seasons.

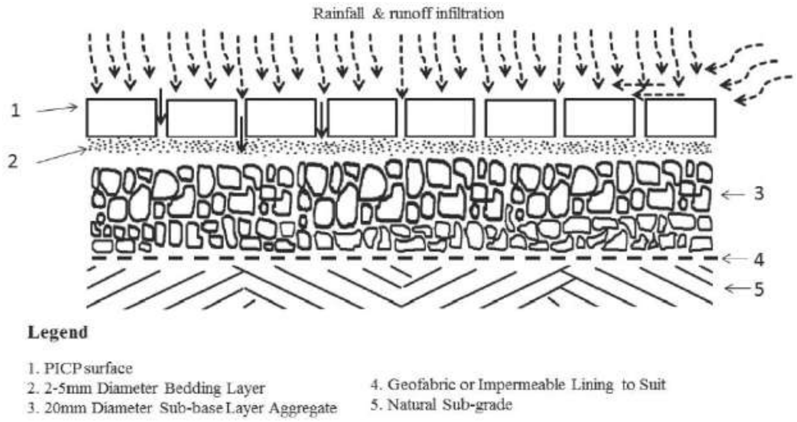


Fig 2.1 Rainwater & Runoff infiltration

2.2 Urbanization and Hydrological Cenario

The process of urbanization in the SWZ zone has drastically altered hydrological behavior in the area. The natural hydrological regime is heavily distorted due to the changes in the topography and soil permeability caused by the development of dense urban buildings. The impermeability of the road surface and pavement has led to an increased runoff. Analysis of satellite imagery indicates that formerly permeable zones have a higher degree of runoff.

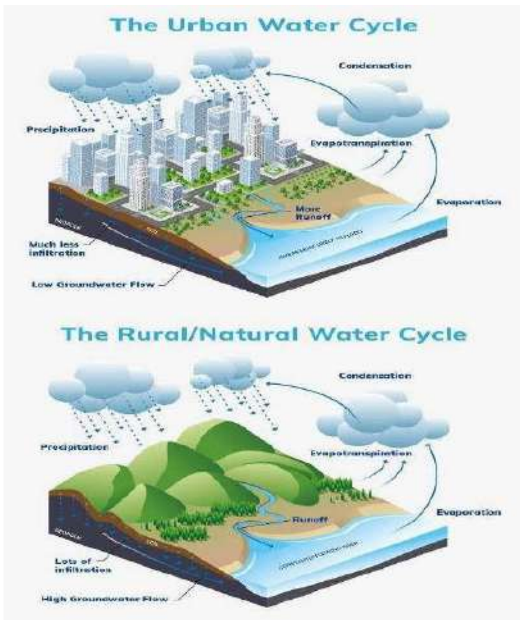


Fig 2.2 Hydrological Cycle

Table 2.1 Flood detail of Past 3 decades

Year	Type of Flood	Main Cause	Imapct	Notes
1994	Major	Rainfall & tapi river overflow	Flood lead toward plague outbreak	Around 56 dealth occurs and widespread of health concern
1998	Major	Water Release from Ukai dam	More than 30% City submerged	_
2006	Extreme	Water Release from Ukai dam & Heavy rainfall	90 -95 City submerged & water level was nearby 4-5 meters	Nearly 150 people died and had 22000cr economic loss
2013	Moderate	Normal rainfall	Nearby to 2006 flood	700000 cusecs water released
2024-2025	Moderate	Heavy Rainfall & drainage Issue	300+ mm rainfall in 24 hrs	Waterlogging

The above provide the flood Detail of past 3 decades with its types, main cause, impact as well as with certain notes.

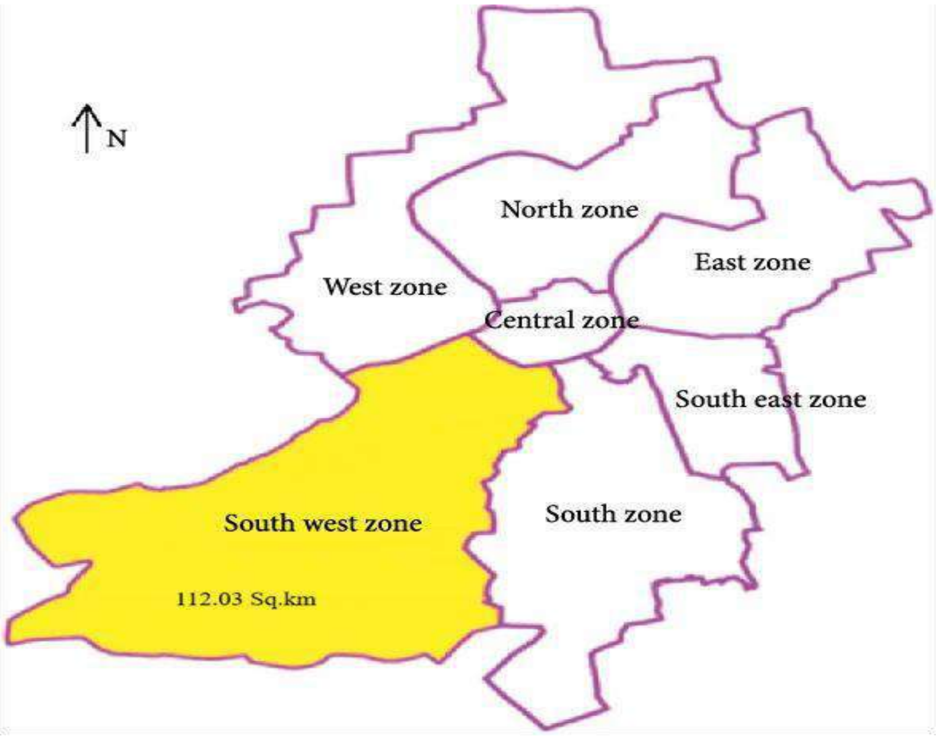


Fig 2.3 Surat base map

2.3 Literature review

1. Semadeni et al. (2007) Climate change is known to have long affected water systems, but most recent impact assessments examine factors such as population growth, landuse change and technology. In this study we assess the impact of climate change and urbanization on hogesborg, Sweden. using simulation models for the present and the future situation. Heavier storms currently cause untreated wastewaters to overflow and pollute the Coasts, and this is likely to increase in the future. We examined sewer flows in two periods, 1994–2003 and 2081–2090. Using thousands of simulations, we altered the model's precipitation records to reflect the effect of climate change, and simulated the effect of population growth and water management by altering the development and map data. Results suggest that both increased precipitation and increasing urbanization are likely to intensify drainage problems.

2. Zhou et al. (2024) Green infrastructure helps in stormwater management; however it is difficult to use in cities where there is limited space.

This paper proposes a optimization approach to maximize the performance of three types of green infrastructure in a highly developed area using infiltration, retention, and storage systems. An optimization model was developed to locate and size these systems to reduce runoff, loadings, and costs. The simulations illustrate the benefits of combining multiple systems are better than using a single green infrastructure type. The effectiveness of each system is related to the intensity of precipitation, the higher the rainfall, the less cost-effective the system becomes. The study also suggested that increasing the number of systems in downstream areas increases their effectiveness. Generally, this approach best manages stormwater in highly urbanized areas at low cost.

3. Gupthaa et al. (2022) Urban inundation is increasing due to rapid urbanization, climate change and inadequacies of drainage system. Therefore, it is essential to evaluate and upgrade the urban drainage system. This paper takes the drainage system of Gurugram, India as a case study, using stormwater model based on a 5-year rainfall with consideration of urbanization and climate change. Results showed that climate change has a larger impact than urbanization, and their combination further aggravates flooding condition. It was found that some segments of the drainage system were frail, and research on long-term drainage strategies such as retention ponds, infiltration trenches were discussed. As a result, the flood levels were reduced, peak flows were delayed and water storage capacities were enhanced, which suggests that these strategies can improve the efficiency and resilience of urban drainage systems.

4. Miller et al. (2014) The changes to storm runoff resulting from the development of rural areas into peri-urban areas was examined in this study. The rainfall, runoff and evaporation values for two catchments within Swindon, UK was collected for comparison. The catchments were both in the same area; the first being highly urbanised and the second newly developed. Storm runoff data indicates the importance of storm drainage systems, rather than the extent of any urbanisation or impervious cover, on runoff quantities. Impervious surfaces increased with development, and the installation of drainage systems increased with development. Peak flows increased and duration of flooding decreased. This information showed the influence of a relatively small amount of urban development and the effects of drainage system introduction. It was also seen that minimal urban development creates a significant change in runoff behavior which was only visible through the effect of drainage systems. This study shows that relying solely on impervious cover analysis is inadequate; drainage changes need to be recognized for effective flood management.

5. Balistrocchi et al. (2025) Rapid urbanisation in China has led to increased flooding in cities, primarily due to the expansion of impervious surfaces that reduce natural infiltration. At the same time, population growth has raised the number of people exposed to flood risks. This study aims to assess how both population growth and urbanisation influence flood risk using a catchment model alongside census data. The findings reveal that flood risk varies significantly across different areas. In highly urbanised regions, population growth contributes substantially to flood risk, while urbanisation itself also plays a critical role. Overall, the study emphasises that both urban development and demographic changes strongly affect flood risk and should be carefully considered in urban planning and flood management strategies.

6. Funke et al. (2025) This paper describes daily urban flooding problems experienced in the small Austrian city of Feldbach. It analyzes the effects that failure of drainage systems in combination with rainfall, has on urban flood extent by utilizing a flood model and comparing different failures against different rainfall events. It demonstrates that failure of central drainage systems results in significant urban flood extent and is directly proportionate to rainfall intensity. Failure of small NBS schemes results in little or no flooding and the effect is opposite to that of central systems. The analysis indicates the effects of drainage failure have a greater impact at less intense rainfall events than very intense ones. Overall the paper highlights the importance of proper maintenance and management of drainage systems.

7. Wang et al. (2024) Climate change increases the frequency and intensity of extreme rainfall, highlighting the risk of flooding of road drainage systems. This study develops a prototype model to assess the potential impact of future rainfall upon road drainage, considering the impact of climate uncertainty and system change. It considers very short duration storms for the period 2071–2100 in the presence of an Irish case study. The results show that the risk of road flooding will likely rise beyond the current safe limits under heavy rainfall. The paper considers implementation of a

current adaptation, which it argues, may need to be refined in order to mitigate future risks cost-effectively

8. Balistrocchi and Grossi (2020) This research is carried out in the north-west of Italy (Milan) to distinguish the effect of storm change on the urban stormwater system. The model developed for the flood frequency analysis which consider seasonal change of rainfall and storm duration, and storm frequency relationships, and then verified through the long-term rainfall dataset. The model forecast shows a trend of increased frequency of flood, approximately 10–20%, under the use of similar rainfall for the next century. This trend identifies the effect of greater bulk of the rain falling in shorter storms in summer and spring which could increase demands on the short-term stormwater drainage system which may not be able to cope.

9. Xiao et al. (2023) Urbanization caused the significant effects on water systems as a consequence of rapid economic growth and urban development. Therefore, the indicator based evaluation for urbanization degree was established and divided into four stages in this study for assessing the impacts. Meanwhile, the relationships between water system patterns and urbanization were investigated from view of landscape ecology. Results show urbanization during 2000- 2019 increased with decreasing of several main features of water system. The negative effect of urbanization degree on water system were confirmed and the strength of relationship increased with urbanization stages. It indicated the significance of urbanization degree for urban water system protection was getting prominently from view of stages as well as overall urbanization.

