GIS and Remote Sensing as a Decision Support Tool for Analysis and Recommendations in Urban Flooding: A Case Study of Vasana Ward of Ahmedabad

Swapnali Patil[1], Suvarna Thakare[2], Subhankar Nag[3]

[1]Architect and Urban Designer, Neeta Associates, Karjat, Maharashtra
Email: *swapnalipatil528[at]gmail.com*

[2]Architect and Urban Designer, Pillai College of Architecture, Navi Mumbai, Maharashtra
Email: *suvarnathakre[at]mes.ac.in*

[3]Architect and Urban Planner, Navi Mumbai, Maharashtra
Email: *archsubhankar[at]gmail.com*

Abstract: ***In recent years, urban flooding caused by heavy rainfall has become a pressing global issue, including in Indian cities that face challenges such as high population density, rapid development, and resulting encroachment on natural resources. The process of urbanization has significantly altered the natural characteristics of cities, such as green spaces, water bodies, and topography, replacing them with densely built areas and increasing the proportion of impermeable surfaces. This transformation has disrupted the natural drainage patterns and reduced the ability of the soil to absorb water. Consequently, urban areas with high imperviousness experience more frequent and severe flooding events, disrupting social life, ecological balance, and economic activities. The primary objective of this research paper is to explore the potential of Geographic Information Systems (GIS) and Remote Sensing as a tool for analysis and recommendations in Urban Flooding in Municipalities of fast-growing cities. The study focuses on the Vasna ward of Ahmedabad city, systematically investigating its current conditions using GIS and remote sensing, and proposing strategies to prevent future flood occurrences by incorporating sustainable urban drainage (SUDS) principles into the planning framework of the city.***

Keywords— Urbanization; Impervious surface, Urban flood; GIS, Sustainable urban drainage systems (SUDS)

1. Introduction

According to the UN-Habitat World Cities Report 2022, urbanization is expected to increase significantly worldwide, with India projected to have 43.2% of its population residing in urban areas by 2030 (IPCC, 2023). In urban areas, the presence of impermeable surfaces, combined with inadequate drainage systems and uncontrolled development near natural drains, amplifies flood risks. Therefore, cities must implement effective solutions to protect themselves and mitigate the impact of flooding, thereby enhancing the urban environment. Sustainable Urban Drainage Systems (SUDS) are considered a viable solution in this context (Cristiano & Tassi, 2012).

Conventional drainage systems prioritize the collection of runoff water from impervious areas, directing it through various conduits to water treatment plants or receiving water bodies. Conversely, SUDS promote on-site infiltration and detention of water. This approach encompasses both above-ground and below-ground elements, incorporating porous paving systems, rainwater harvesting, green walls and roofs, constructed wetlands, and swales. These techniques allow for water to be either infiltrated into the ground or detained and released gradually in retention ponds, thus reducing the rapid discharge of surface runoff (Charlesworth, 2010) (Cristiano & Tassi, 2012). Blue-Green Infrastructure (BGI) refers to the utilization of vegetation, soils, and natural elements within an urban context to provide landscape and water management benefits. BGI elements encompass soil, topography, vegetation, rainwater or stormwater links, natural filtration, and storage tanks or stormwater detention systems. BGI solutions, such as detention ponds that can be utilized as open spaces during dry periods, offer multiple on-surface functions. It is important to note that BGI plays a significant role in designing SUDS for urban areas, with infiltration practices often referred to as Sustainable Urban Drainage Systems (SUDS) (Muthanna, Sivertsen, Kliewer, & Lensa, 2018). Geographical Information Systems (GIS) provide an efficient means of analyzing various satellite and remote sensing datasets. By generating maps that depict watersheds, slopes, stream direction, land use and land cover changes, and population density, GIS facilitates a comprehensive understanding of the existing conditions. As a decision-making tool, GIS aids in targeting the implementation of BGI and SUDS in the urban planning framework, enabling the formulation of guidelines for future development.

The objective of this research paper is to explore the usage of GIS as a decision-support tool in analyzing and recommending strategies to mitigate urban flooding, a problem mostly faced in fast-growing cities.

