Urban Expansion and Its Impact on the Low-Lying Areas of the Vishwamitri River:

"A Case Study of Vadodara"

Thesis submitted in
Partial Fulfilment for
the Award of the Degree of

Master of Urban and Regional Planning

By

Amar Vaghela
Second Semester, MURP II – 2024-25

Primary Guide: Ms. Vignya Shah
Secondary Guide/s: Ms. Ami Rawat

Master of Urban and Regional Planning (MURP) Program
Department of Architecture Faculty of Technology and Engineering
The Maharaja Sayajirao University of Baroda
D. N. Hall, PratapGunj, Vadodara, Gujarat, India.

May 2025

THE MAHARAJA SAYAJIRAO UNIVERSITY OF BARODA
सत्यं शिवं सुन्दरम्

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Abstract

Due to global climate change, Frequent Occurrence of floods in the country has become a serious concern for the planners and policy makers. Irregular and varied spatial distribution of rainfall coupled with failure and mismanagement of human constructed water body reservoirs have resulted in reoccurring floods affecting large areas of population. Vadodara city has suffered from events of floods incurred due to such causality. The study focuses on evaluating the reasons of flooding and defining strategic solutions for a better flood management approach.

A river to basin network is prepared for better understanding the relationship of the river Vishwamitri and its connections to various water bodies present in its basin. This approach further deepens into study of different parameters related to flood events for Vadodara city. Frequency analysis is carried from the available hydro meteorological historical rainfall data series of past four decades for Vadodara city, Gujarat. A Hydrologic Model is prepared to understand the rainfall-runoff relationship by using GIS and ARCSWAT software which can act as a warning indicator for Vadodara city to cope up with future occurrences of floods.

The mixed Global probability distribution is adopted to explore the re- occurrence of rainfall events with certain return period. Analysis has also revealed the Flood reoccurrence Time duration is 25years. Statutory Recommendations and Policies are recommended for reducing the Rainfall runoff of Vadodara and to ensure the better flood management approach.

Acknowledgment

Above all, I offer my sincere thanks to the Almighty for granting me the strength, patience, and determination to complete this thesis. This journey has been filled with growth, learning, and self-reflection, and I am truly grateful to everyone who stood by me throughout this process.

I would like to express my heartfelt gratitude to my respected guides, Ms. Vignya Shah and Ms. Ami Rawat, for their continuous guidance, encouragement, and thoughtful suggestions. Your faith in my abilities and constant support have kept me motivated at every stage.

A special thanks goes to the street vendors of Vadodara City, who kindly shared their experiences, insights, and time with me. This research would not have been possible without their cooperation and openness.

To my family, thank you for your endless love, support, and understanding. Your encouragement, even during the most difficult moments, has been the foundation of my strength.

To my friends and fellow students, I truly appreciate your support, honest feedback, and shared moments that have made this journey meaningful and memorable.

This thesis is dedicated to all those who work towards recognizing, supporting, and integrating informal livelihoods into the vision of an inclusive and equitable urban futur

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CHAPTER - 1

INTRODUCTION

1.1 - INTRODUCTION

Floods are natural hazards occurring on regular basis in developed, developing, and underdeveloped countries. The effect of floods has an impact on livelihood systems, property, people, infrastructure, and public utilities. Recent trends have shown an increase in flood-related damages. This can be attributed to a steep increase in population, rapid urbanization, growing development and economical activities in flood plains coupled with global warming. (Natural Disaster Floods, 2014).

The carrying capacity of rivers has been constantly decreasing, mainly responsible for causing floods, drainage congestion, and erosion of river- banks. Cyclones, cyclonic circulations, and cloud bursts cause flash floods and further lead to huge losses. Large-scale loss of lives and damage to public and private property due to floods indicate that we are still to develop an effective response to floods. (Natural Disaster-Floods, 2014)

Change in Rainfall patterns is one of the effects of climate change. Every year rainfall occurs for three to four months in most of the districts of India. Floods affect vast areas of the country, sometimes transcending the state boundaries. Proper study should be conducted as prior planning, to manage the circumstance of floods which are essential at the National level. In the Vadodara district, the rainfall pattern is highly variable. Rainfall mainly occurs in July, August, September, and October. Heavy rainfall and flood cause severe damage to the livelihood and infrastructure of the town. Erroneous planning and construction near the drainage channel are additionally among the explanations for flooding in the Vadodara district.

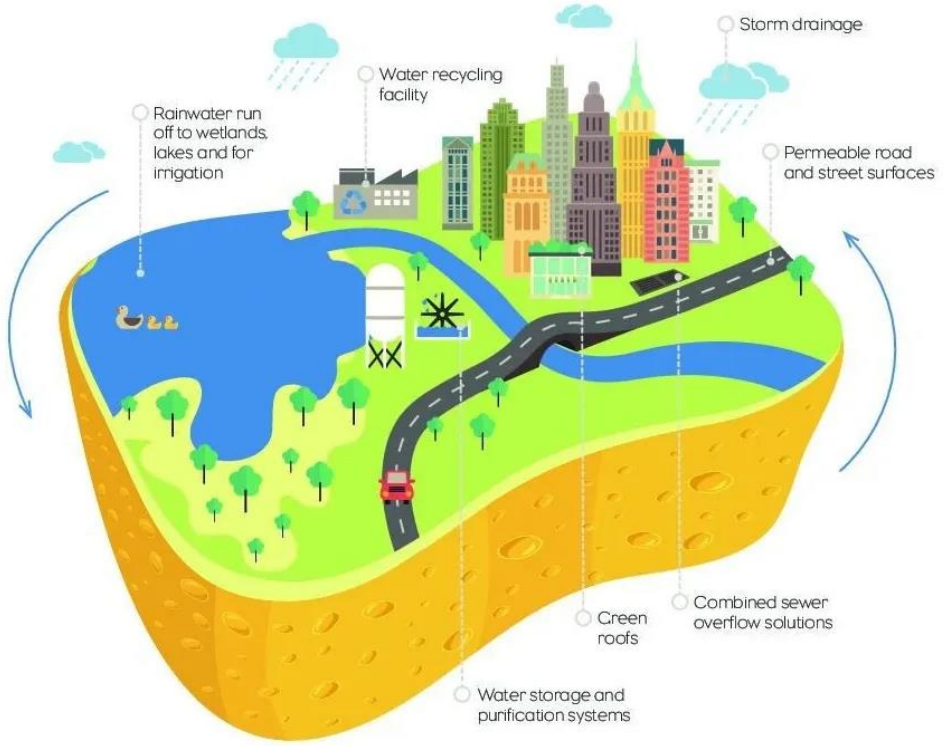

Figure 1. Urban Water Sources (Source – Search _Informal sector, google image)

1.2 - WHAT IS URBAN FLOODING?

Flooding is an overflowing of water toward land that's normally dry and adjacent to water body. Floods can happen during heavy rains, when ocean waves come on shore, when snow melts quickly, or when dams or levees break. Damaging flooding may happen with only some inches of water, or it's going to cover a house to the rooftop. Floods can occur within minutes or over a protracted period, and will last days, weeks, or longer. Floods are the foremost common and widespread of all weather- related natural disasters.

Flash floods are the foremost dangerous reasonably floods, because they combine the destructive power of a flood with incredible speed. Flash floods occur when heavy rainfall exceeds the power of the bottom to soak up it. They also occur when water fills normally dry creeks or streams or enough water accumulates for streams to overtop their banks, causing rapid rises of water in an exceedingly short amount of your time. They'll happen within minutes of the causative rainfall, limiting the time available to warn and protect the general public

1.3 - WHAT AREAS ARE AT RISK FROM FLASH FLOODS?

Densely populated areas are at a high risk for flash floods. The construction of buildings, highways, driveways, and parking lots increases runoff by reducing the quantity of rain absorbed by the bottom. This runoff increases the flash flood potential. Sometimes, streams through cities and towns are routed underground into storm drains. During heavy rain, the storm drains can become overwhelmed or plugged by debris and flood the roads and buildings nearby. Low spots, like underpasses, underground parking garages, basements, and low tide crossings can become death traps.

Areas near rivers re at risk from floods. Embankments, referred to as levees, are often built along rivers and are wont to prevent high water from flooding bordering land. Dam failures can send a sudden destructive surge of water downstream. Mountains and steep hills produce rapid runoff, which causes streams to rise quickly. Rocks and shallow, clayey soils don't allow much water to infiltrate into the bottom. Saturated soils also can cause rapid flash flooding. Camping or recreating along streams or rivers are often a risk if there are thunderstorms within the area. A creek only 6 inches deep in mountainous areas can swell to a 10-foot deep raging river in but an hour if a thunderstorm lingers over a neighborhood for an extended period of time. Sometimes the thunderstorms that produce the heavy rainfall may happen well upstream from the impacted area, making it harder to acknowledge a dangerous situation.

1.1.2 Factor Causing Urban Floods in India

Majorly the factors causing urban floods are sub divided into three categories i.e.

1. **Hydrological factors:**

- Change in course of rivers
- Type of soil and water retention capacity
- Infiltration rate and Ground water level prior to floods
- Synchronization of runoffs from various parts of the watershed
- Channeled Storm water network. cross-sectional shape and roughness

2. Meteorological Factors :

- Unprecedented Rainfall
- Cyclones
- Heavy Thunderstorms
- Global warming
- Influence of Urban microclimate

3. Man-Made factors:

- Surface sealing due to urbanization and deforestation
- Building design without regard to flood risk
- Encroachment of floodplains and low-lying areas
- Lack of maintenance of infrastructure and drainage channels
- Siltation and improper solid waste disposal in Drainage channels
- Unplanned release of water from dams / lakes located upstream of cities and towns
- Absence of administrative framework & Lack of preparedness.

Primary Losses	Loss of life & physical injury
	Damage to buildings, contents & infrastructures
	Disruptions to industrial production
	Loss of, or disruptions to utility supplies
	Loss of heritage or archaeological site
Secondary Losses	Increased stress; physical & psychological trauma
	Enhanced rate of property deterioration & decay
	Lost value added to IND
	Increased traffic congestion; disruption of flow of employees to work
	Contamination of water supplies; food and other shortages
	Loss of exports; Reduced national gross domestic product

Table 1.1.

Showcasing Major Losses.

1.1.3 Urban Flood: Man-Made Disaster

Overburdened drainage, unregulated construction, no regard to the natural topography and hydro-geomorphology all make urban floods a man-made disaster. Below is the diagram showing how heavy rains penetrate into the water bodies and its path.