10. Sehrawat and Shekhar (2025) Urban flooding has become an alarming issue in rapidly developing cities where the paved areas are increasing along with sewage system. In the present study, the impact of best management practices for runoff reduction using Low Impact Development (LID) techniques has been studied for the valley city of India, Urburb. Using model simulation, the runoff comparisons have been made between various types of LID techniques such as green roofs, permeable pavements, stored rainwater and combined application of all the techniques in the study area. The results indicated that all of these techniques reduce the flow and volume of runoff from the study area. The green roofs could not outperform the combined use of all three techniques, but was the best among all options. The combined use of all the techniques is enhanced by a significant reduction in the runoff volume and discharge. The various challenges, such as operational, financial, as well as management, has been discussed along with recommendations to facilitate a long-term implementation of the techniques.

11. Bibi et al. (2023) This study in town of Robe, Ethiopia, examines the influences of climate change land-use change on peak flow and the existing storm water drain system. The PCSWMM model is applied to analyze four different scenarios to determine how volume of flooding and existing drainage systems are functioning. Low-impact development technique compared to rain barrels, rain gardens and combined uses of the two were applied to examine its role in mitigating flooding. The results reveal that extent of peak flow impoundment for 10 to 70% rates of imperviousness changed from 45.13 to 68.72 m3/sec, and flooding volume increased substantially. The study found that climate change increased runoff, leading to worse effects, by up to 46.9% for different models, and it was argued that current drainage systems would be insufficient to deal with runoff for the future, while LID could alleviate the amount of flooding substantially.

12. Tian et al. (2025) Heavy rainfall due to climate change has resulted in serious damage to underground tunnels all over the world while poor or blocked drainage is the main triggers. In this paper, a deep karst tunnel under the impact of heavy rainfall was investigated, where through the field inspection, a strong correlation between water drainage blockages and types of structural damages was found. Three forms of defects (non-leaking cracks, leaking cracks and seepages at joints) existed. The hydromechanical finite element model was used to assess the effect of different levels of drain blockages on structural response of tunnel lining, modified relative permeability (RP) concept was introduced to reflect the changes due to blockage. Results show that, with the severity of drainage blockages increases, pore water pressure ratio behind lining increases in three steps, slow increase, rapid increase and linear increased respectively. Heavy rainfall will exacerbate the damage severity by intensifying the blockages and directly increasing the pore water pressure.

13. Nagare and Supekar (2024) The changes in urbanization and climate are affecting the way rain behaves through alteration of the runoff and rainfall patterns which ultimately leads to increased

flooding, landslips and contaminated stormwater. The growth associated with urbanization puts more pressure on the drainage systems and this can have effect on 3 main areas: economically, socially and environmentally, the negative effects are most likely to impact on the less affluent. By 2050, the world's water stressed and flooding cities, urban droughts and the urban heat would become crucial issues. The solutions to these problems have been developed in the form of Sustainable Urban Drainage Systems (SUDS), Low Impact Development (LID) and Best Management Practices (BMPs) which includes the likes of bioswales, green roofs, rainwater harvesting, infiltration systems, ponds, permeable pavements etc. This report looks at such solutions in the context of maintaining sustainable urban drainage.

14. Datta et al. (2017) Urbanization in Bangladesh is increasing at a very rapid rate, which is unplanned, uncontrolled leading to overall environmental degradation. This is evident from the situation of Netrokona Municipal. In this research the present state of drainage system has been evaluated by field survey and interviewing in 50 people from different wards. The evaluation result showed that different dimensions of the drains are open, defects, neglected and weak in different ways. Several types of drains are constructed with cheap materials which had the no systematic design and layout. The issues of deodorization and trash dumping, clogging, track shrinkage were the major problems encountered. These characteristics resulted in frequent occurrence of flash flood, specific diseases such as skin disease. Land reclamation, proper use of biodegradable or non- degradable material and construction of proper opening drains with adequate width have been suggested in this research. There has been shown the relation between the existing poor drainage system, environment damage and public health. Most of the people interviewed indicated that strict regulation on garbage dumping in the drains would be an effective solution.

15 Abd-Elhamid et al. (2020) Urban expansion significantly increases the flooding potential since any natural land surface is replaced with impermeable surfaces such as pavements or roofs. The runoff coefficient increases and the surface runoffs become more rapid. This has a direct effect in the design of stormwater systems since it increases the peak flow rate and the flow velocity, reduces lag time and increases building costs. The work is based on the use of various software programs such as Hyfran, StormCAD, GIS to analyze several scenarios in Dammam in Saudi Arabia and an empirical equation to estimate the peak outflow based on several factors including rainfall depth, catchment area size and type of runoff was developed. A South Korean case study of the equation has been performed verifying it was accurate because it was very close with the gathered data. The results obtained demonstrate that the degree of urbanization influences greatly the effectiveness and cost of the storm drainage system. This explains the importance of finding an adequate flood management planning.

16. Jia et al. (2019) Designing urban drainage systems is becoming more difficult as urban areas develop, yet urban form is often not considered. This paper explores the effects of different types of urban form on drainage system performance, by creating an integrated model of urban form with waste water and storm water drainage networks. Three urban forms, used in built environments, are considered via images of hypothetical cities: square, star, and strip. The Storm Water Management Model (SWMM) was used to automatically generate and evaluate drainage networks. Outcomes from 200 different systems are used to evaluate system performance based on cost, efficiency, and flexibility. Results suggest that the influence of urban form on rain water collection were far greater than existing waste water collection. The analysis confirmed that as system performance increases, costs increase, and as costs increase, system flexibility decreases. However, all urban forms continue to face difficult compromises between affordability, performance, and flexibility. These impacts highlight the need to integrate urban form considerations into sustainable drainage system development.

17. Jemberie et al. (2023) Failure of urban drainage is a result of poor assets management, extreme poor maintenance and design and construction problems. The study shows the failure is in dumpskin deposits of solid waste and sediments followed by structural and design problems. In dumpskin and solid waste, clogging is more in the urban cities while siltation and forestation are in semi-urban and agricultural lands respectively. Structural problems like inadequacy of cross drainage openings in the catchments also deteriorates the situation. Blockage caused by solid waste causes damage to roads, traffic congestion and safety hazards. It concludes by recommendation

of Improvement of maintenance Supervision during construction Creation of mass awareness To avoid this problem. In addition, inherent design characteristics can significantly improve the performance of urban drainage system and control urban floods.

18. Zhang et al. (2014) And all that urbanisation is ever increasing, most of the urban drainage systems are under strain by virtue of more and more intensive storms events. As a result sustainable systems are proved to be a popular choice, because they are flexible for the needs of quantity and quality of water, and the landscape benefit and improved the quality of urban environment. This paper presents an overview of latest developments in sustainable drainage by looking at a number of disciplines. It discusses important design principles, and demonstrates methods and approaches that can be practical used in the real world. It reports on innovative modelling approaches and decision- making aids. While they offer advantages, they still have some shortcomings that require resolution before implementation. The evidence gathered highlights that a coherent and holistic approach is vital to the planning and design of sustainable urban drainage systems.

19. Zhang et al. (2022) Urbanization in China with every increasing speed places additional burden on water resources and urban drainage systems. Based on statistics and modeling techniques, this paper explores the impact of urbanization on the performance of drainage system with the aid of Jinxi, a small city. The outcome reveals a steady upward trend of urbanization from 2009 to 2020 and the dynamic changing of drainage performance which respectively deteriorates and enhances with a U-shaped pattern having a prominent turning point in 2016. Urbanization and drainage system show harmony with each other in 2014 and 2018. Urbanization might have positive or negative impacts on drainage system depending on the amount of infrastructure development and the level of water demand. The projection of development in drainage system suggests a trail to facilitate sustainable urban development, especially after the achievement of certain levels of urbanization (high urbanization rate, higher industrial development, and recovering retailing business).

20. Mendes et al. (2025) This paper builds a city typology based on UDSM services, applying it to a set of Brazilian cities. The k-prootype clustering algorithm helped researchers to identify four different city types plus a fifth cluster without UDSM data. The typology indicates that cities govern and provide UDSM services under very different contexts. It also presents evidence that structural complexity and institutional capacity tend to increase from Type 1 to Type 4 cities. The paper contributes to research for sustainable stormwater solutions by providing a meaningful analytical framework to efficiently deal with issues of governance, and could be adapted to other settings.

21. Oyebode and Umar (2023) Proper stormwater management is one of the way to control water quantity and water quality, protects the environment, prevents flooding and minimizes pollution. Poor management results in pollution, jeopardizing the source of water. This research also studied the Westro Nile cum Demumbaer (Nigeria) on a small scale rain water harvesting model in order to gain more insight into treatment methodology and management of stormwater at neighborhood levels. It was observed from the study that optimum use of materials such as Memory foam, alum, chlorine supported in improving water quality by reducing various pollutants. A significant which is the decrease in the ultimate concentration was observed in total dissipated solids, biological and chemical oxygen demand, calcium hardness and metal ions following treatment. Slight increase in turbidity, salinity, and condminuty and a decrease in dissolved oxygen was observed. Overall, the results demonstrate the usefulness and shortcomings of simple treatment processes. It is also worthwhile noting that stormwater management has not been adequate in many locations in Nigeria due to poorly or intermittently functioning drainage systems,There is a need to improve implementation of environmental rules and policies to move toward sustainable stormwater management.

22. Zhang and Ariaratnam (2018) Rapid global economic growth has sped up the process of urbanization, which has led to large numbers of people moving to cities in search of work. This growth often causes urban sprawl, which is when natural land resources like green spaces and permeable soils are replaced by man-made things like roads, parking lots, and buildings. These changes make it harder for the land to soak up rainwater, which makes more water run off the surface during rainstorms. Because of this, underground drainage systems are built to handle extra stormwater. But the speed and size of urban growth have changed runoff patterns a lot, often

going beyond what the current drainage systems can handle. Research on major cities around the world has shown that storms can cause huge economic losses, damage to property, the displacement of residents, and even death. Different ways to reduce stormwater runoff show that these measures can cut down on stormwater flow by about 43% to 61%, depending on how hard it rains and what the local conditions are like. This can help relieve pressure on drainage systems.

23. Bai et al. (2018) LID is an effective way to treat urban stormwater and lower the risk of urban flooding. Chinese researcher employed SWMM to analyze four different conditions of stormwater runoff treatment(lidnone, infiltration-based systems, storage-based systems, and combined systems) in Sucheng District, Suqian City. it is learned that measures of infiltration are more environmentally effective than storage measures in reducing surface runoff, while combined solution yields advantage in overall efficiency which within the range of reducing peak flow by 32.5% and flood volume by 31.8%. Place-to-place effect is varied by the location; somewhere a system of infiltration is efficient in reducing urban water flood; while somewhere storage measure is more beneficial. Flood generation is negatively correlated with monthly rainfall intensity and the couple, while positively correlated with maximum 24-h volume of rain, which would sustain at higher degree of precipitatio. Combined management measures are recommended to adopt in urban runoff control.

24. Binesh et al. (2019) Although best management practices (BMPs) are widely adopted to alleviate urban flooding, the role of BMPs on drainage system sustainability, particularly when BMPs are used in upstream areas, is still in controversy. This work revisit the concept of urban drainage system sustainability based on the concept that BMPs help improve system performance in the face of changing climates. System performance was evaluated with different indicator such as reliability, robustness and adaptability. The three scenarios no BMP, BMP applied in urban area and BMP applied upstream and urban area were examined by rainfall-runoff simulations as well as drainage network modeling to assess the flood-prone areas in present and future. The findings indicate that climate change exacerbates the flood risk and worsens system performance. However, BMP application in upstream suburban areas greatly enhances system performance, especially for reliability and sustainability than BMP application in urban area only.