2. Literature Study – Usage of GIS in Flood Management

Copenhagen – The Cloudburst Management Plan

In July 2011, Copenhagen was hit by a cloudburst. Around 150mm of rain left large areas of the city under up to one meter of water causing huge damage to infrastructure, private properties, and commercial activities and along with it, created social damage for the entire community. It became a recurring event in 2014, and it got clear that the traditional drainage system is not capable to handle extreme weather events. A Cloudburst management plan was brought in 2012 to manage the phenomena of pluvial flooding, which bridged the gap between planning and site-specific solutions. The Blue-Green Approach developed a synergistic relationship between the conventional drainage system and BGI by integrating climate adaptation solutions within the limited confines of urban space, encouraging a solution utilizing the best of both techniques.

To prepare the cloudburst management plan, the entire Copenhagen city was divided into 26 water catchment areas, all of which eventually drain into the sea, and priority catchments were selected. As a pilot, the high-risk catchment of Lådegåds-Åen (area 10 sq. km.) was selected.

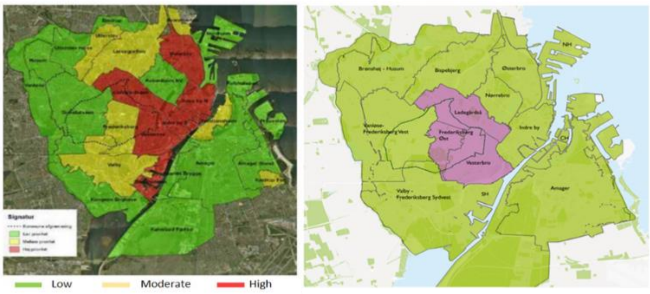

Figure 1: Map Showing flood zones of Copenhagen city and selected area of a case study (Source: ASLA Professional Awards 2016)

Various data sets were created on GIS to analyze the ground situation such as a terrain model to understand slope, sub-catchment areas to understand the potential area under flooding and catchment water routes, and a map of mobility corridors to understand the major residential and commercial activity areas in the city (American Society of Landscape Architects, 2016).

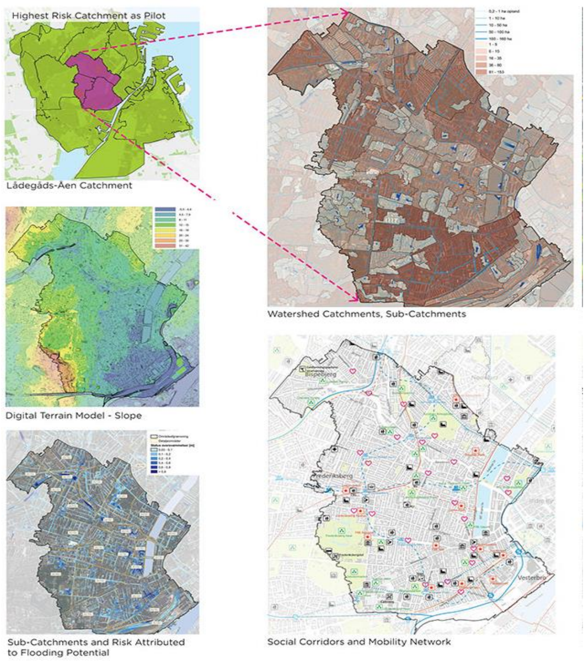

Figure 2: Selection of catchment, risk analysis mapping with the help of GIS (Source: ASLA Professional Awards 2016)

Maps processed in GIS were overlapped to analyze and suggest site-specific solutions to mitigate the risk of flooding created during unprecedented rainfall events. GIS has helped in devising low-tech solutions such as demarcating cloudburst roads, designing green roads, designing water detention streets, and water detention areas that act as amenity spaces in dry seasons.