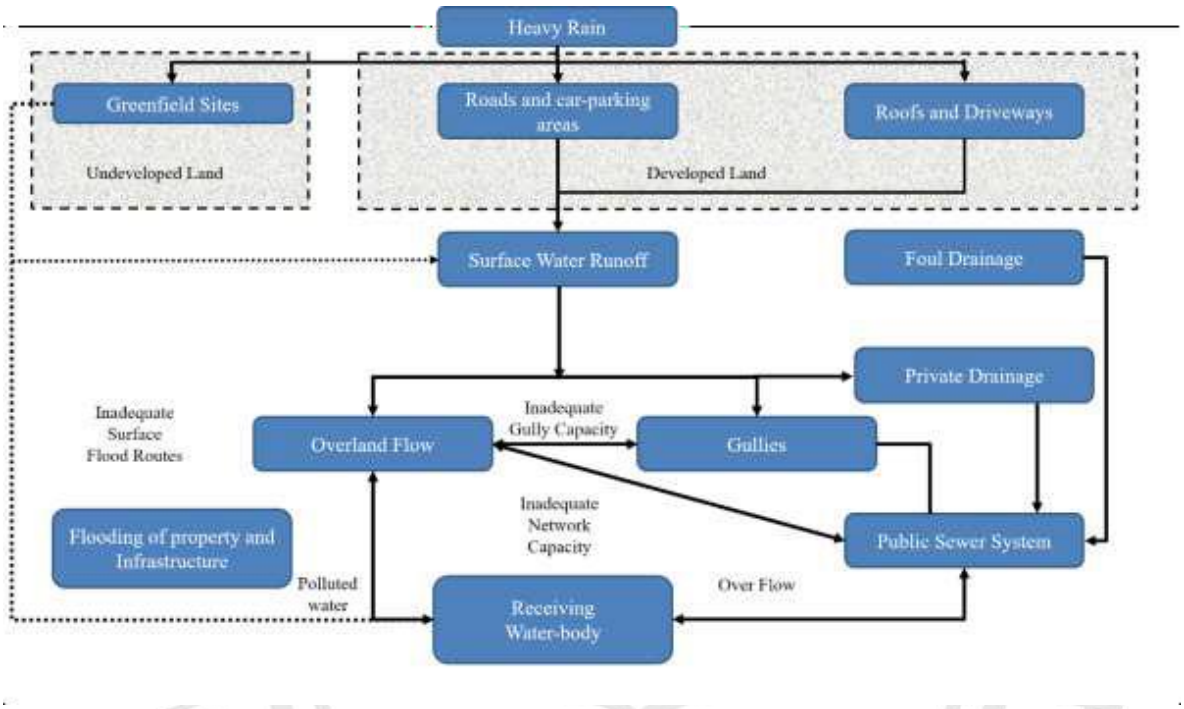

Figure 2. Rain System (Source – Search _Informal sector, google image)

CHAPTER - 2

LITERATURE REVIEW

2.1 LITERATURE REVIEW

2.1.1 Causes of Flood

Shastri, H.K et. al (2010) studied the floods situation that occurred in Vadodara city in 2005 and concluded how natural disasters enhances due to improper planning of resources and gives importance of consideration of natural water bodies in any town-planning scheme as the same situation may be faced in all developing cities.

U.S. De, G. P. Singh* and D. M. Rase*(April 2013)**

Urban flooding in recent decades in four mega cities of India

In this paper flood situations of the four most populated mega cities of India is discussed: Delhi, Kolkata, Mumbai and Chennai. Uncontrolled growth of mega cities has increased their vulnerability to flooding. Impacts can be reduced by various measures with help of Doppler radars, Identification of vulnerable zones in and around the mega cities , Improvement of old drainage systems, Implementation of health and sanitation measures, Pollution control measures with planning of green cities, including urban reforestation

2.1.2 Geomorphology of Watershed

Patel, A. et. al (2014) has attempted in the present study to prioritized watersheds based on morphometric parameters derived from Indian Remote Sensing Satellite (IRS) Cartosat1 DEM-10m data and LISS-IV data covering Vishwamitri watershed in Vadodara and Panchmahals districts in Gujarat State. The morphometric parameters like stream length, bifurcation ratio, drainage density, stream frequency, texture ratio, form factor, circularity ratio and compactness coefficient and elongation ratio are considered for prioritization of all the mini watersheds in the study area.

Shah, S.D. et. al (2009) has done morphometric analysis and their relative parameters for the Vishwamitri river basin. The quantitative analyses of the morphmetric characteristics of the basin include stream order, stream length, bifurcation ratio, drainage density, drainage frequency; relief ratio, elongation ratio & circularity ratio etc. were computed in present study using Geographical Information System (GIS) Software (Geomedia Professional V 5.1).

2.1.3 Mitigation methods for Flood Control

Nehmat Khosla, (2019) Impact of urban floods on the community living in informal settlements: The case of VADODARA FLOODS

After Analyzing the situation and the recommendations which were made such as:

1. **ERADICATING PHYSICAL VULNERABILITY:** A suitable relocation policy is recommended for adversely affected settlements at appropriate high elevated areas with sufficient job centers.

2. **REMOVING THE DILAPIDATED HOUSING CONDITIONS:** Devising job and livelihood opportunities

Stokkom, H.T. et. al (2005) has discussed about how the Dutch government is currently trying to achieve sustainable water and river management by developing and implementing a new approach to flood defense. New approaches includes Awareness, Three-step-strategy: Water by Restoring Rivulets, Temporarily Storing Water and Delaying Runoff, Spatial planning, Responsibilities

2.1.4 Development through ARC-SWAT model

Vikas Kumar Rana & Tallavajhala Maruthi Venkata Suryanarayana (2020) presents in their paper a case study of Godavari river flood modeling using SWAT software. The flood released for Gangapur dam, which is constructed on upstream of Nashik city at 14 km distance is considered for the modeling. The flood discharge is based on the worst discharge of 1969 flood. The runoff was calculated for the particular events. The model facilitates to locate the flood plain and its extent for effective flood mitigation measures.

Sunil Kumar and N. K. Goel (2015) In the present study the hydro-meteorological data of Dhadhar river basin have been analysed in detail for the presence of any non-stationary like changes in mean, presence of short and long term dependence and presence of trend etc. For this purpose observed data of rainfall and temperature at various stations over Dhadhar basin have been analysed and results presented.

CHAPTER - 3
DEFINING THE RESEARCH FRAMEWORK

3.1 PROBLEM STATEMENT

Due to constant growth rate in urbanization, floods are most frequently occurring and causing natural disasters. In the past decade Vadodara city has witnessed floods several time which have resulted into loss of property and lives. Flooding in

urban areas and has brought down city to halt. The city as well as the surrounding villages are prone to flood risk. Even with such frequent occurrences of floods in the city an effective flood management plan has not been worked out.

In order to provide a proper flood management plan first it is necessary to understand the relative causes of flood. So the main problem lies with understanding the causes of flood with respect to the city characteristic. Many governmental & nongovernmental agency are working to reduce the effects of flood which include construction of check dams, inter basin water exchange, channelizing & diversion of flood water, etc.

Being a citizen of Vadodara city and a student of Urban Planning is tremendous urge to find out why the city was still on the verge of flooding every year, in spite of having experienced the same situation before. Even with such occurrences, at present the city is lacking with a proper flood management strategy. This motivated to focus on research of the disaster management aspect of urban planning. This study also demanded to work on cross-platforms fields such as planning, engineering, hydrology and geology which are both, interesting and a challenging tasks.

3.2 AIM OF THE STUDY

To study the Urban flood Impacts & its causes on the Vadodara City and presenting a set of operative strategies and practical recommendations to increase the level of resilience in urban space with regards to flooding.

3.3 RESEARCH OBJECTIVES OF THE STUDY

This research would mainly focus on fact that how the flood impacts the Vadodara City, How the Rainfall and Surface water Runoff are interlinked. The objectives of the study will be as following:

1. To study the occurrence, its causes and mismanagement of floods for Vadodara city. (Current and Past)
2. To Identify Features and Characteristics that hinder Main Natural flow of the water in Existing Urban Environment.
3. To assess the effects of land use/land cover change on the hydrological processes and the effects of human activity on it.

3.4 RESEARCH QUESTIONS OF THE STUDY

In order to achieve the above objectives, the research questions to be answered are:

1. What is the contemporary understanding regarding phenomenon of flood?
2. How the natural water bodies, including river Vishwamitri, its tributaries and water courses, have been responding to sudden heavy rainfall in the catchment areas?
3. What are the causes for occurrence of such Urban floods?
4. How are flooding adaptation measures being performed in the city in past?
5. Depending on the context, which measures that deal with urban flooding can be considered the most effective to manage floods in Vadodara?

3.5 SCOPE OF THE STUDY

The scope of the study is focused on the parameters that have caused floods in Vadodara city.

- In context on the present study, the flood analysis is done for the situation emerged in the city along the banks of Vishwamitri river when it flows above its High Flood Level (H.F.L)
- Vishwamitri river basin which is part of Dhadhar river basin is delineated for the present study.

3.6 LIMITATIONS OF THE STUDY

The study limits itself to Vishwamitri River and its streams existing within the city only. Flood analysis for the entire city is done and solution will be provided as statutory because Flood occurrence is an Act of God. Morphometric analysis of Vishwamitri sub-basin is done for specific parameters which are related to research objectives. The flood model would have been more accurate if specific data related to cross-section, discharge data of the catchment and local runoff were available. The meandering effect of river reach was not taken account.

CHAPTER - 4
ANALYSING VADODARA AS A CITY

4. STUDY AREA

In this study the years which are considered to be base years are from 1980-2024 and on the basis of this calculations inventory forecasts are made for 2021, 2031, 2041 and 2051.

4.1 GENERAL OVERVIEW

The study area comprises of Vadodara city and Vishwamitri river sub- basin. In Vadodara city the study area for flood analysis is limited to area along the banks of Vishwamitri river and its streams which is flowing through the city and the flood accumulating spots. Flooding situation has occurred when the river has crossed its H.F.L. The entire city is taken up for flood analysis. Vishwamitri river sub-basin encompasses the origin of the river and major water bodies which have relationship with the city and flood hazard.