25. Wang et al. (2024) This paper investigates the effect of the changing river network on flood regulation capacity for the Taihu Lake Basin – Changzhou Plain in Eastern China. Through an event- based method, using the coupled flood model, the long-term changes (from 1980s to 2020s) of the river network were examined. In this period, the total length of river network was reduced, which was caused by decreasing of the tributaries, while the length of the main river network was slightly increased, which was contributed to improving their connection. Two indicators, flood storage capacity and remaining flood storage capacity, were established to evaluate the flood regulation capacity. Results show that the overall flood storage capacity is improved in the changing period, which is mostly aroused by the decreasing of tributary rivers, while the good connection of the main rivers made no much contribution to improving the flood capacity.

26. Li et al. (2025) Coastal cities are blossoming being more and more populous, and face more and more severe natural disasters. It is necessary to look into the disaster processes through the living time. Disaster trends was investigated in Shanghai in the period of 1980-2019 using a comprehensive database and some indicators. The results revealed that typhoon, flood and hails were the most malicious type, typhoons step up as the main one affecting the human beings, crops and homes. The crop damaging typhoons were mostly caused by floods, while the most problematic one for human body was hails. The spatial. temporal distribution using urban/rural and developing/developed are proposed to demonstrate that suburban area suffered stronger threat than city center area, the urbanization, with an increased investment on urban planning, construction, governance and technological development, as well as an improved early warning system links to the mitigations. And Shanghai is a normal instance to illustrate the importance of planning and investment.

27. Tian et al. (2025) This paper studies the concern of summer monsoon flood risk in period affected by the subtropical monsoon climate in the Poyang Lake region. It takes the Seasonal Water Yield model of the InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) model system to study how climatic and urbanization change influence regional flood risk, locating areas sensitive to flood risk dynamics by matching that model

simulation with urbanization pattern, and helping communities to find effective strategies to respond to flood in the future climate change and rapid urbanization. The results demonstrate that under the subtropical monsoon climate, the effect of the subtropical monsoon climate takes 35.98% of flood season surface runoff changes; the effect of urbanization result in 26% of the increased due to land use change. Urbanization has a significant influence on the flood risk; in urbanized area, the surface runoff increased by about 30mm, and the 60-90mm surface runoff changed a lot. Ecological management, such as conserving lakes and riverbanks has relieved regional flood risk in 22 administrative regions.

28. Le et al. (2024) Flooding in the cities have become a serious problem on cities, which want to develop in a sustainable manner. Investment on drainage improvement has been a common approach to reduce flood risk, yet, drainage infrastructure more often fails to handle increased volume of stormwater when rapid urbanization and climate change proceed simultaneously. This paper explores the effect of aforementioned factors on flood risk, using the EPA SWMM to simulate the efficiency of drainage in An Ha urban catchment. It shows that urbanization reduces capacity of land to absorb rain which accelerates runoff occurrence. Climate change, on the other hand, increases intensity of rain and raise water level of inflow bodies. Urbanization rate over 70%, the combined influence of the both aspects significantly increase flood risk, making it worse and less manageable.

29. Feng et al. (2021) Increased urbanization results in an increase in the amount of impervious surfaces (buildings and roads) and thus a decrease in the time it takes for runoff to drain through an area as well as an increased chance of flooding. The objective of this research paper is to evaluate the effects of urbanization on flood flows by modeling flood flows at different rates of development, under different flood stages. A sub-watershed in Toronto was selected and land use files from different years was used along with hydrologic and hydraulic models, with scenarios from 0% to 100% impervious surface coverage. It is concluded that the higher the amount of urbanization, the higher the discharge of surface runoff and river flow, and the sooner the peak flows take place. With urbanization, the number of areas revealed to flood is the quantity of recognized or flash floods increases. Both total percentages of imperviousness as well as the dispersal of perceived storm water intensity inflows contorts the flood prevalence.

30. Ertan and Celik (2021) Rapid urbanization can have adverse effects on land use and land cover change (LULCC), and adversely affect natural processes of rainfall and runoff, resulting in the increased risk of flooding. This paper explores the implementation of sustainable drainage strategies (green infrastructure) to reduce the probability of flooding in a 1653ha catchment area of the Kathane Stream. A GIS-based method was used to investigate different scenarios such as the current land use, green roof, permeable roads, rain water storage system, drainage channel, a combination of green infrastructures and maximum urbanization. The findings indicate that green infrastructure provides effective reduction in the runoff and maximum discharge leading to the reduction of the number of affected buildings and size of flooding. It has also been demonstrated that employing more than one green infrastructure is better than employing just one.

31. Wenping Xu et al. (2024) Urbanization may result in sp form land use change all of which can enhance the natural rain and runoff process and increase flood hazards. The present study focuses to explore the use of sustainable drainage techniques, especially green infrastructure in the form of rain gardens to manage floods in 1653 ha catchment of Kagthane Stream. A GIS based method was used to simulate the different scenarios of land uses for the various points in time, i.e., Present State, Green Roof and Permeable Road, Rain water harvesting, Drainage channels, a combination of green infrastructure measures and complete urbanization. The results indicate that green infrastructure reduces runoff and maximum discharge, thereby reducing the number of people affected and duration of floods. It is also depicted that interacting using more than one green measure seems to be better than using one. An integrated GIS and HEC-RAS model based evaluation was used to explore the impact of green infrastructure measures, thus revealing their relative importance for flood hazard mitigation.

32. Zope et al. (2015) Landsat images for 1966, 1989 and 2009 and topo sheets for 1966 and 2009 are used to analyze land cover and urbanization changes in the catchment. Urbanization has increased by 59.66% since 1966 since the human population had a significant impact on the river and catchment system. The HEC-HMS was employed for hydrological simulation while the results of GIS and

remote sensing was used for water routing and flood mapping. Small increases in peak discharge and runoff volume are observed. However, when combined with the effects of tides this can lead to extreme floods. The study shows that an integrated approach has potential for modeling floods and generating hazard maps and this can be used for mitigation of flood hazards in Mumbai.

33. Shah et al. (2022) In the last four decade the city of Srinagar has undergone rapid urban expansion which has major implications on its water resources and natural drainage system. In this study, evolution of city from 1971 to 2020 has been extracted using morphometric and urban growth indicators and verified in four field plots. It has been found that built up area has increased four times with rise in edge expansion that resulted in loss of natural streams leading to a drainage system which can carry only a marginal of 15% of its earlier capacity. These trend analyses point to a critical importance of natural drainage conservation in Srinagar city.

34. Bibi and Kara (2023) A model was used to assess the combined effects of climate change, urban development, and low impact developments (LIDs) on flooding at Robe town, Ethiopia. The model simulations for four different scenarios indicated considerable increases in inundation volume and peak runoff with an increase in urbanization from 10% to 70%. The three regional climate models indicating climate change also reported high peak runoff increases. The existing drainage systems are insufficient to contain the increased flood pressures, especially around the Welmel sub-city to roundabout. LIDs would be useful in reducing peak runoff and flood severity, but the best approach to reduce future flood risks in Robe town is to combine LIDs with improved drainage systems.

35. Francis et al. (2022) Urban drainage systems are faced with many obstacles that inhibit their performance; however, the them are poorly understood. This research presents the most important obstacles by reviewing published studies as well as a survey of 30 Brazilian practitioners. Fifteen important barriers were surveyed and all were considered as important obstacles by practitioners. The most important problems are poorly functioning drainage systems, over-developed cities, inadequately maintained systems, over-sensitive urban areas and ineffective public policy and investments.

36. Jha et al. (2007) Groundwater as an essential reserve is suffering from the adverse effects of overuse and pollution. Advances in remote sensing (RS) and geographic information systems (GIS) have revolutionized land-and water-management. They are extremely helpful in groundwater studies. This paper reviews six major applications of RS-GIS in groundwater hydrology, namely, groundwater resource exploration and assessment, artificial recharge site identification, model for subsurface flow and pollution, assessment of pollution hazard, estimation of natural recharge, and hydrogeologic data analysis. Despite its expansion since the early 1990s, many applications are still in exploratory stages, especially in developing countries.The paper highlights the importance of integrating RS-GIS studies with field investigations in refining current techniques and developing newer ones for improved groundwater management.

2.4 Case study

1. Ahmedabad, Gujarat, India (2015–2020)
Ahmedabad is one of the fastest developing industrial cities of India. Over the last decade, tremendous developments have taken place in the city limits of Ahmedabad and the increase is mainly at the center and western parts of the city limits. GIS analysis, historic rainfall data analysis and field investigation towards drainage, have revealed that expansion of residential neighborhoods, commercial areas and industrial estate, has increased the surface runoff, which comprises of impervious surface like roofs, roads and pavements, resulting into increase in the groundwater recharge by rapid surface runoff flow and increased surface runoff during the monsoon season. In the low-lying areas like Maninagar, Jamalpur and Bapunagar, water-logging are observed. Encroachments along natural water channels and lack of proper maintenance of drains are aggravating the situation. The amount of floods can be minimized by widening of storm water drains, protection of natural water bodies, implementation of land use policies and scheduled maintenance of drains.

2. Kolkata, West Bengal, India (2010–2018)
Kolkata has a history of many canals and wetlands present around, but now it has grown out which have worsened by encroachments especially on rivers and former wetlands. Attempting to estimate the "Flood Susceptibility Index" for different

floodprone zones inside Kolkata through historical maps based on multitemporal time-series satellite imagery of the city and applying Geographical Information System from 1990-2018, study shows that conversion of wetlands, ponds, and open spaces into residential and commercial complexes has decreased their ability to store water subsequently increased runoff. Impenetrable drainage and poor water disposal resulted in seeping of water inlow and floodoccasions occurred to Tollygunge, Howrah and Topsia continuously during monther period. Old canal networks was blocked by barrage and walls and choked by silted sediments and previous bad stonwater management practices caused the problem and recommendations were the preservation of conservation of existing marsh, dredging and widening of networks of canals, implementation of best management practices or stormwater controls, integration of flood control measures into city development plan.

3. Bangalore, Karnataka, India (2012–2019)
The rapid expansion of Bangalore city, mainly driven by the IT industry, resulted in significant changes in urban land use over 8,000 ha of open land was converted to roads, pavements and high-rise buildings. SWMM (Storm Water Management Model) hydrological modeling indicated that runoff depths and peak flows were significantly increased on highly developed areas thereby causing stress to pre-existing drainage systems. During moderate to heavy rainfall events, streets in neighborhoods such as Koramangala, Whitefield and Marathahalli were severely inundated. The results of this investigation suggested that improper drainage exacerbated by unregulated construction along natural waterways led to flooding of streets during rainfall events. Recommendations for sound runoff management included the construction of additional drainage channels, promotion of rainwater harvesting, permeable pavements and SUDS.

4. Surat, Gujarat (2014–2021)
The South-West Zone of Surat was experiencing heavy pressure due to influx of population, industries and urban growth along with heavy nnew development construction. GIS was used to study the Flood regularity, rainfall records, drainage system to depict that the impervious area has replaced the natural drainage courses, marsh and water bodies which was conducive to high runoff and flooding. Field observations indicated that drains often were found chocked due to garbage dumps by industries as well as hota and faroz fields. Even small amount of rain out of for just flood South-West region like Parle Point, Piplod, Adajan, etc. It was recommended to widen the existing drains in the area, preserve greens, develop regularity of drains, take into consideration the urban drainage on master plan.

5. Jakarta, Indonesia (2010–2016)
Jakarta, a deltab City, with low-lying planning areas, has a significant problem of flooding which is associated with the rapid growth of population and unplanned densification using canal network as waste disposal areas. They examined the drainage system performance using a combination of remote sensing, hydrodynamic modeling, and field survey. The inadequate drainage system could not cope with water runoff generated from heavy monsoo. n rains, and illegal constructions along canal blocks to flow especially in the northern districts, resulting in severe accumulations of water in residential and commercial premises, Some recommendations were dredging and widening the canals, improvement of building policies along or near waterways and environmentally sound urban drainage techniques.