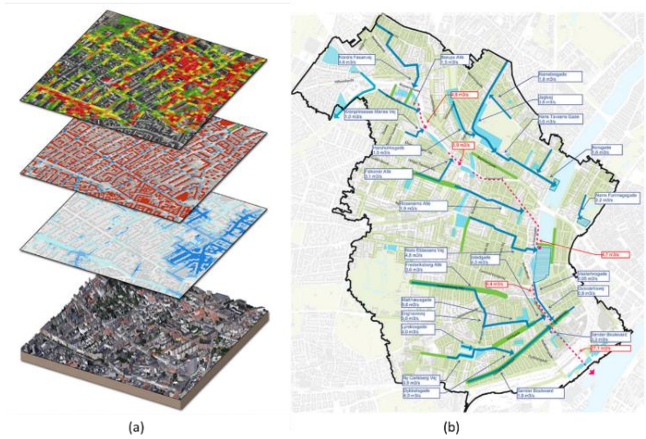

Figure 3: (a)Overlays of maps help to design Cloudburst boulevards which follow natural drainage patterns towards waterbody and opportunity for developing green infrastructure (b) Master plan showing integrated BGI and high-quality open spaces and low-tech solutions (Source: ASLA Professional Awards 2016)

3. Methods and Data

3.1 Methodology

The methodology of the research encompasses two key steps- a) selection of the city and focus area based on various datasets and news data, followed by, b) existing situation analysis of the study area using various remote sensing data sets to ascertain and arrive at the various problems faced. It acknowledges the challenges associated with ground surveys in such cities, which is almost impossible owing to the dense urbanization in such cities. During the selection of the study city, apart from data available from the news and that of population growth, remote sensing data is utilized with the help of GIS processing to track the green cover and water bodies of the city over time, as these are crucial elements for understanding the urbanization pattern and its growth, and also justify the selection of the city. The area of interest is chosen based on registered flooding complaints in 2022 and the population density. The existing situation analysis entails generating various thematic maps using GIS and conducting a brief site visit. Lastly, the optimization guidelines, provides a set of location specific guidelines aimed at reducing flooding incidents in the city.

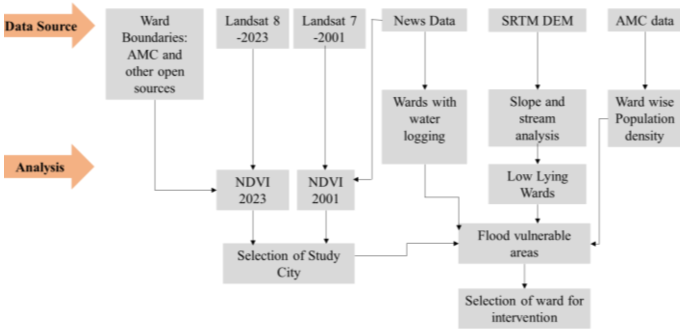

Figure 4: Methodology: A: Site and Focus area selection

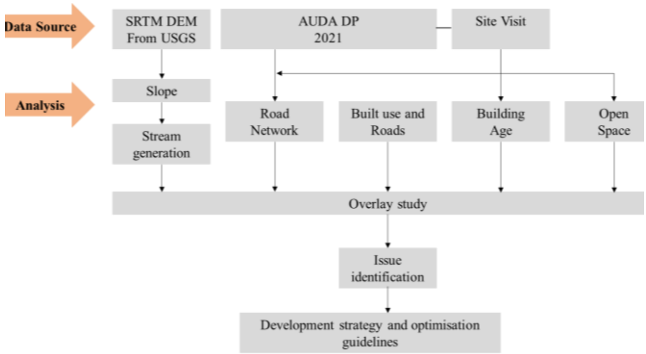

Figure 5: Methodology: B: Existing situation analysis

1) Data Sets

The following datasets were used for the analysis of the entire study

a) Ward boundaries – Amdavad Municipal Corporation and other open sources.
b) Ward-wise Population density– Census 2011 data and Amdavad Municipal Corporation data.
c) AUDA Development Plan- Correlating the land use and built use as noted from a site visit conducted in June 2022.
d) SRTM DEM, Arc 1 Second Global Data (2014) from USGS Portal - this data is used for slope and topography analysis and analysis of natural streams in the study area
e) Landsat 8 OLI data from USGS portal –
   - Band 4 and Band 5 for Normalized Density Vegetation Index (NDVI) for understanding the green cover variation in the study city. Data for the year 2023 has been used.
   - Band 3 and Band 5 for Normalized Density Water Index (NDWI) for mapping the water bodies inside the study area. Data for the year 2023 has been used.
f) Landsat 7 ETM data from USGS portal –
   - Band 3 and Band 5 for Normalized Density Vegetation Index (NDVI) for understanding the green cover variation in the study city. Data for the year 2001 has been used.