4.2 VADODARA

4.2.1 PROFILE

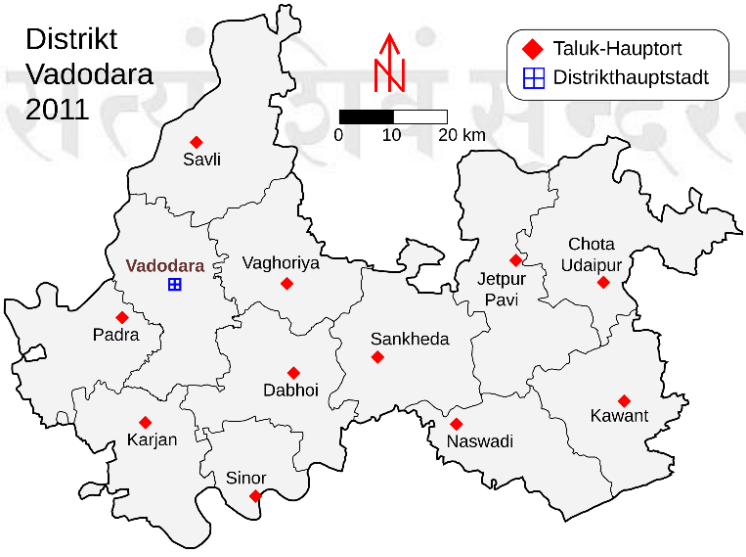

Figure 3. Vadodara & its Blocks (Source – Search _Informal sector, google image)

- Vadodara is located in the middle east side of Gujarat state, India.
- It is the third largest city of Gujarat also known as the cultural city.
- The geographical location is 22°18'N 73°19'E . Total area of city within the municipal limits is about 159.95 sq. kms.
- The city has population of 16,66,495 people and is divided into 4 zones, 28 election wards and 12 administrative wards.
- The 15th largest city in India with the area of 260.33 sq. km.

Vadodara District Map

Figure 4 Location map of Vadodara city

4.2.1 CLIMATE

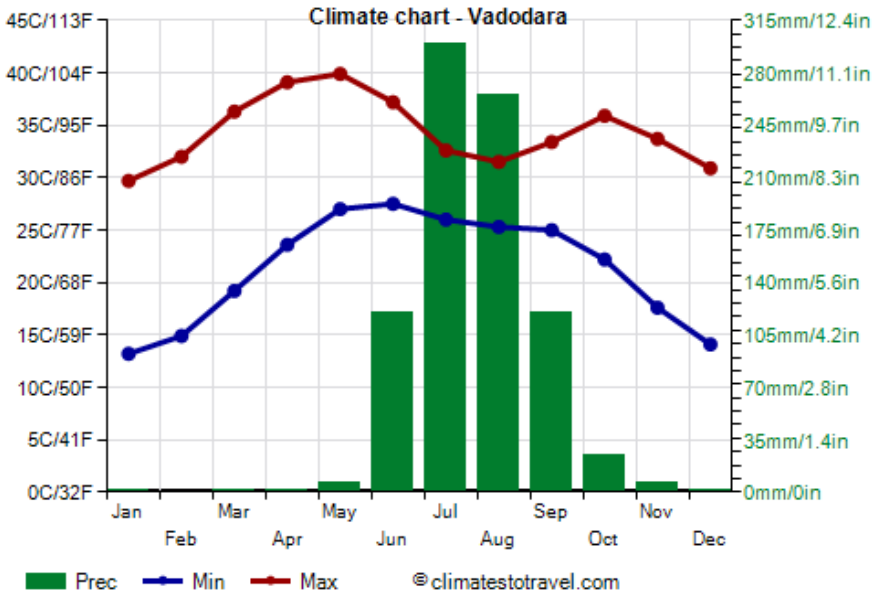

Figure 5 Climate of Vadodara city

Vadodara features a tropical savanna climate under Koppen's climate classification. There are three main seasons: Summer, Monsoon and winter. The climate is dry. The weather is hot through the months of March to July — the average maximum summer is 36 °C, and the average minimum is 23 °C. From November to February, the average maximum temperature is 30 °C, the average minimum is 15 °C, and the climate is extremely dry. Cold northerly winds are responsible for a mild chill in January. The southwest monsoon brings a humid climate from mid-June to mid-September. The highest temperature recorded is 47 °C and the lowest is 15 °C.

2.2.2 RAINFALL

The average annual rainfall in Vadodara is 930 mm. The rainfall occurs almost entirely during the monsoon months of June, July, August and September.

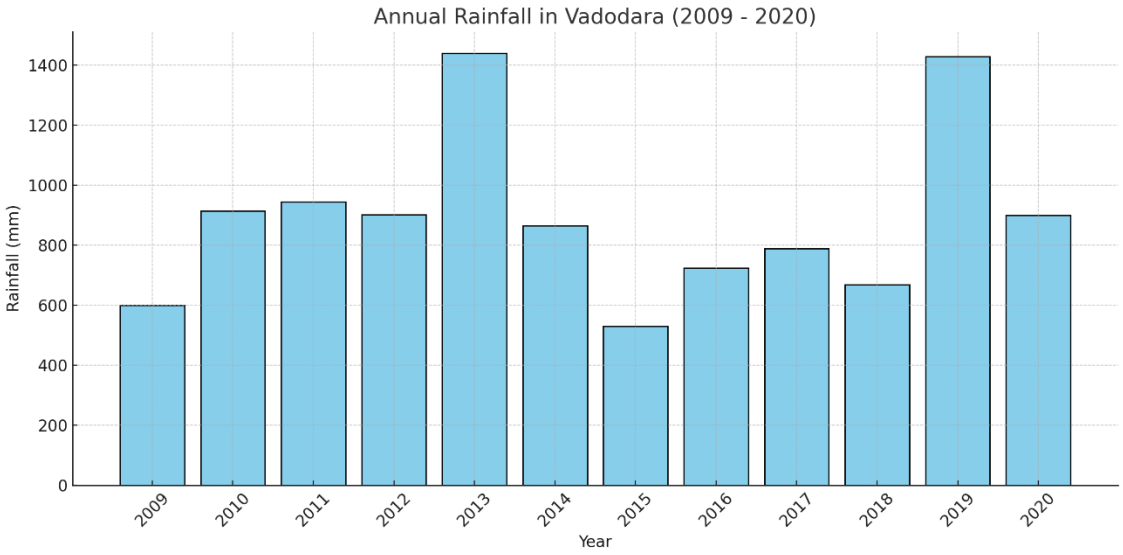

Figure 6: Average Rainfall (Source: Google Images)

CHAPTER - 5
UNDERSTANDING VISHWAMITRI RIVER AND VADODARA CITY

5.1VISHWAMITRI RIVER AND VADODARA CITY IN VISHWAMITRI DHARADHAR WATERSHED

- A seasonal river originating from the Pavagadh hills in Gujarat.
- Flows through Vadodara city for about 80 km before merging with the Dhadhar River and reaching the Arabian Sea.
- Supports rich biodiversity, including mugger crocodiles and wetland ecosystems.
- Holds cultural and ecological significance for the region.

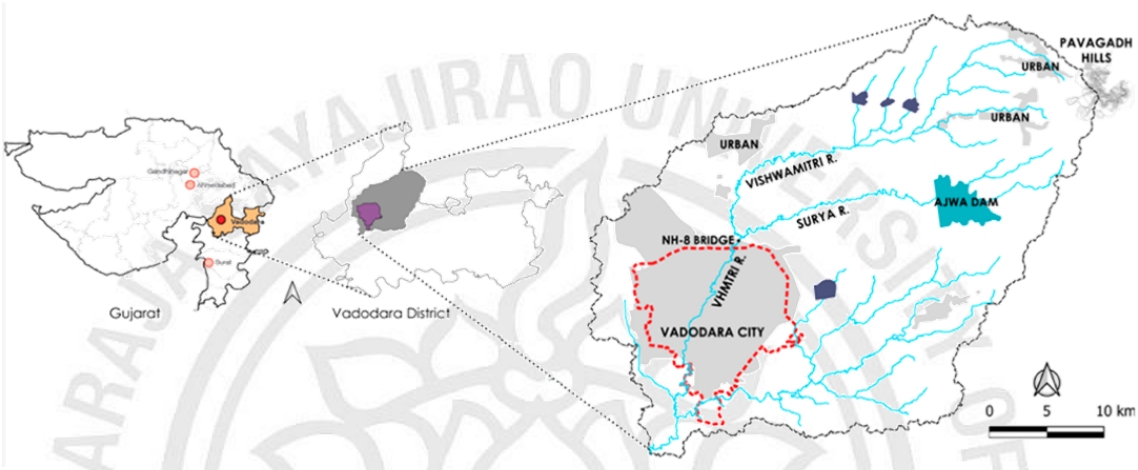

Figure 7 : Dhandhar Basin (Source : Google Images)

5.2 CODIFICATION OF VISHWAMITRI RIVER CATCHMENT AREA

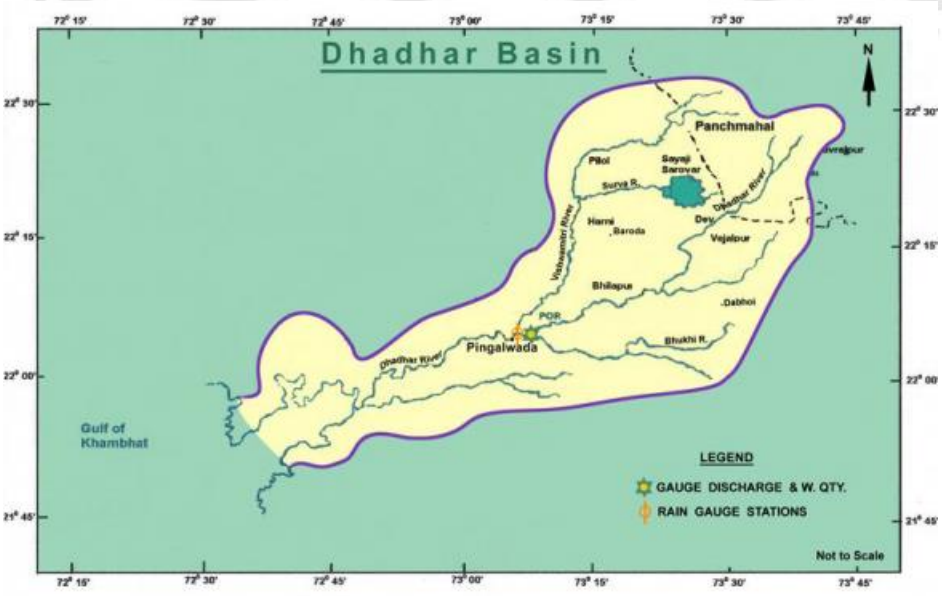

Figure 8 : Dhandhar Basin (Source : Google Images)

The study comprises of Vishwamitri sub-basin and Vishwamitri River. The

catchment area of the Dhadhar basin is 3423 Sq.km. The Vishwamitri river is a major tributary of the Dhadhar river (It is a part of Lower Mahi Basin). The study area covers the Vishwamitri sub-basin. The catchment area of the basin is 624 Sq.km. Upper catchment produces approximately 5020 cubic meter runoff per second during peak rainfall. It is located in the north-east direction of Dhadhar river basin.