6. London, United Kingdom (2000–2015)
Based on historical analysis of various time series of rainfall, surface water flood events, and sewer capacity, it was determined that there has been a greater number of surface water flooding throughout London, a city with ancient infrastructure and a high number of existing buildings due to the city ‘s long historic existence with an increase in hardscape surfaces. Excessively high intensity precipitation event caused locality flooding due to the incapability of aging drainage system. Sustainable urban drainage systems (SUDS) are implemented to mitigate potential flood risk and peak flow runoff, which includes green roofs, retention basins, bio-retentions, cobble-lined channels, and permeable pavement.

7. Dhaka, Bangladesh (2012–2018)
Rapid and unplanned growth in Dhaka has caused enormous stress on the city drainage systems. Hydrological studies, flood maps and field investigations have proved that high density of development has prevented rainwater from getting into the ground and blocked the drains and canals, which are hard to maintain. Old Dhaka gets flooded

during the monsoons. The recommendations of the study indicated that in order to reduce the capacity of flood damages in dense urban sites, existing natural drains need to be rehabilitated, storm water drainage system should be expanded, maintenance system should be upgrade and building norms should be maintained

8. Lagos, Nigeria (2010–2017)
Lagos is a coastal city with a rapidly increasing population. As the land area of the city has increased, new urban drainage networks have not been developed to accommodate the growth. Through rainfall analysis, GIS mapping, hydrological modeling and field surveys, it was observed that urban waterlogging and flooding were frequently caused by profligate land surfaces and un-maintained drainage systems particularly in Victoria Island, Ikeja and Surulere. And the unregulated construction on or near waterways and constricted waterways exacerbated the blocking effect of water courses on drainage network at extreme rainfall condition.

9. Singapore (2005–2018)
Singapore (one of the most developed city states) has spent years attempting to plan for urban development and drainage. Because of the rapid development and extensive land reclamation, Singapore has increased the amount of impervious surfaces, leading to significantly increased surface runoff during extreme rainfall events. Hydrological modeling and GIS analysis showed that extreme storm events could generate far more runoff than existing drainage systems could handle, leading Singapore to develop a comprehensive drainage system consisting of both canals and pipelines. To accompany, this system, the city implemented a series of engineered and green, or Sustainable Urban Drainage System (SUDS) elements, including green rooftops, bio-retention systems, and permeable surfaces. Overall, Singapore's drainage planning can serve as an example for how a developing country can come to terms with a more urban future.

10. Mumbai, Maharashtra, India (2008–2017)
Mumbai- An overcrowded coastal mega-city, experiencing much urban flooding problems due to excessive monsoon rains and haphazard urban growth in low-lying areas, is one of the most prone cities in India. Large-scale reclamation, haphazard high-rise construction and encroachment along natural water bodies have caused reduction in soil percolation and increased surface runoff, thus overloading the existing drainage infrastructure in Mumbai. Visualization using field tests and flood maps showed frequent flooding in localities such as Andheri, Dadar and Kurla, often worsened by poor maintenance of drainage (blocked drains) and inadequate spacing of storm-water drains. Proposed measures to reduce the hazards, apart from flood plain control, included improved maintenance and widening of drains, preservation/restoration of water bodies, construction of detention/retention (infiltration) basins, use of SUDS and effective planning of urban infrastructure.

III. STUDY AREA

3.1 Overview of Surat City

Surat is a rapidly expanding city in western state of Gujarat. On the banks of the Tapi River and close to the Arabian Sea. Surat is often called the 'Diamond City' because of its thriving diamond and textile industries. The city has expanded rapidly in recent decades. The city is naturally vulnerable to floods (particularly during the monsoons). Due to its low lying riverine and coastal plains. The city is divided into several administrative zones. The most significant being the South-West Zone because of its high residential and commercial population and its contribution to the city economy. The Piplod, Parle Point and surrounding neighborhood, which are key neighborhoods in the South-West Zone. It has a combination of planned urban forms and unplanned settlements. As a result, urban fabric can vary significantly from upscale housing developments to outdated neighborhoods. The intensification of urban areas has converted open spaces, wetlands and natural waterways into built-up areas. More paved areas, roads and buildings have all increased the impervious surfaces, slowing down the rain water permeation into the ground. This has led to a higher surface runoff and increased stress on of the city drainage system when heavy rainfalls occur leading to widespread water logging.
There are stormwater drains, sewer lines, pumping stations and sewage treatment plants in this system. They were originally designed to cope well with the runoff, but rapid urbanization, construction on natural drainage channels and improper disposal of waste have caused their inefficiency. Several drains are blocked or inadequate in size causing water logging even during light showers. Piplod and some

of the low-lying areas of Parle Point are most vulnerable. All of this point to the need for a modernized system, regular maintenance and the planned clustering of cities according to flow models.

South-West Zone is the economically vital part of the city as it harbours most of the textile markets, business districts and major transit routes in Surat. Deep flooding or drainage problem in this zone would render life and business meaningless for the citizens and the businesses operating here. The City has also lost part of its natural drainage due to loss of wetland and natural drainage routes thereby increasing the dependency on artificial drainage.

The south west zone, demonstrates the faults of having rapidly expanding cities with so many people, industry and unplanned development happening simultaneously with environmental and topographical problems.

3.2 Location and Extent of South-West Zone

South-West Zone of Surat region is one of the major administrative parts of the Surat. This zone is falling in south western part of surat city. Surat city is in south Gujarat lying on Tapi River and near the Arabian Sea. So, the physical and the environmental conditions of the south- west zone is li ked as per the place of position. The major localities of this zone are Vesu, Athwalines, Piplod, Bhimrad and Althan which are suburban and quickly developing places were the estate is developing as planned, these areas are fully developed and institutional.

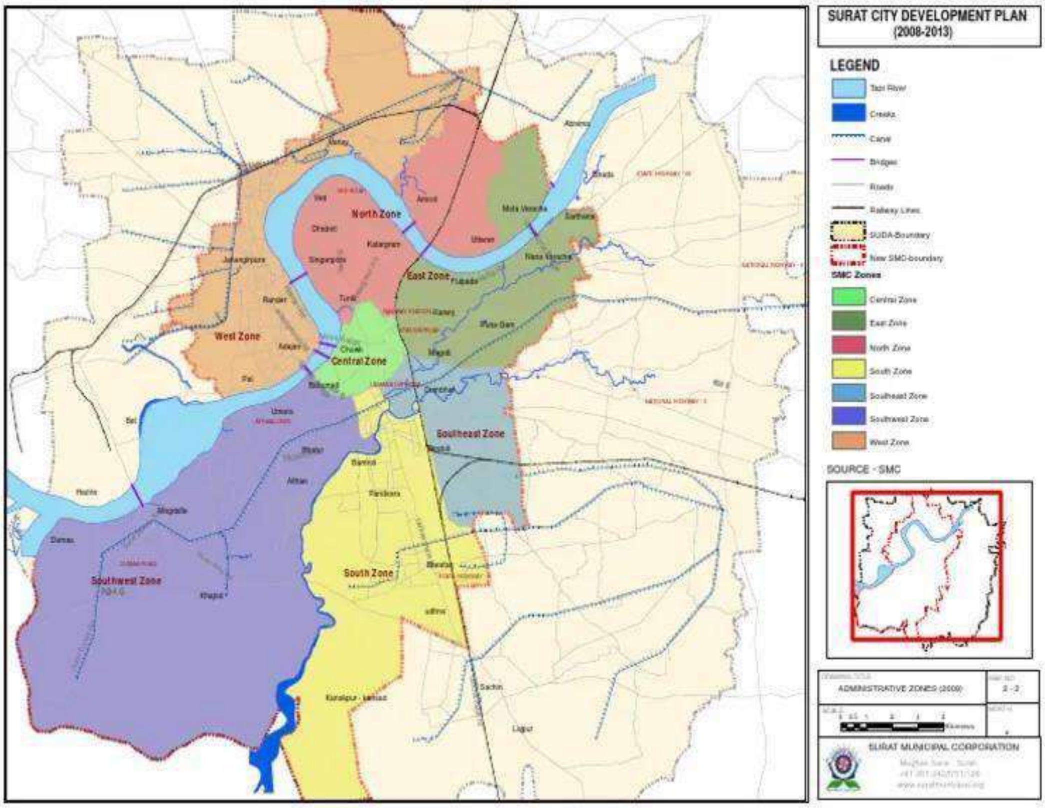


Fig 3.1 South-West Zone Layout Map

As far as the extent concerned South-West Zone covers reasonably large land area i.e. 111.9 sq.km.. Broad boundary of South-West zone at the northern limits is defined by Tapi River and western parts of Surat city. Its eastern limits are defined by central & southern zones and extended suburban area while its southern boundary is defined by growth of suburban areas. The border of South-West zone at the western limits is close to Dumas and Arabian Sea. Area is located in low lying coastal plain which is prone to water logging and floods during heavy rain. Due to fast urbanization and growth of impervious surface i.e. roads, buildings, etc. natural drainage pattern is being disturbed.

3.3 Climate and Rainfall in Surat

Surat has a tropical savanna climate, with three main seasons–summer, monsoon and winter. The city experiences high humidity all throughout the year owing to its proximity to the Arabian sea and the Tapi River. This climatic condition affects the city systems directly, and has a bearing on stormwater drainage and flood control strategies. Surat's summer lasts from March to June and is very hot. It can reach about 45 Degrees C and rarely drops below about 35 Degrees C, peaking in May. It is dry for the season with just some early rainfall before the monsoon arrives.

The winter season (November to February) is comparatively cooler and more pleasant, with average temperatures ranging from 15°C to 28°C, making it the most favorable period of the year.

The four months period (June to September) of the monsoon season is important as it has a very high influence on the climate. The average rainfall received in a year is around 1200 to 1400 mm with 85 90% of the amount of rainfall being received in the above aforementioned period. Both these months receive high rainfall, generally in the form of intense, persistent showers. The fact that it is not persistent when received in the form of showers, contributes to a rapid run off in the flood prone areas of the city.

Heavy rainfall and rapid urbanisation puts much pressure on the drainage system of the city. With the high water levels of the river Tapi and heavy rainfall, Waterlogging and temporary flooding occurs in some parts of the city.