The major water bodies in the basin are Ajwa sarovar, Pratapura lake, Dhanora lake and Dhansarvav lake. Ajwa Reservoir accounts for 40% of the watersupply.

The climate of the basin is characterized by a hot dry summer, an moderate winter and humid monsoon. There are total seven IMD (Indian Meteorological Department) stations in the catchment area where rainfall is recorded. They are Vadodara city (MS University, Observatory), Pilol, Bhaniara, Ajwa, Pratapura, Dhansarvav and Dhanora. The two rivers majorly receives water from rainfall in catchment and through these water bodies. Ajwa sarovar fulfils 40% need of water to the city.

5.3 **VADODARA CITY IN VISHWAMITRI-DHADHAR WATERSHED**

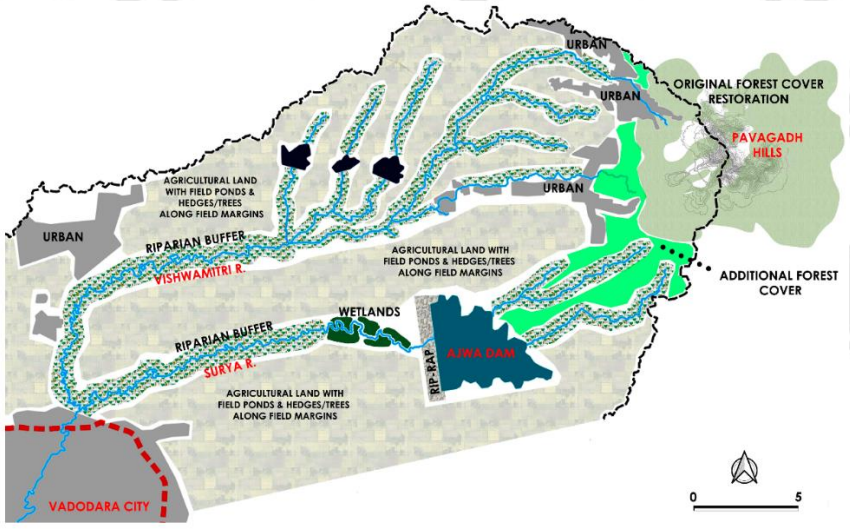

Figure 9 : Dhandhar Watershed (Source : Google Images)

- Vadodara is a major urban center situated within the Vishwamitri-Dhadhar watershed.
- The watershed comprises the interconnected Vishwamitri and Dhadhar

river systems.

- These rivers play a vital role in regional water supply, agriculture, and groundwater recharge.
- Rapid urbanization has led to challenges such as pollution, encroachment, and habitat degradation.
- Conservation initiatives are underway to restore the river and manage the watershed sustainably.
- The goal is to ensure ecological health and long-term water security for the city and surrounding areas.

5.4 **VADODARA CITY IN VISHWAMITRI-DHADHAR WATERSHED**

The basin receives most of the rainfall from the south west monsoon from June to September. There are total seven IMD (Indian Meteorological Department) stations in the catchment area where rainfall is recorded. They are Vadodara city (MS University, Observatory), Ajwa, Pratapura, Dhansarvav, Dhanora, Pilol and Bhaniara. Presently there are only three stations in the catchment area where discharge/water level/discharge is recorded. They are at Vadodara City (Kalaghoda) Bridge, Pilol, Bhaniara.

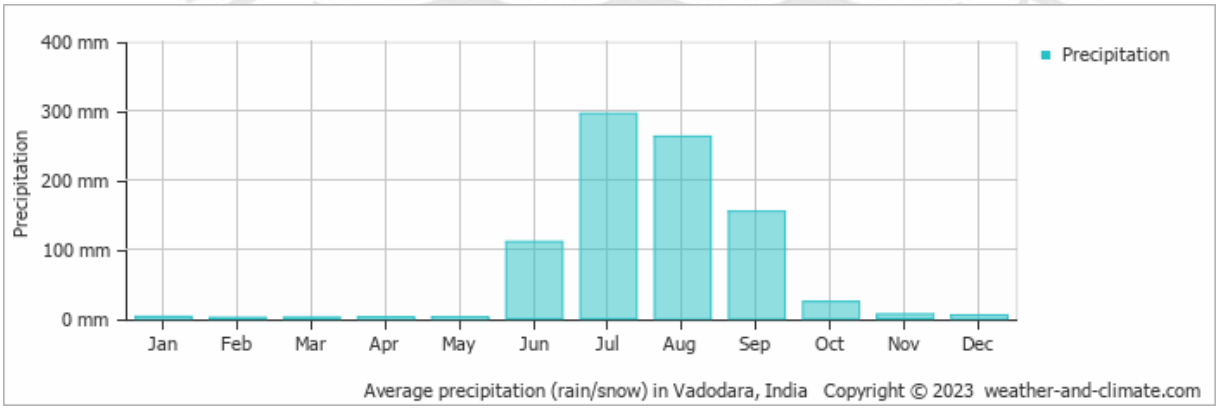

Figure 10: Average Precipitation (Source: Weather-and-climate.com)

5.5 **RIVER SYSTEM AND ITS INTERCONNECTION WITH LAKES**

Vishwamitri river originates from the Pavagadh hill which is located 40 k.m. in the north-east direction from the city.

- River length within VUDA boundary: 27 km
- River length within VMC boundary: 16.5 km
- River length with branches and loops: 23.5 km
- River width: 60-80 m
- River depth: 8-10 m

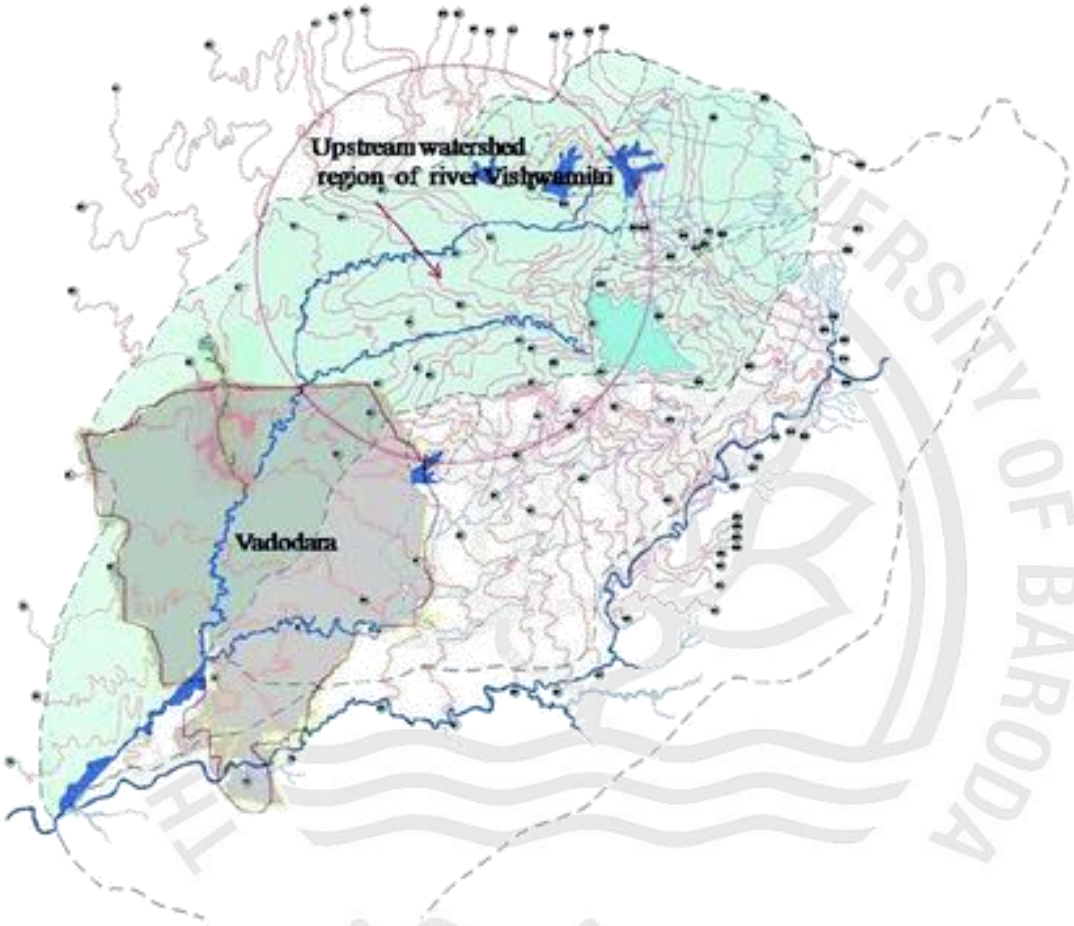

Figure 11 : Vishwamitri River Streams (Source: Google Images)

CHAPTER - 6
URBANIZATION IN VADODARA

6.1 Urbanization in Vadodara

It has accelerated significantly over the past few decades, shaped by industrial growth, infrastructure development, and increasing population.

- Growth Drivers: Expansion of industries (petrochemicals, engineering), IT parks, and improved connectivity (e.g., highways, railway links) have driven

rapid urban expansion.

- Spatial Expansion: Vadodara has grown beyond its traditional core, absorbing peripheral villages and agricultural land into the urban fabric, especially towards the northeast and southeast.
- Population Rise: The city's population has steadily increased—from around 1.5 million in 2001 to over 2.2 million in recent estimates—intensifying demand for housing, transport, and utilities.
- Environmental Impact: Urbanization has encroached upon natural features like the Vishwamitri River and green buffers, contributing to habitat loss, water pollution, and urban flooding.
- Land Use Shift: There's been a clear transition from agriculture to residential and commercial zones, often with inadequate planning, leading to pressure on infrastructure.
- Governance Response: Initiatives under the Smart Cities Mission and AMRUT aim to modernize infrastructure and manage urban growth sustainably.

Figure 12 : Urbanization along Vishwamitri River (Source: Google Images)

Figure 13 : Urbanization along Vishwamitri River (Source: Google Images)

6.2 URBANIZATION AND ITS IMPACT ON VISHWAMITRI RIVER

"HAS HAD A PROFOUND AND LARGELY NEGATIVE IMPACT ON THE VISHWAMITRI RIVER."

This timeline reflects how urbanization has progressively restricted the Vishwamitri River's natural floodplain, increasing both flood risk and ecological degradation.

Year	Urban Development Status	Floodplain Condition	Impact Observed	Source
2000	Limited expansion beyond city core	Natural floodplain with wetlands, vegetation	Moderate seasonal flooding, minimal damage	GSDMA Reports
2004	Growth towards outskirts begins	Partial encroachments along riverbanks	Vishwamitri crossed 21 ft; flood warning issued	[IMD, Vadodara Municipal Records]
2010	Rapid real estate development in Bhayli, Atladara, Gotri	Major filling of low-lying areas; narrowed floodplain	29 ft river level; city witnessed serious flooding	[VMC Disaster Report 2010]
2014	Urban sprawl accelerates; roads built near river	Encroachments block natural drainage paths	River reached 34 ft; large-scale urban flooding in July	Times of India, July 2014
2019	Construction near river peaks; slums near floodplain increase	Natural buffers destroyed; riverbanks concretised	35.5 ft river level; 5000+ displaced	Wikipedia - 2019 Vadodara Flood
2023	Peripheral towns integrated; ring road project underway	Minor restoration efforts, but urban pressure remains	Moderate waterlogging; Vishwamitri at 7.9 ft	Gujarat Samachar, July 2023
2024	Record rainfall & peak urbanisation	Floodplain almost entirely urbanised; minimal absorption zones	River hit 35.25 ft; major flood disaster declared in August	Desh Gujarat, Aug 2024

Table 2: Impact of Urbanisation

- **Encroachment & Loss of Riparian Zones:** Expansion of housing, roads, and industries has led to the encroachment of the riverbanks, narrowing the natural river corridor and destroying riparian vegetation crucial for ecosystem balance.
- **Pollution:** The river receives untreated sewage, solid waste, and industrial effluents. Over 50% of the city's wastewater enters the river directly, degrading water quality and harming aquatic life.
- **Flooding:** Concretization and blocked drainage channels reduce the river's natural ability to absorb and redirect water, leading to frequent urban flooding during monsoons (e.g., 2014 and 2019 floods).Crocodile Habitat Disruption: The Vishwamitri is one of the few urban rivers with a natural population of mugger crocodiles. Habitat loss, pollution, and human interference endanger these species and increase human-wildlife conflict.
- **Hydrological Changes:** Increased surface runoff and reduced groundwater recharge due to urban surfaces (roads, pavements) have altered the river's flow pattern, making it more seasonal and less resilient.
- **Loss of Cultural and Ecological Value:** The river, once a source of cultural pride and ecological richness, is now viewed by many as a drainage channel, reducing community engagement and stewardship.

6.3 IMPACT OF URBANIZATION ON WATER BODIES

Every year 10% hard surface is increasing as per observation. The encroachment on riparian belts, filling of ravines, floodplains and water bodies has affected carrying capacity for rainwater causing urban floods.

The concretization of storm water drains and increase in impervious surfaces has increased intensity of runoff and reduction in groundwater percolation. This is the map showing flood prone zone of Vadodara City

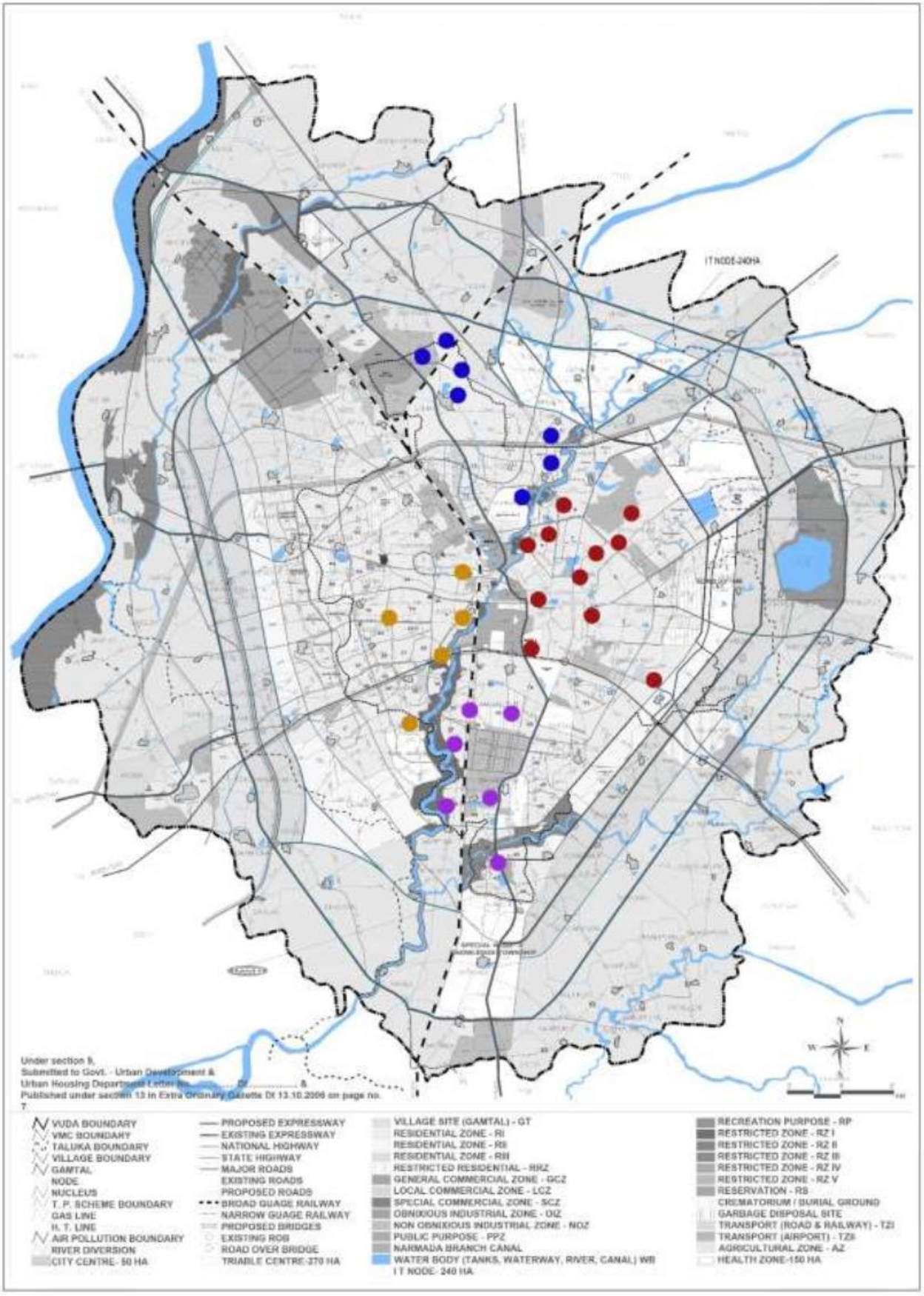

Fig 14. Ward wise Affected Areas (Source: Google Images)

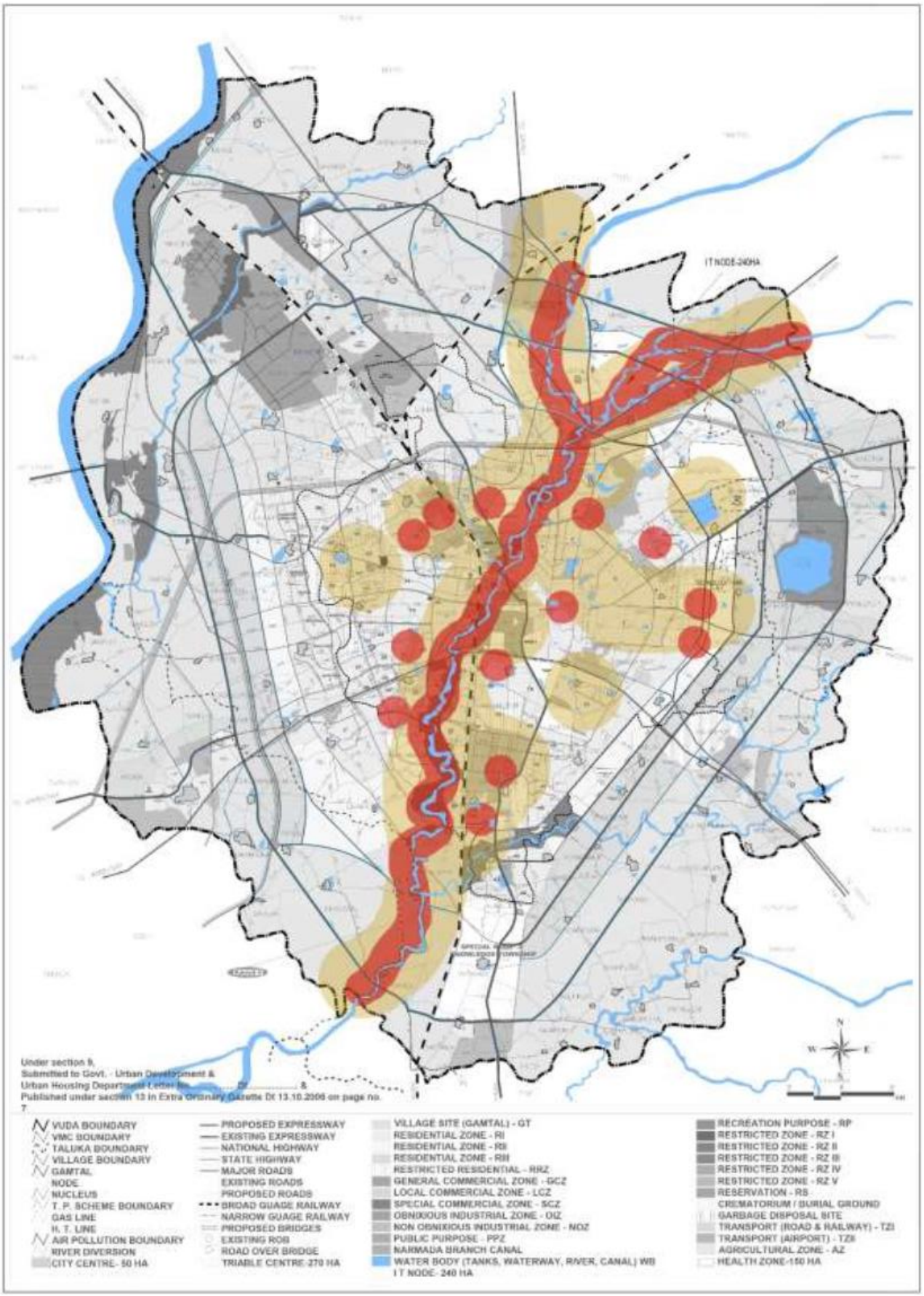

Fig 15. Flood Prone Area of Vadodara City (Source: Google Images)

6.4 MAPS OF URBAN SPRAWL

Fig 16. Urban Sprawl of Vadodara : Year 2013 (Source: Google Earth)

Fig 17. Urban Sprawl of Vadodara : Year 2016 (Source: Google Earth)