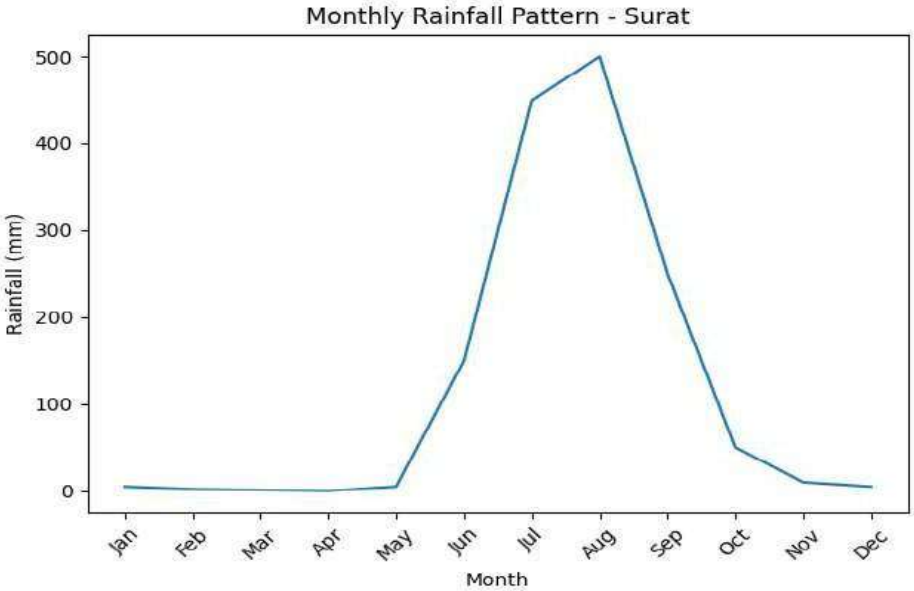


Fig 3.2 Rainfall Pattern

Table 3.1 Monthly Rainfall Pattern

Month	Rainfall (mm)	Avg Temperature (°C)
Jan	5	24
Feb	2	26
Mar	1	30
Apr	0	33
May	5	36
Jun	150	34
Jul	450	30
Aug	500	29
Sep	250	30
Oct	50	32
Nov	10	29
Dec	5	25

3.4 Population and Urban Growth

Population growth Surat has experienced rapid population growth over the last few decades and is one of the rapidly increasing cities in the state. The population of the city (from the SMC) was around 4.46 million in 2011, and after the city limits were extended in 2020, the population increased to almost 4.65 million. It had a very high decadal growth rate of about 55.29% during 2001-2011. This can be attributed to industrialization, natural growth of population as well as outward extension of the city limits.

The population of Surat has been steadily rising over the years from approximately 2.88 lakh in 1961 to over 44 lakh in 2011. This increase has been mainly due to increase in the pace of development and economic growth. Recent estimates put the population of the urban agglomeration at over 70 lakh. This highlights the fact that the city is a leading economic hub in the country with a prominent textile and diamond industry.

Table 3.2 Population Growth

Sr no	Name of Area	Area sq.km	Population		
			1991	2001	2011
1	Athwa –Umara	1.7	8186	9204	8538
2	Bhatar	2.3	8679	28622	45628
3	Althan	3.23	10900	53960	53960
4	Piplod	1.92	2668	8871	17595
5	Bharthana Vesu	2.194	1219	1920	5414
6	Abhava	21.96	2505	2881	3249
7	Vesu	8.99	3298	6251	26471
8	Magdalla	2.299	2021	5257	6104
9	Gaviyar	4.061	1413	2449	2585
10	Dumas	20.577	7266	6868	7224
11	Bhimpor	6.389	7239	7553	7862

The population of Surat has increased over years from about 2.88 lakh in 1961 to over 44 lakh in 2011. This is basically due to the fact that the city has been experiencing a steady growth and economic growth in the region. The estimated population of the urban agglomeration has increased to over 70 lakhs recently. This definitively points out the fact that the Surat city is one of the major economic hub of the country due to its diamond and textile industries. The South-West Zone of Surat has also become highly populated due to planned infrastructure and rapid urbanization. Vesu, Piplod and Athnwalines have seen transformation from a few hundred inhabitants to attractive residential and commercial zones (Khan 2004). This zone still has lower population density than the old city but tremendous scope in the future. Nagar Roads, BRTS routes, new housing schemes have made it highly populous.

3.5 Research Gap

- Most research is done at the city level, so there aren't many studies that focus on the South-West Zone of Surat.
- Few studies have examined the effects of land-use change and the proliferation of impervious surfaces on drainage systems in this area.
- There is not enough testing of the current drainage network's ability to handle more runoff because cities are growing quickly.
- There is limited use of GIS and remote sensing techniques to analyze land-use changes and their impact on drainage in the South-West Zone.

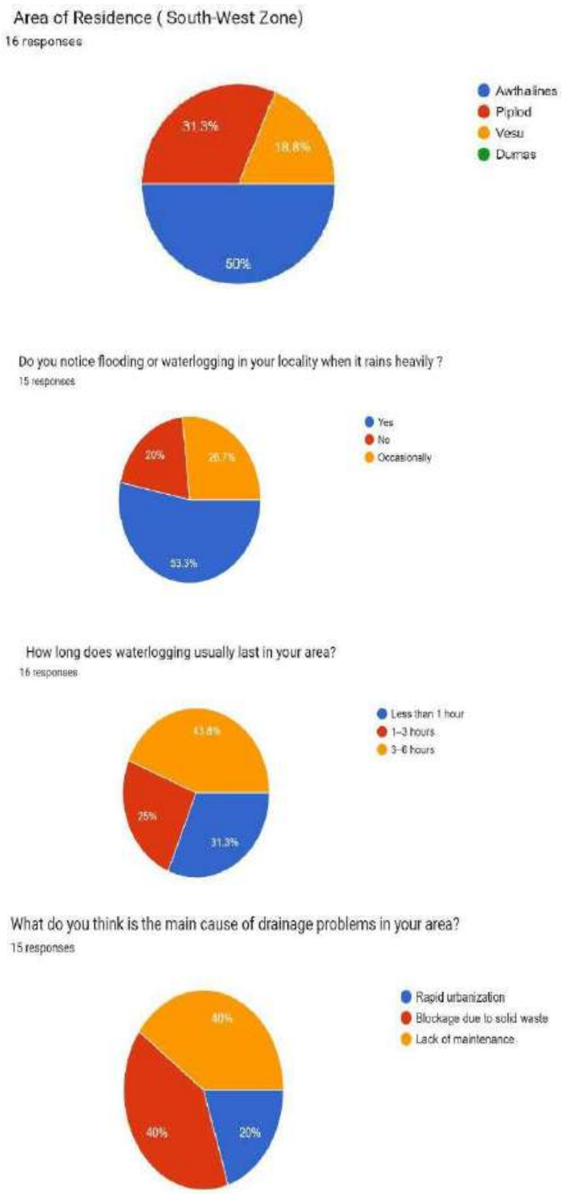
IV. DATA ANALYSIS & METHOD

4.1 General

The research design for studying the impact of urbanization to drainage systems is designed as an applied research integrating qualitative and quantitative methods. It utilizes both descriptive and analytical approaches to study the impacts of urbanization on both natural and constructed drainage systems. The beginning of the research is the selecting of a fast growing, flood-prone urban area; collecting information through primary and secondary data. Primary data could take the form of the observation of drainage structure and conditions during fieldwork, the Global Positioning System (GPS) surveys, or structured interviews or questionnaires of residents and municipal authorities. And secondary data can be obtained through satellite images, the maps of land-use and land-cover, population and housing census records, rainfall data, drainage plans.

Beside the house surveys, the spatial approaches such as Geographic Information System (GIS) and Remote Sensing are utilized to analyze the change of land use and the influences it has on the surface runoff flow pattern. The statistical approaches are employed to investigate the influence of indicators of urbanization, such as the demographic growth and urban build-up expansion, in the performances of the drainage system. Meanwhile, the hydrological approaches such as runoff simulation are applied to assess if the present drainage system is able to manage the requirements or not. In the research, urbanization as the independent variable is investigated while the performance of drainage and urban flooding are considered as the dependent variables. Deduction and trend analysis are adopted to determine the magnitude of implications and propose the appropriate and sustainable drainage management strategy. This research design provides a systematic and comprehensive framework to explain the relationship among urbanization, the drainage inadequacy and urban flooding.

4.2 Primary & Secondary data
Primary data for this study is collected directly from areas which are part of the South- West Zone of Surat. These areas are highly urbanized and prone to waterlogging due to low elevation and rapid development.



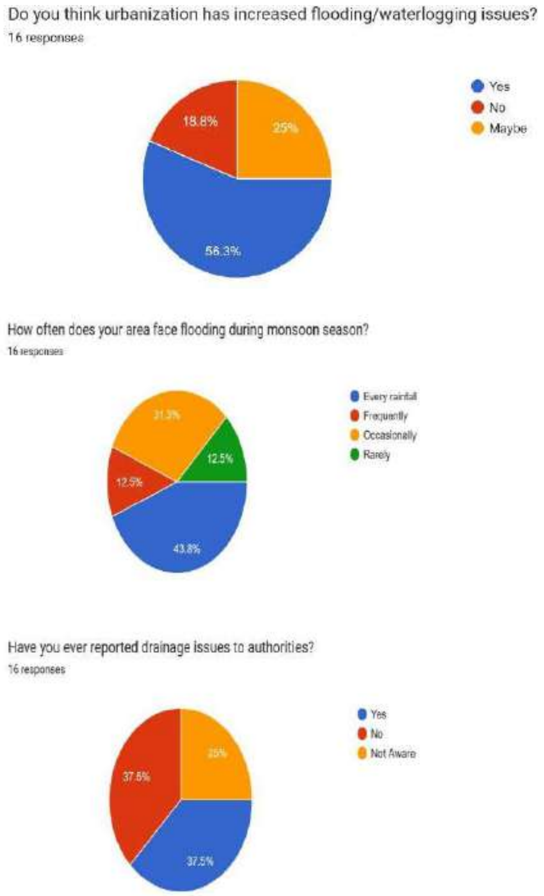


Fig 4.1 Survey Response

Figure data presents a comparative analysis of survey responses from residents of the South- West Zone regarding drainage and flooding issues. The majority of respondents belong to Athwalines (50%), followed by Piplod (31.3%) and Vesu (18.8%), while no responses were recorded from Dumas. This indicates that the findings are largely representative of Athwalines. A significant proportion (53.3%) reported experiencing waterlogging during heavy rainfall, compared to 26.7% who observed it occasionally and 20% who did not face such issues, highlighting that flooding is a common concern.

In comparison with the duration of waterlogging, 43.8% of respondents stated that it lasts for 3–6 hours, while 31.3% reported less than 1 hour and 25% experienced 1–3 hours. This shows that flooding is not only frequent but also persists for considerable durations.

Regarding the causes, blockage due to solid waste and lack of maintenance were equally identified as the major factors (40% each), whereas only 20% directly attributed the problem to rapid urbanization. However, a majority (56.3%) still believe that urbanization has increased flooding, indicating an indirect link between urban growth and drainage issues.

Further comparison reveals that 43.8% of respondents face flooding during every rainfall event, while 31.3% experience it occasionally, and only 12.5% report frequent or rare occurrences each. Despite the high frequency of flooding, only 37.5% of respondents have reported issues to authorities, while an equal proportion have not, and 25% are unaware of reporting mechanisms. Overall, the findings suggest that drainage problems are widespread and persistent, mainly due to poor maintenance and waste blockage, with urbanization acting as an underlying contributing factor, along with limited public awareness and engagement.

4.2.1 Field Survey of Drainage System

Fieldwork is done in places to look at the condition and structure of drainage networks. Observations encompass the nature of drainage (whether open or subterranean), physical degradation, sediment deposition, and impediments resulting from waste. This helps you understand how the performance of drainage has changed as built-up areas have grown.

Fig 4.2 Drainage Manhole

Fig 4.3 Drainage Pipe Leakage

Fig 4.4 Maintenance Work

Fig 4.5 Drainage pipe Installation

4.2.2 GPS and Location Mapping

Geographical coordinates of drainage lines, flood-prone points, and blockage locations are recorded using GPS tools. This data is useful for spatial mapping and identifying critical zones affected by rapid urban growth.

4.2.3 Measurement of Drainage Characteristics

Field surveys are used to measure drainage characteristics in the South-West Zone of Surat. These surveys look at how well drainage systems work and how much water they can handle in places like Vesu, Dumas Piplod etc. To determine how much water can flow through and how fast it can flow, important factors like the width, depth, cross-section, and slope of the drain are measured. We also figure out the speed of the water to see how well the runoff discharge works during rain. People watch for siltation, waste buildup, and encroachments because these things make drainage less effective. To figure out how bad the problem is, they measure how deep the waterlogging is in places that are likely to flood. The study shows that rapid urbanization has led to more surface runoff, which often exceeds the capacity of existing drainage systems. This shows that better planning and management are needed.