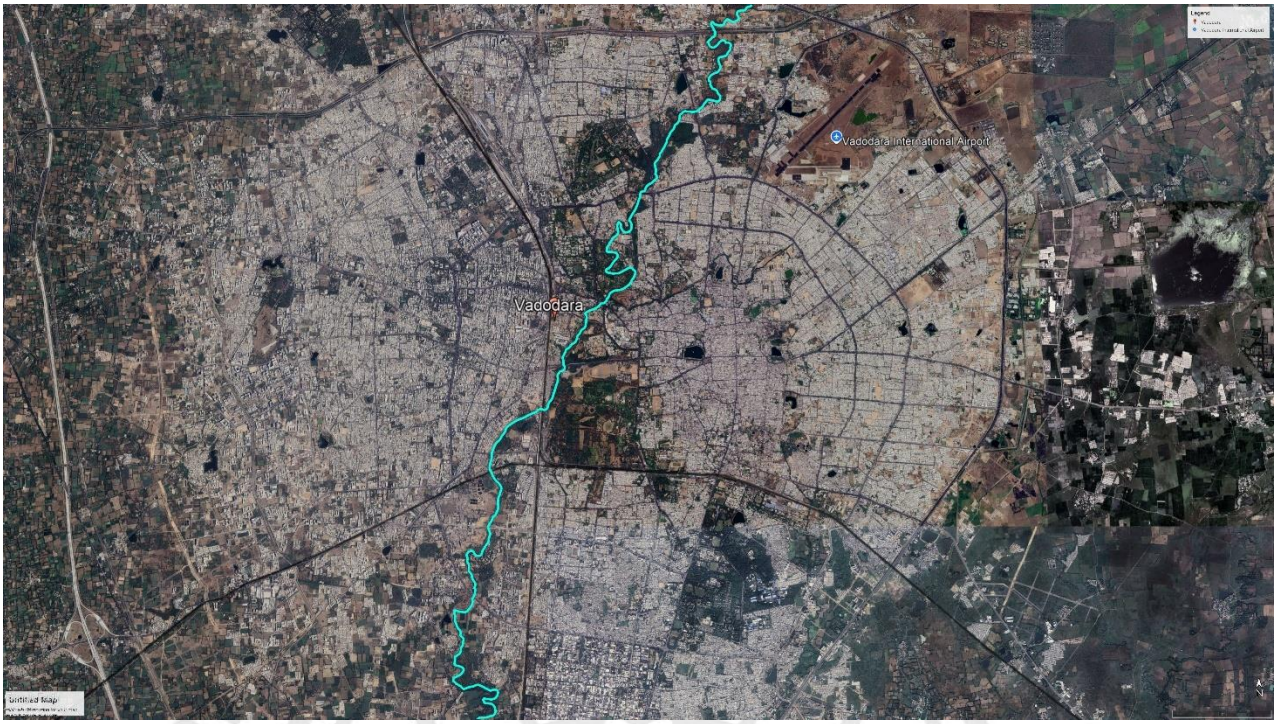

Fig 18. Urban Sprawl of Vadodara : Year 2022 (Source: Google Earth)

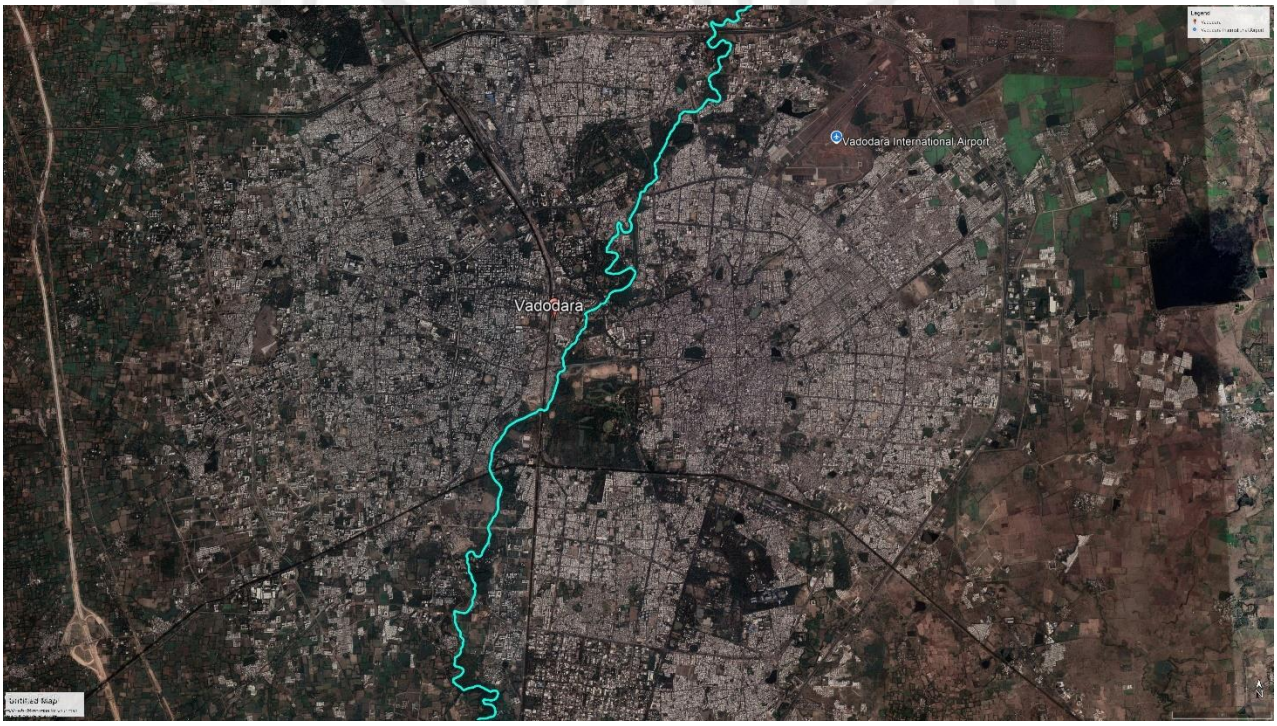

Fig 19. Urban Sprawl of Vadodara : Year 2025 (Source: Google Earth)

6.5 ISSUES THAT DEGRADE WATER BODIES AND WETLANDS IN VUDA BOUNDARY

1. Urban Encroachment and Land Use Change

- Rapid expansion of **residential colonies**, **commercial complexes**, and **infrastructure projects** leads to shrinking of lakes, ponds, and natural drains.
- Wetlands are often treated as "wastelands" and filled for development.

2. Solid Waste Dumping

- Many water bodies are used as informal **garbage dumping grounds**, especially on the periphery.
- Plastics, construction debris, and organic waste degrade water quality and destroy aquatic habitats.

3. Sewage and Industrial Waste Discharge

- **Untreated or partially treated sewage** from urban and peri-urban areas flows into ponds and lakes.
- **Effluents from small-scale industries** (e.g., chemical, textile units) often find their way into nearby drains and water bodies.

4. Loss of Catchment Areas and Natural Drainage

- Construction on **natural drainage lines (nalas)** restricts water flow, reduces recharge, and causes sedimentation.
- Encroachment on **wetland catchments** leads to their gradual drying up or seasonal functioning only.

5. Invasive Plant Species

- Water hyacinth and other invasive aquatic plants choke lakes and reduce oxygen levels, harming biodiversity.

6. Neglect and Poor Maintenance

- Many community tanks and water bodies are neglected due to lack of

awareness or funds.

- Absence of **regular de-silting**, **cleaning**, and **boundary protection** allows further degradation.

7. Climate Variability

- **Irregular rainfall** and increased heat due to climate change exacerbate water body shrinkage and evaporation.
- Drought-prone years lead to dry lakes, while high-intensity rains cause flooding due to poor water holding capacity.

Fig 20. Bar chart showcasing Issues at Wetlands (Source:Google Images)

Fig 21. Degraded Wet Lands (Source: Google Images)

Fig 22. Degraded Wet Lands (Source: Google Images)

6.6 HIGHEST WATER LEVELS: AJWA DAM & VISHWAMITRI RIVER (2019–2024)

In August 2024, Vadodara experienced severe flooding as the Vishwamitri River surged to 35.25 feet, surpassing the danger mark of 26 feet. Simultaneously, the Ajwa Dam's water level peaked at 213.85 feet. This extreme situation was triggered by heavy rainfall, leading to widespread flooding across the city.

Year	Ajwa Dam Level (ft)	Vishwamitri River Level (ft)	Date of Peak Level	Notes/Source
2019	213.1	35.5	July 31, 2019	Severe flooding occurred due to heavy rains. (en.wikipedia.org)
2020	Data not available	Data not available	—	—
2021	Data not available	Data not available	—	—
2022	Data not available	Data not available	—	—
2023	210.25	7.9	July 17, 2023	Ajwa reservoir nearly full; Vishwamitri River flowed on both banks. (gujaratsamachar.com)
2024	213.85	35.25	August 27, 2024	Record-breaking flood; Vishwamitri River reached unprecedented levels. (deshgujarat.com)

Table 3: Water levels at Ajwa Dam

CHAPTER - 7
PROPOSALS BASED ON THE STUDY PERFORMED

7.1 FLOODPLAIN OF VISHWAMITRI RIVER IN VADODARA CITY

Fig 23. Flood Plain of Vishwamitri River (Source: Google Earth & Author)

Primary objective of this study is to suggest strategies to mitigate the flood risk in Vadodara City. Nevertheless, there is a need for improvement in water and habitat quality as well. The simulated floodplain of Vishwamitri River within Vadodara City is shown in this Figure.

Flood risk can be reduced in the city by increasing the river carrying capacity, making slums safer, restoring off channel storage, discouraging impervious encroachment, promoting infiltration by providing green buffers etc.

Furthermore, water quality of the river stretch lying within the city can be improved by discouraging garbage dumping into the river and dealing with the sewage flow from grey infrastructure into the river.

At last, restoration of lost riparian cover and reduction of human intervention in natural environment can ensure a rich habitat quality in the river ecosystem.

7.2 PROPOSALS

7.2.1 RIVER CARRYING CAPACITY

Previous riverfront development proposals within city limits often focused on channelizing the river using rigid rectangular or trapezoidal cross-sections. However, this approach posed significant drawbacks. It required deep excavation to accommodate the highest recorded flood levels and often came at the expense of riparian vegetation along the riverbanks, threatening the natural ecosystem and reducing ecological resilience.