4.3 Tools and Techniques

4.3.1 Land Use Land Cover (LULC) Analysis (QGIS)

Land Use and Land Cover (LULC) refers to the classification and characterization of the Earth's surface based on how land is utilized by humans (land use) and the physical features present on it (land cover). Land use includes activities such as residential, industrial, agricultural, and commercial development, while land cover represents natural elements like vegetation, water bodies, forests, and barren land.

LULC plays a crucial role in understanding environmental changes, urban growth, and resource management. It helps in analyzing how human activities transform natural landscapes over time and how these changes impact ecosystems, climate, and hydrological processes. For instance, the conversion of vegetation or open land into built-up areas increases impervious surfaces, which can lead to higher surface runoff and urban flooding.

With the advancement of geospatial technologies such as Geographic Information Systems (GIS) and remote sensing, LULC mapping has become more accurate and efficient.

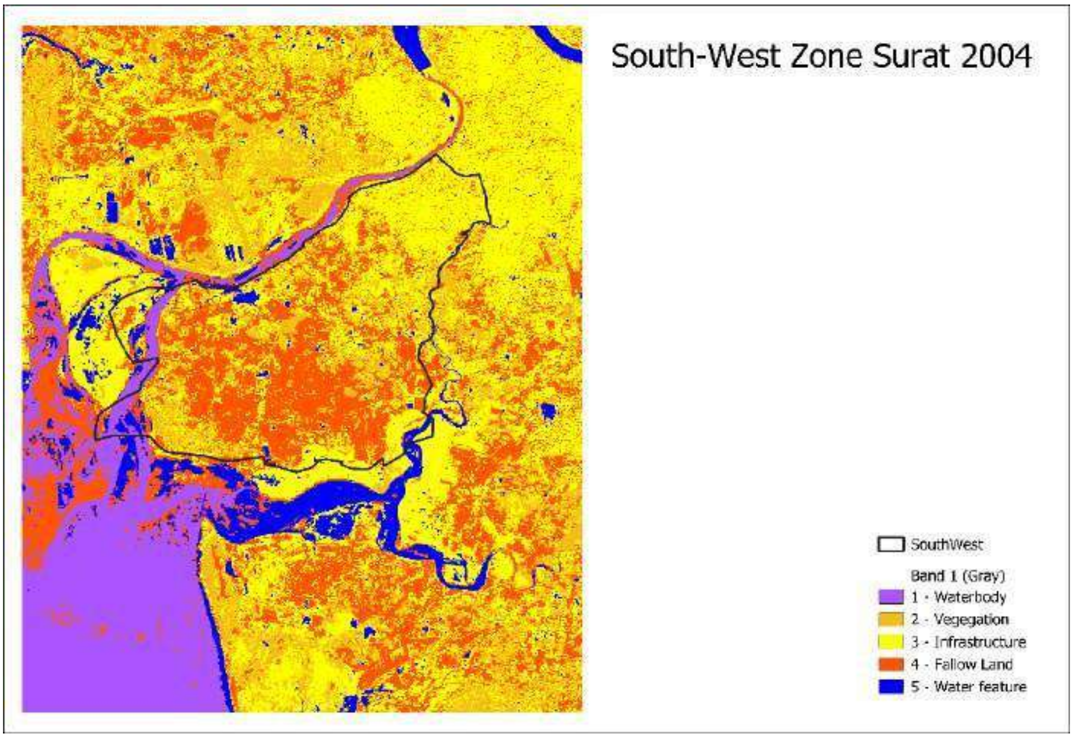


Fig 4.6 LULC & Satellite Image 2004

Table 4. LULC Area Statistics Table 2004

Index	Class_Name	Area(Sq.km)	Area(%)
1	Waterbody	2.47	2.34
2	Vegetation	12.24	11.55
3	Infrastructure	42.81	40.4
4	Fallow Land	45.03	42.5
5	Water Feature	3.39	3.2

The LULC analysis for 2004 in the South-West Zone of Surat shows that the area was mainly dominated by fallow land (42.5%) and infrastructure (40.4%), indicating a developing urban region with large vacant spaces available for future growth. Vegetation covered 11.55% of the area, reflecting moderate green cover, while waterbody (2.34%) and water features (3.2%) occupied only a small portion. Overall, the pattern suggests that the zone was in a transitional stage of urbanization, with increasing built-up development and significant potential for expansion.

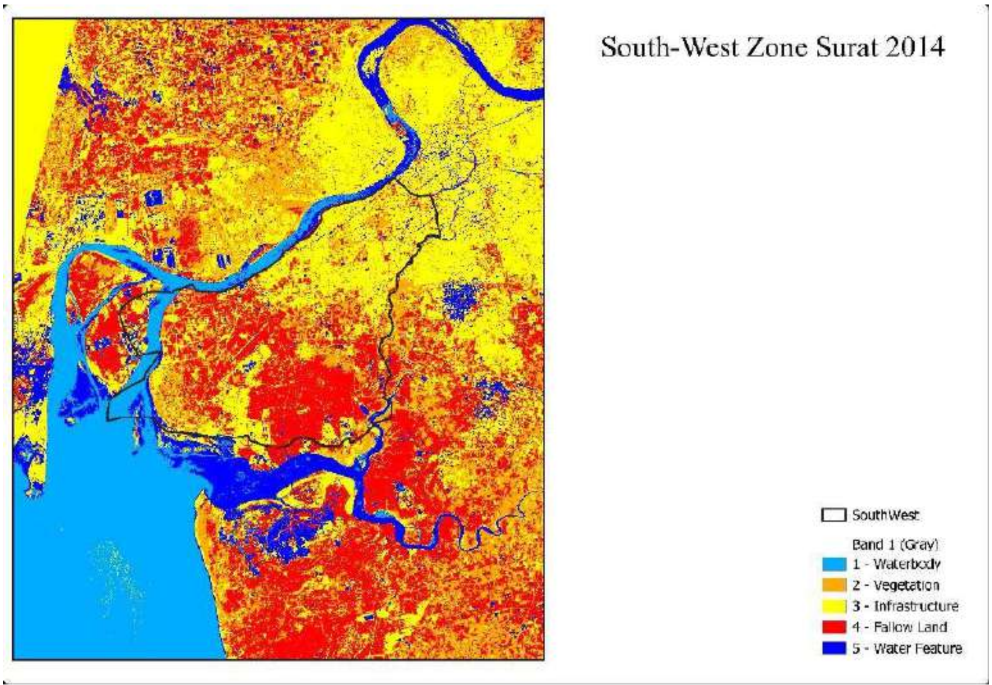
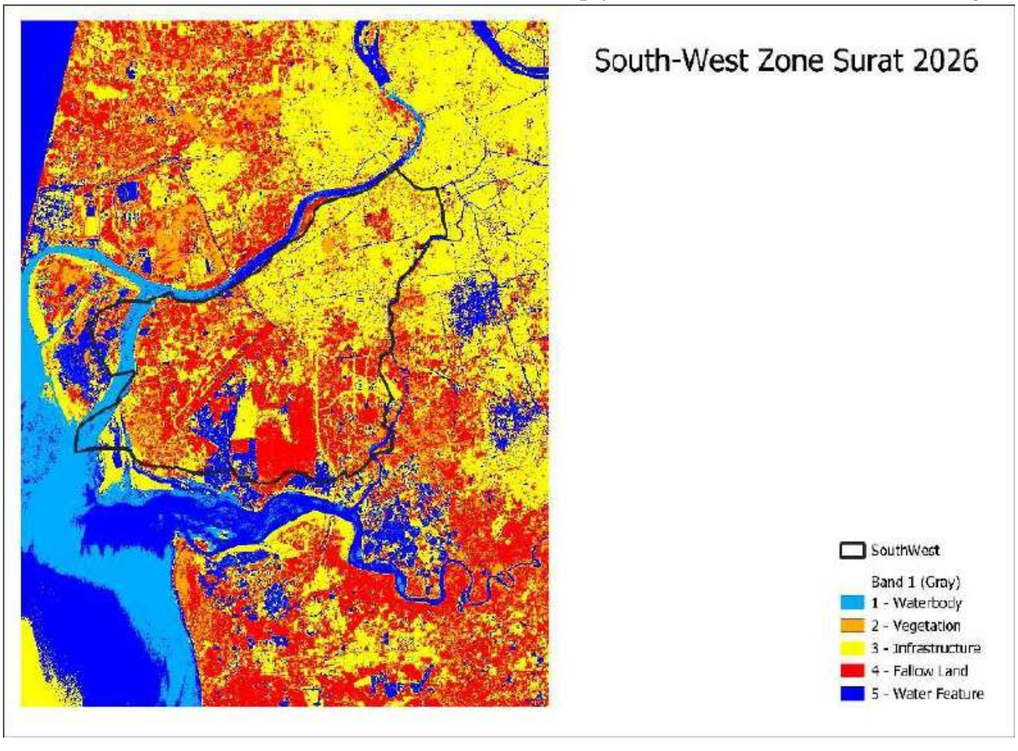


Fig 4.7 LULC & Satellite Image 2014

Table 4.2 LULC Area Statistics Table 2014

Index	Class_Name	Area(Sq.km)	Area(%)
1	Waterbody	4.92	4.65
2	Vegetation	12	11.33
3	Infrastructure	44.19	41.70
4	Fallow Land	40.91	38.61
5	Water Feature	3.93	3.71

The LULC analysis for this time period in Surat's South-West Zone shows that infrastructure (41.70%) and fallow land (38.61%) are the most common types of land. This shows that urban development is still going on, but there are still open spaces. Vegetation covers about 11.33% of the area, which means there aren't many green spaces. Water bodies (4.65%) and water features (3.71%) make up a small part of the area. Overall, the pattern shows that more buildings are being built and less land is being left empty, which means that cities are still growing.



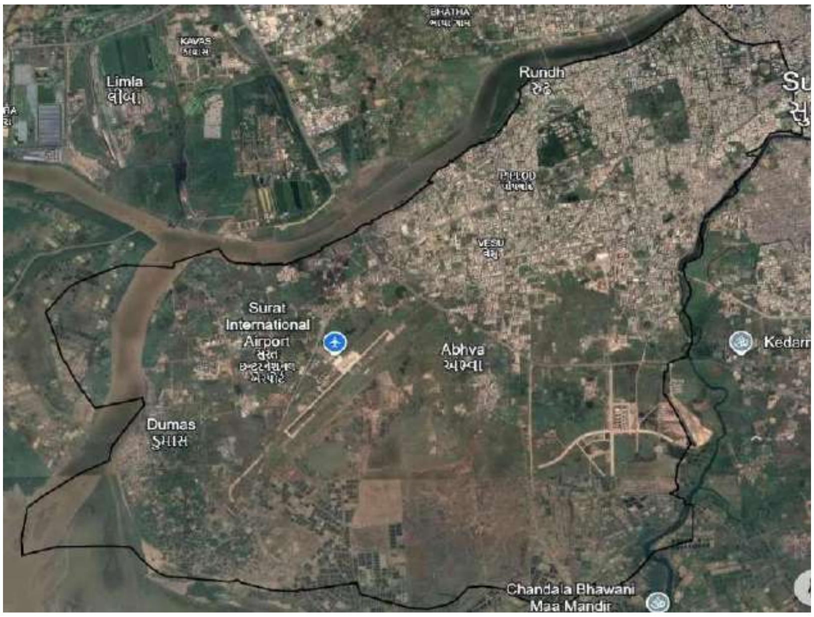


Fig 4.8 LULC & Satellite Image 2026

Table 4.3 LULC Area Statistics Table 2026

Index	Class_Name	Area(Sq.km)	Area(%)
1	Waterbody	4.18	3.94
2	Vegetation	8.03	7.58
3	Infrastructure	46.29	43.68
4	Fallow Land	37.93	35.80
5	Water Feature	9.53	9

The LULC study for this time period in Surat's South-West Zone shows that infrastructure makes up 43.68% of the area. This means that the city is growing quickly. Fallow land has dropped to 35.80%, which means that open areas are being turned into built-up areas. The amount of vegetation has dropped to 7.58%, which means that the green cover has gotten smaller because of development. Water bodies account for 3.94% of the total, while water features now comprise 9%. This means that the way surface water is spread out has changed. The overall trend is that cities are growing quickly, with more hard surfaces and less natural land cover.

Table 4.4 LULC 3 decades Area Statistics

Year	Waterbody	Vegetation	Infrastructure	Fallow Land	Water Feature
2004	2.47	12.24	42.18	45.03	3.39
2014	4.92	12	44.19	40.91	3.93
2026	4.18	8.03	46.29	37.93	9.53

The LULC trends for Surat's South-West Zone show a clear shift toward more urban areas over time. Infrastructure has been growing steadily since 2004, while fallow land has been getting smaller. This shows that open land is being developed into built-up areas. The loss of green cover has also led to a decrease in plants. Water bodies don't change much, but since 2026, water features have gotten a lot bigger. The data show that cities are growing quickly and that there are more surfaces that can't be broken down, which could affect the natural drainage system and make flooding in cities more likely.

4.3.2 Hydrological Analysis Techniques

Hydrological approaches are applied to estimate surface runoff and assess the capacity of drainage systems. Methods such as the Rational Method are used to determine whether the existing drainage network can effectively manage rainfall intensity in urban environments.

- $Q_P = \frac{1}{3.6} C(i_{tc,p}) A$

Q_P = peak discharge (m^3/s)

C = coefficient of runoff

$i_{tc,p}$ = the mean intensityof precipitation (mm/h) for a duration equal to t_c and an exceedance peobality P

A = drainage area in km^2

- Kirpich Equation

$t_c = 0.01947\ L^{0.77}\ S^{-0.385}$

t_c = time of concentration (min)

L = max length of travel of water(m)

S = slope of the catchment = $\frac{\Delta H}{L}$

ΔH = difference in elevation between the most remote point on the catchment and the outlet.

$t_c = 0.01947\ L^{0.77}\ S^{-0.385}$

$= 0.01947\ (3000)^{0.77}\ (0.0026)^{-0.385}$

= 0.01947*475.7*9.89

= 91.59 min

$S = \frac{\Delta H}{L}$

=8/0.0026

= 0.0026

Where the value of ΔH is 8m and L=3000m

- $i_{tc,p} = \frac{KT^x}{(t_c + a)^n}$

Where the value of P lies between 0.05 to 1 for urban area drainage.

- $C_e = \sum_1^N C_i A_i$ / A

By interpolation,

Max depth of rainfall for 91.59 min duration

= 110 – 90 / 30 * (91.59 – 90) + 90

= 2/3 * 91.59

= 0.666 * 91.59

= 61.06 min

Average intensity = $i_{tc,p}$ = 61.06 / 91.59 * 60

$$= 0.667 * 60$$

$$= 40 \text{ min/hr}$$

$$C_e = \sum_1^N C_i A_i \, / \, A$$

$$= \frac{(1 * 4.18) + (0.25 * 8.03) + (0.80 * 46.29) + (0.40 * 37.93) + (0.95 * 9.53)}{(4.18 + 8.03 + 46.29 + 37.93 + 9.53)}$$

$$= 67.432/105.96$$

$$= 0.63$$

$$Q_P = \frac{1}{3.6} C(i_{tc,p}) A$$

$$= \frac{1}{3.6} * 0.63 * 40 * 105.96$$

$$= 0.2778 * 2670.19$$

$$= 7.41 m^3/s$$

V. EXISTING DRAINAGE SYSTEM

5.1 South West Drainage Zone

In this zone 76.88 percent of the area & 92.12% of population has been covered by the sewerage network. While sewage is treated in the 120 MLD capacity sewage treatment plant at Bhatar and 25 MLD capacity sewage treatment plant at Khajod and the treated sewage is disposed off into the Kakra khadi. In the area bereft of the network, the sewage along with wastewater from local small-scale industries is being discharged into the River Tapi/Khadis through storm water drains or is being disposed through septic tanks and cesspools.

According to the sewerage scheme of this zone, there will be a sewage treatment plant at Bhatar, with an ultimate capacity of 236.0 MLD and at Khajod with an ultimate capacity of 51 MLD, Nine sewage pumping stations, and transmission lines from each pumping station to the sewage treatment plant and sewerage network of NP-3 / NP-4 class RCC pipes.

5.2 Stormwater Drainage Network

The stormwater drainage network of Surat has been constructed to manage excessive rainfall prevalent during the monsoon season and prevent flooding within the urban city limits. The rainfall occurs on roads and pavements and then drains down the roadside gutters as the first point of collection. Surface drains are connected to an extensive underground drainage network comprising RCC pipeline drains and box drains capable of managing a huge amount of runoff.

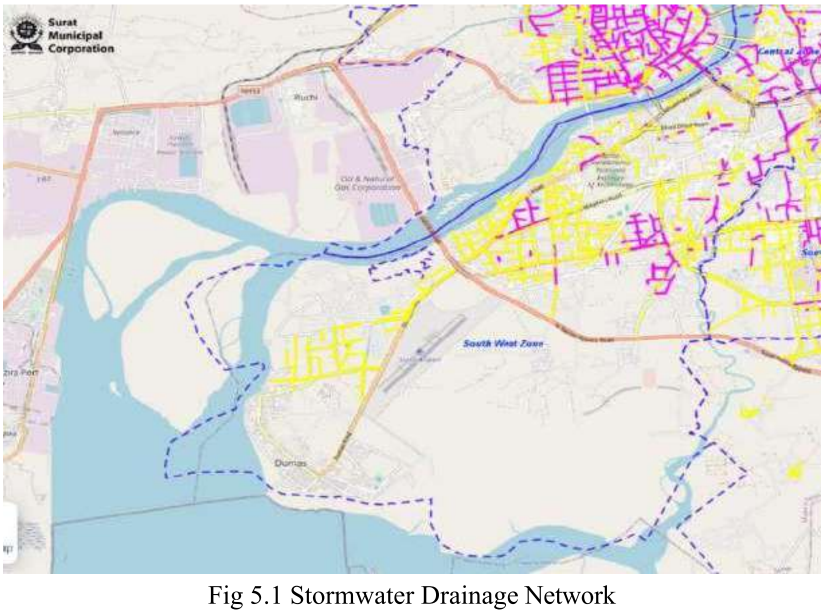


Fig 5.1 Stormwater Drainage Network

Gravity drainage is primarily used; however, in low elevation regions and poor terrain, pumping stations have been set up to eliminate excess water. In the flow process, the collected water is directed through natural drainage pathways such as canals and creeks that serve as temporary conduits. Finally, the collected stormwater is discharged into the Tapi River through controlled outlets having sluice gates that prevent water recirculation during high tides. Over the years, significant improvements have been made; however, issues such as rapid urbanization, debris, and encroachment pose threats to its performance in vulnerable locations.

5.3 Sewerage System

The sewerage infrastructure of Surat encompasses a complex underground network of pipes and channels for the safe collection, transportation, treatment, and disposal of sewage. First, sewage collection takes place through individual connections servicing residential, commercial, and industrial premises. Next, the collected sewage flows through the system of laterals, branches, and trunk sewers. Usually, the pipelines use the principle of gravity discharge, relying on the natural slope of the terrain. Pumping stations are constructed at certain points along the pipelines where there is not enough slope to ensure continuous pumping of wastewater through gravity discharge. Treatment plants serve as the final destination point where sewage is subjected to various processes aimed at removing contaminants, organic matters, and solid materials.