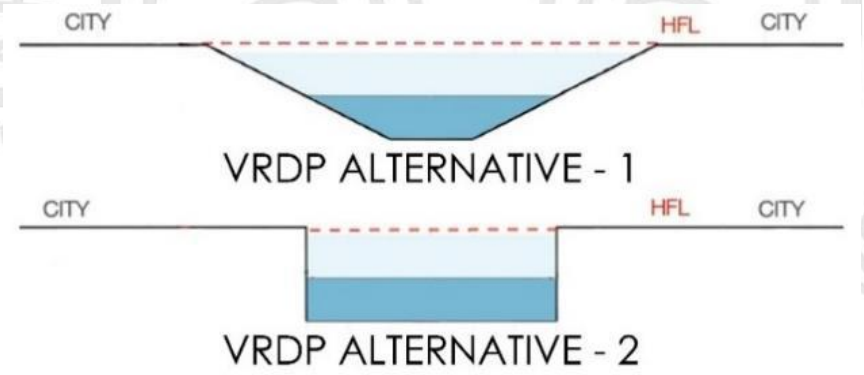

Fig 24. Alternatives of River Carrying Capacity (Source: Author)

Plants that grow along rivers, called riparian vegetation, help keep the river healthy. They hold water in the soil, let it soak in slowly, and give animals a nice place to live. These plants also slow down water and mud when there is a flood. But when people change the shape of the river to make it straighter or deeper (called river channelization), the water flows faster. This can hurt the animals and plants that live in the river.

In the past 40 years, the amount of water the river can safely carry through the city has dropped by 25%. This happened because people threw garbage, building waste, and dirty water into the river. To make the river healthy again, we need to

clean it by removing all the waste—but we must be careful not to harm the plants already growing along the river.

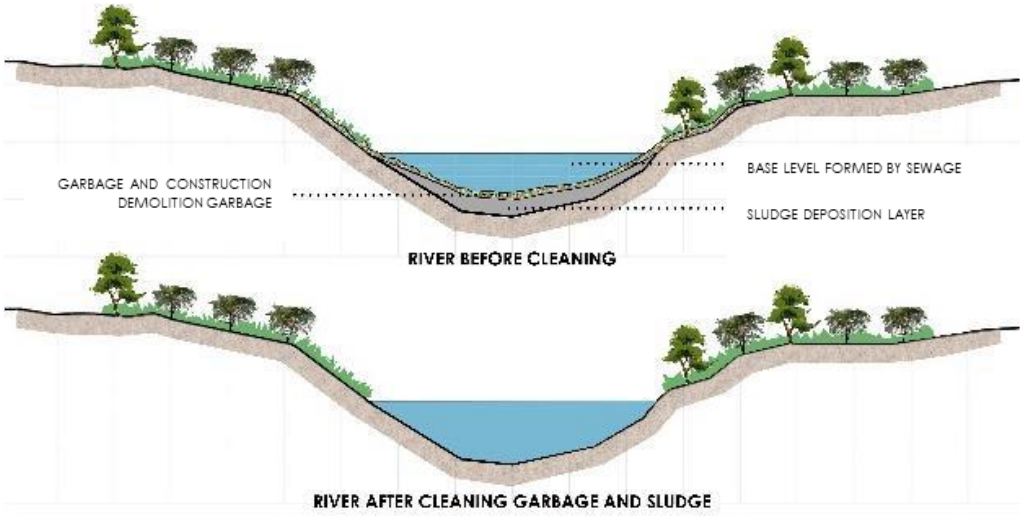

Figure 25: How the river looked before and after it was cleaned. (Source : Author)

7.2.2 RIVER POLLUTION

Approximately 200 MLD sewage flows into the river through several outlets. The challenge lies to stop the sewage water from entering the river as well as to maintain the base flow of river for dependent species to sustain. To stop the sewage water from entering the river, interceptor sewer lines are pro-posed parallel to the river banks to divert the flow. This diverted water will be led to nearby STPs (Sewage Treatment Plants). The treated water will then be eventually re-leased back into the river at outlets located at a uniform interval. A conceptual diagram of this method is shown in Figure. A similar approach was followed in Delhi for pollution in Yamuna River.

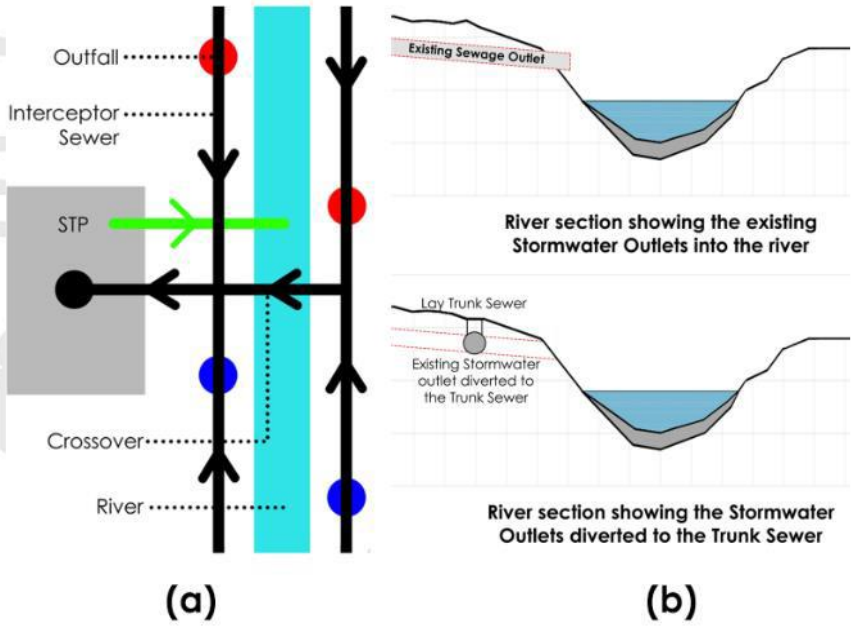

Figure 26: Stromwater Outlet - Solution (Source : Author)

As shown in Figure, STP1, STP2 and STP3 each having capacity of 50 MLD are proposed on vacant lands along the banks without disturbing the eco-corridor. STP4 is existing and has a maximum capacity of 80 MLD. During monsoon when the discharge is high, overflow can be diverted back into the river to avoid overload. Pumping stations need to be provided along the interceptor network as the distances are large and slope gradient required may not be feasible on site.

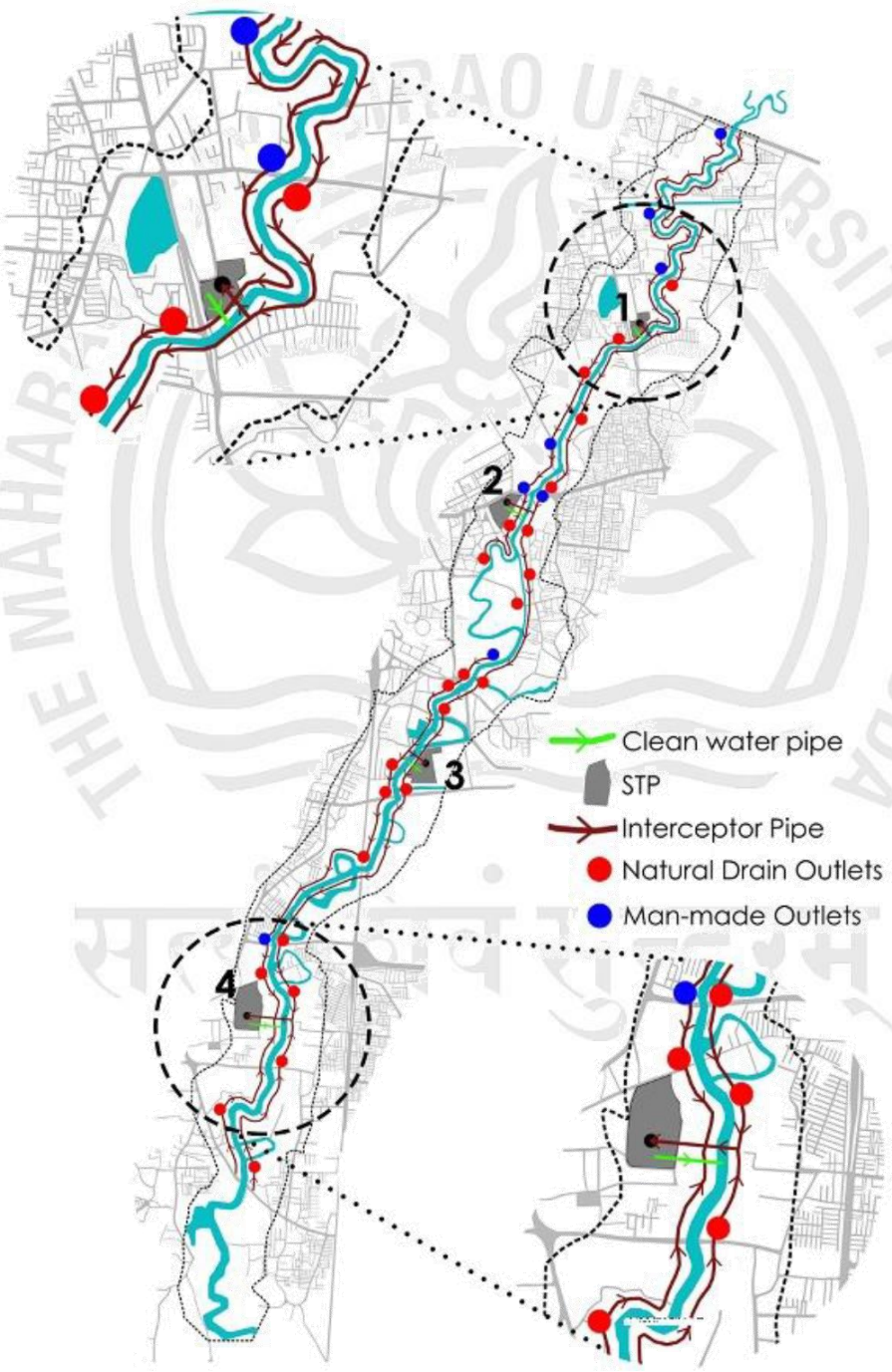

Figure 26: Stromwater Outlets Solutions (Source : Author)

7.2.3. SLUMS

Three intervention strategies are suggested based on the location and age of the in-formal settlements: removal, relocation and redevelopment. Firstly, new slums which have come up in the last ten years should be removed as these huts were con-structed despite knowledge of frequent flood events. Old encampments located on or near crocodile nesting sites should be relocated to some other place. Lastly, remaining old slums should be redeveloped.

7.2.4 REDEVELOPMENT

Currently, old slums are in a bad state due to frequent floods and unsuitable living conditions. In addition, these informal settlements have depleted the green buffer near banks. Hence, it is necessary to restore vegetation and make it safe for people to live in these low laying areas.

Existing condition of Shantinagar slum is shown in Figures. Here slums have encroached river banks by depleting the original vegetation. Also, houses are all G structures which makes it difficult for slum dwellers to stay at their homes during floods.