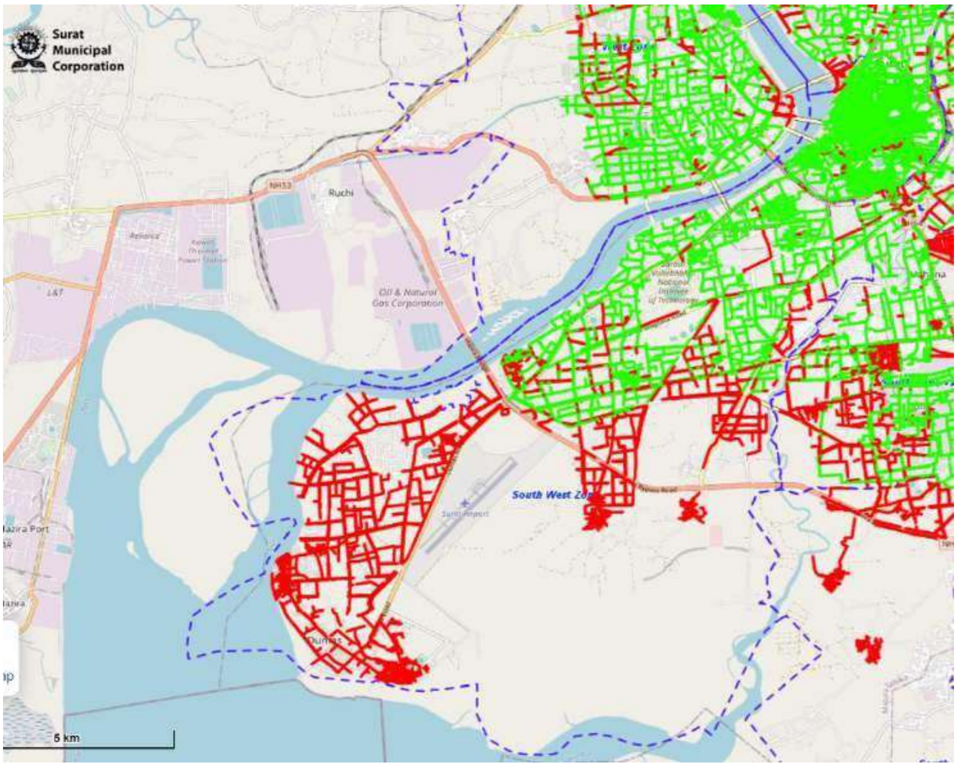


Fig 5.2 Sewage System Network

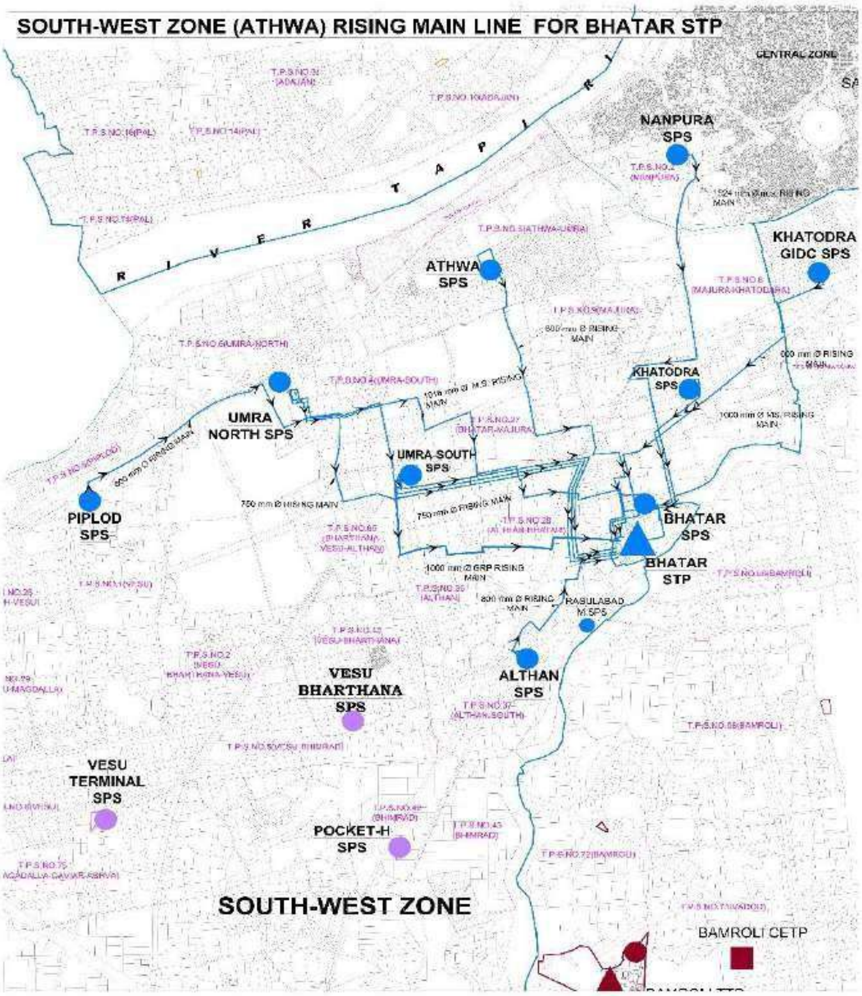


Fig 5.3 Bhatar Sewage Treatment Plant

Once the process of cleaning is complete, treated water can be returned to natural sources of water, such as the Tapi River, or reused for agricultural or industrial purposes. The development of Surat's sewerage infrastructure is a continuous process of making it more efficient and environmentally friendly. However, some aspects of operations in the system are experiencing certain difficulties due to population growth, pipeline congestion, and maintenance challenges.

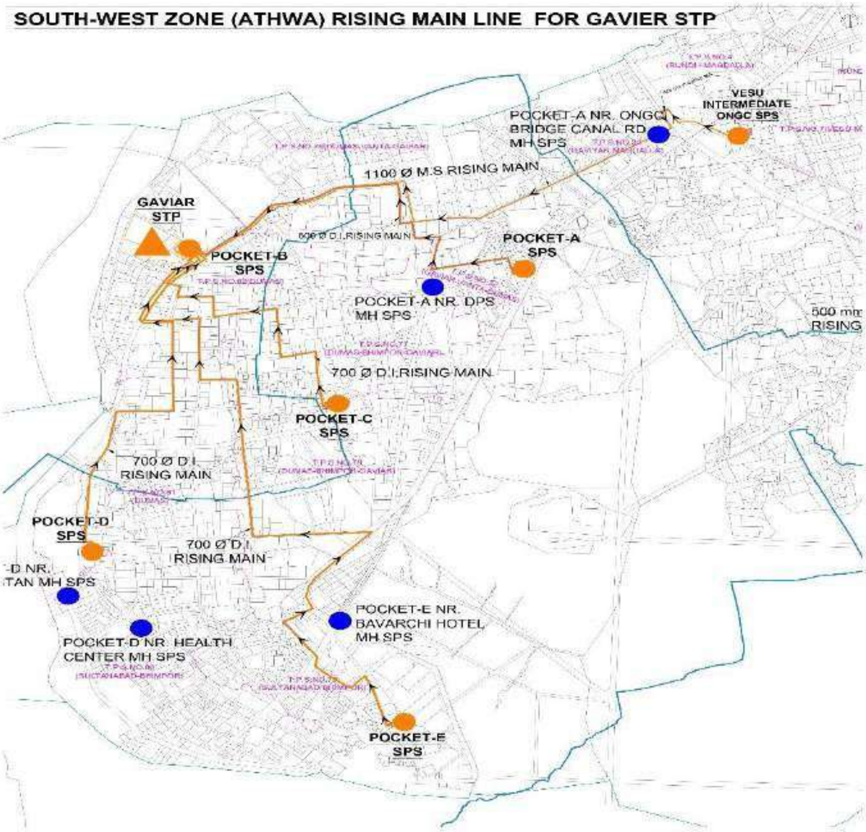


Fig. 5.4 Gavier Sewage Treatment Plant

Table 5.1 Sewage treatment plant S-W Zone Surat

Sr.no	Location of Treatment plant	Capacity (MLD)
1	Bhatar	162
2	Gavier	53

5.4 Drainage Capacity and Design

The capacity of a drainage network is determined by its drainage capacity and design and shows the efficiency of movement of stormwater without the formation of floods and overflows. During the design of such facilities, various climatic data are taken into account. These include rainfall statistics, as well as land type, relief, and the proportion of impervious surfaces within the project area. With the increase in the area of urbanization, the amount of impervious surfaces increases, which leads to an increase in runoff. The designers should take into consideration this information during the design. The calculation of peak discharge is carried out using standard hydrologic methods, after which it is possible to determine the required capacity of drainage elements. At the next stage, the optimal cross-sectional characteristics, slopes, materials for the construction of drainage channels or piping are selected. The design is usually complemented by appropriate provision of drainage elements. In addition, such facilities have in-built flood mitigation measures (e.g., freeboards and backflow protection mechanisms). Such measures are necessary when there is a threat of excessive precipitation. Properly designed drainage networks prevent floods and provide additional benefits in terms of protecting structures and ensuring safety.

Table 5.2 Sewage treatment plant Data

Name of STP	Reused/ Recycled (MLD)	Type of Use
Gavier STP	1.25	Gardening, Road washing, Sewer jetting machine
Bhatar STP	110.12	Industrial & Gardening use

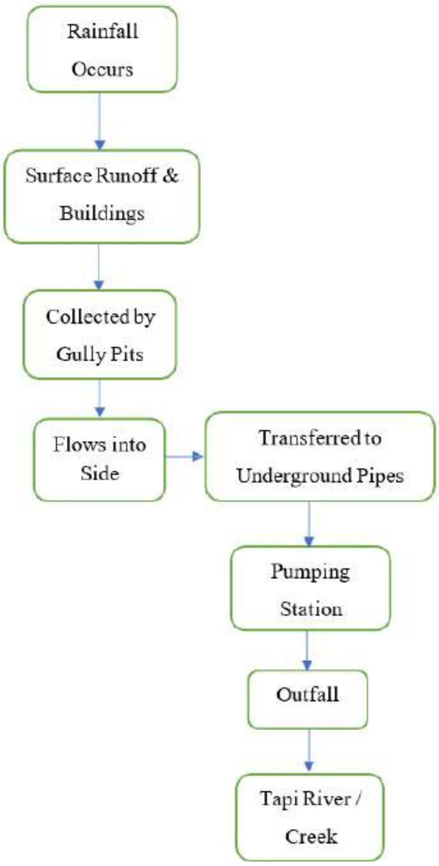


Fig 5.5 Flowchart of surface Runoff and Drainage Network

VI. IMPACT OF URBANIZATION ON DRAINAGE SYSTEM

6.1 Increase in Impervious Surfaces

The increase in impervious surfaces in Surat is mostly due to the city's ongoing growth and the building of new infrastructure. Rainwater can't naturally soak into the ground because of things like cemented roads, bitumen pavements, building rooftops, and parking lots. This makes surface runoff go up a lot. As open spaces, farmland, and natural drainage paths are slowly turned into built-up areas, the rate at which groundwater is recharged goes down, while the amount of stormwater that enters the drainage system goes up.

A lot of construction has replaced soft, absorbent soil surfaces with hard, non-permeable layers. This has upset the natural hydrological cycle. This change makes runoff flow faster during rain, which puts more stress on the stormwater drainage system that is already in place. Because of this, even moderate rain can cause temporary water buildup when the system's capacity is reached.

An increase in impervious cover also causes a number of related problems in cities, such as lower soil moisture levels, higher surface temperatures because of the urban heat island effect, and a slow decline in groundwater reserves. Also, not having enough green spaces and places for water to soak in makes it harder for the ground to soak up rainwater naturally, which makes people rely more on man-made drainage systems.

To lessen these effects, planners are pushing for things like using permeable paving materials, collecting rainwater, building green infrastructure, and protecting open spaces. These steps help improve infiltration, reduce runoff volumes, and make the city's drainage system more efficient and long-lasting.

6.2 Changes in Runoff Patterns

Rapid urban growth and changes in land use have greatly changed the way surface runoff works in Surat. In the past, rainwater would naturally seep into open soil, farmland, and green spaces. This made runoff slower and drainage more gradual. But as cities have grown, with more roads, buildings, and paved surfaces, the ground's ability to naturally soak up water has been greatly reduced. The way rainwater flows through the city has changed because of this shift.

In the current situation, rain quickly turns into surface runoff, which flows over surfaces that don't absorb water and gets to drainage channels much faster. This causes a higher peak discharge over a shorter period of time, which puts more strain on the stormwater drainage system. During heavy rain, areas like Adajan, Pal, and Rander quickly fill up with water because the drainage system gets a sudden surge of runoff instead of a steady stream.

Table 6.1 Runoff condition

Years	Drainage Coverage (%)	Sewer Coverage (%)	Runoff Condition
1990-2000	70-80% (old city)	60–70%	Low–moderate runoff, good infiltration
2000-2010	85%	70–75%	Increasing runoff, drainage stress begins
2010-2023	61.8%	76.88%	Very high runoff, frequent waterlogging

6.3 Urban Flooding Issues

Urban flooding has become a common problem in Surat because the city is growing quickly, the way people use land is changing, and the drainage system is under more stress. The city often has problems with waterlogging during heavy monsoon rains, especially in areas that are low-lying and densely built. One of the main causes of this problem is the rise in impervious surfaces like roads, buildings, and paved areas. These surfaces stop natural infiltration and cause surface runoff to build up quickly.

VII. CONCLUSION

7.1 Summary of Study

Rapid urban development in the South-West Zone of Surat, has transformed the natural drainage behavior of the area. The shift from open and agricultural land to built-up spaces has increased impervious surfaces, reducing infiltration and generating higher surface runoff. This has resulted in increased peak discharge during rainfall, putting pressure on the existing drainage system.

The drainage infrastructure, originally planned for lower runoff volumes, is now frequently overloaded, causing waterlogging and localized flooding during moderate to heavy rains. Issues such as solid waste blockage, poor maintenance, and encroachment on natural drainage paths have further reduced its efficiency.

Tidal effects from the Tapi River also hinder proper drainage by limiting outflow and causing backflow in some areas. Additionally, intense short-duration rainfall events have increased flood risks.

Urban growth has exceeded the drainage system's capacity, highlighting the need for infrastructure upgrades, better maintenance, protection of natural channels, and adoption of sustainable solutions to manage runoff effectively.

7.2 Major Conculsion :

- Fast-paced urban growth has expanded impervious areas, which limits infiltration and leads to greater surface runoff.
- Increased peak flow during rainfall often exceeds the capacity of the drainage network, resulting in overloading.
- Since the system was originally planned for lower runoff volumes, frequent water accumulation occurs.
- Drain performance is affected by silt buildup, improper disposal of waste, and inadequate maintenance.
- Natural drainage paths have been disturbed

due to encroachment, leading to localized flooding issues.

7.3 Suggestions for Future Research

- Study the impact of changing rainfall patterns on runoff and drainage efficiency.
- Use hydrological and hydraulic models to analyze flow behavior and peak discharge under extreme conditions.
- Assess whether existing drainage infrastructure can handle current and future urban growth.
- Explore green solutions such as permeable surfaces and rainwater harvesting to reduce runoff.
- Apply GIS and remote sensing to map drainage networks and flood-prone zones.
- Analyse Tapi discharge and backflow Data.

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