Figure 27: Existing Developements (Source : Author)

Figure 28: Proposed Developments (Source : Author)

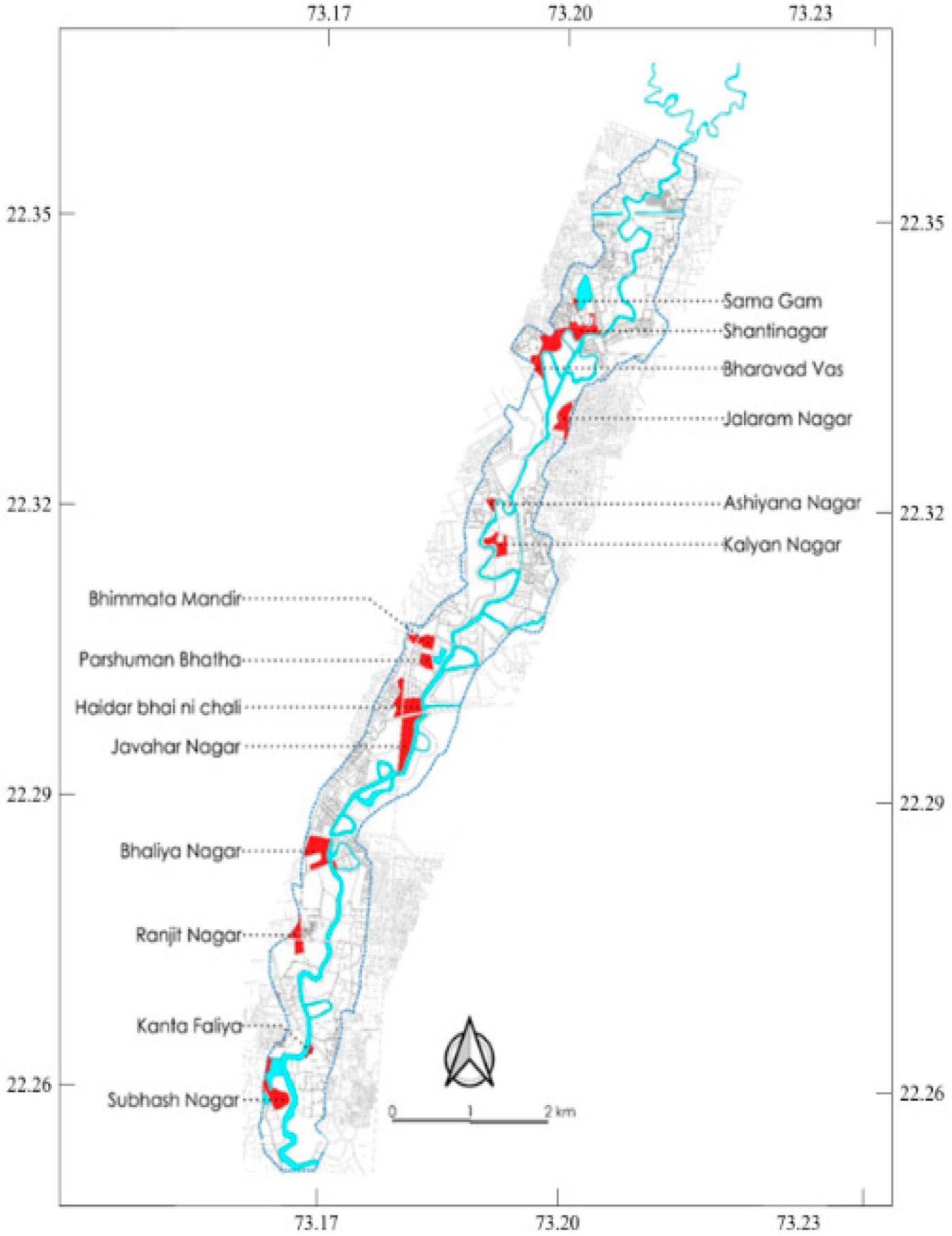

Figure 29: Existing Slums (Source : Author)

7.1.5 RIVER RIPARIAN BUFFER

Several eco-zones/large open spaces are still found along the river in Vadodara city despite urban encroachment. However, there are river stretches where very little or no green buffer is present. At such stretches, a minimum of 50 m buffer is proposed mainly at the cost of agricultural lands, vacant lands and slums (after redevelopment, relocation and removal). Figure shows existing vs proposed vegetation buffer within the simulated floodplain.

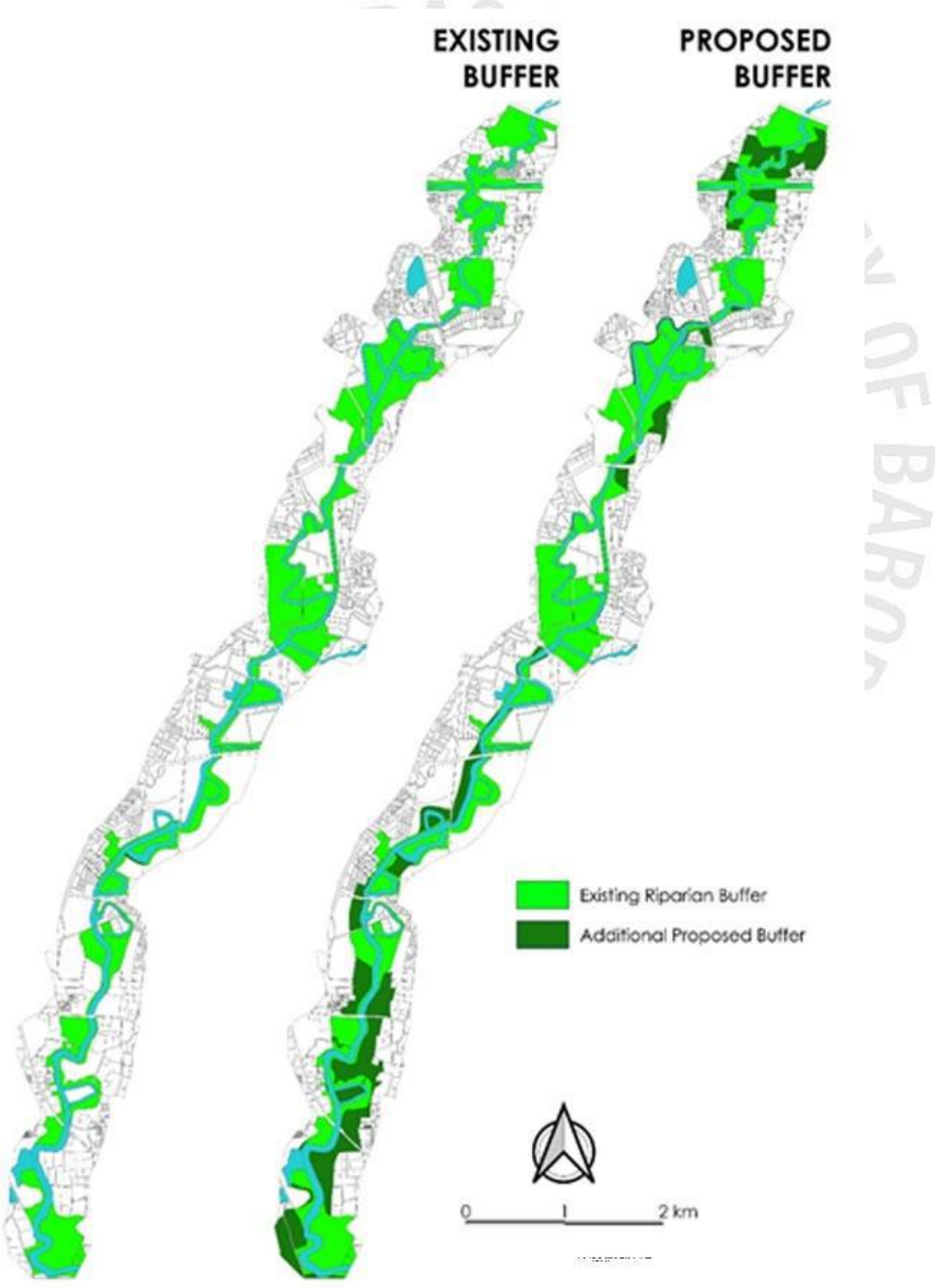

Figure 30: River Riparian Buffer (Source : Author)

7.2.6 OFF CHANNEL STORAGE

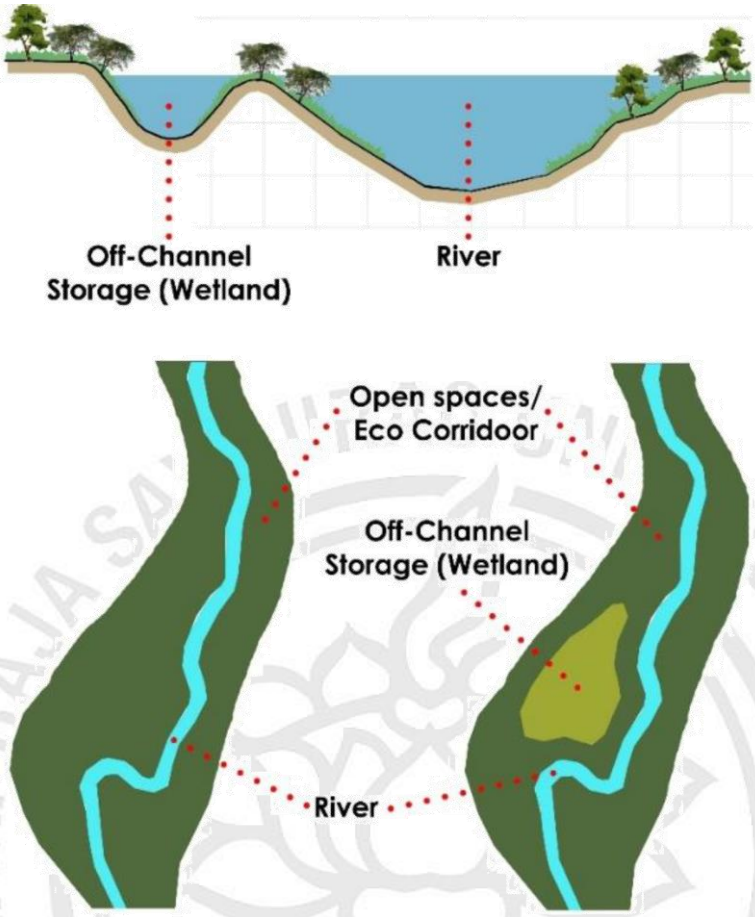

Figure 31: Off Channel Storage (Source : Author)

A significant proportion of wetlands have been lost in the city. Between 2005 and 2018, 41.04 hectares of wetlands was lost due to reclamation. Wetlands store excess water, help in ground water recharge and enrich biodiversity. Consequently, lost wet-lands should be restored as much as possible.

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