2) Study City selection

The study area selected is Ahmedabad city, in the Gujarat State of India, located between coordinates 23.03°N and 72.58°E, and situated on the banks of the river Sabarmati. The city is presently the seventh-largest metropolis in India and the third fastest-growing city as per Forbes magazine 2010. The total area of the city is 466 sq.kms. The population of the city as per the census of 2011 is 55,85,528 with a population density of 11,948 people per sq.km. There has been a steady growth of population and urban growth as per the Census data. Although the average annual rainfall of the city is 782 mm (Amdavad Municipal Corporation, 2023), which is considerably lower than that of Mumbai, which is 2213 mm, still in 2022, Ahmedabad experienced a flood-like situation causing losses in human lives and property (The New Indian Express, 2022). Presently, Ahmedabad has about 980 km of stormwater drains, which covers around 55% of the city area and as per the AMC data, the efficiency at which the runoff is drained is just 25% to 50% of the peak rainfall (Times of India, 2022).

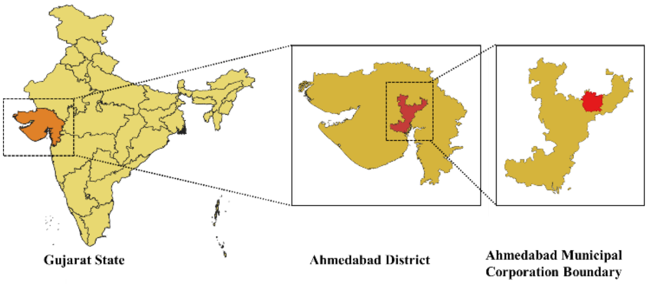

Figure 6: Location of Ahmedabad

The authors have studied the overall topography of the city, from SRTM DEM data sets processed using QGIS v 3.28.2. The analysis shows that the relatively lower part of the city is toward the south.

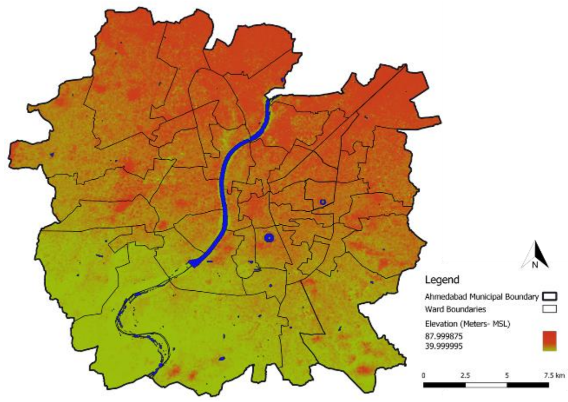

Figure 7: Ahmedabad city with wards and topography (Source: Author- using SRTM DEM data and AMC ward boundaries : Water bodies mapped through NDWI analysis)

Further analysis of the change in land use land cover of the city was conducted using the Normalized Difference Vegetation Index (NDVI). The said index uses the visible red band and Near Infrared (NIR) band from the Landsat 7 and Landsat 8 satellite images using the formula below:

$$NDVI = (NIR - R) / (NIR + R).$$

The said index measures the surface reflectance to determine the condition of vegetation (no vegetation, low vegetation, moderate vegetation, and dense vegetation). The results of the study have been shown below:

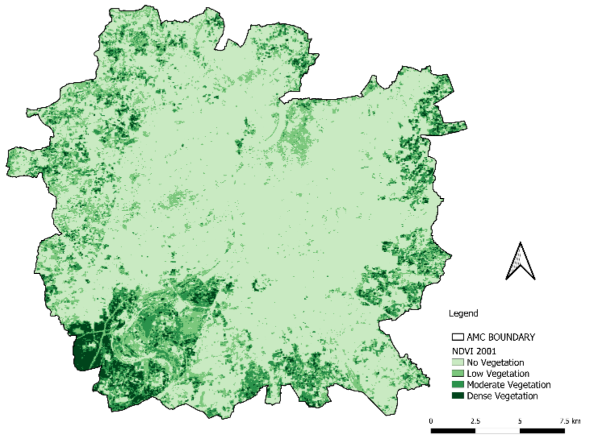

Figure 8: NDVI Ahmedabad City 2001 (Source: Landsat 7 ETM- processed by authors)

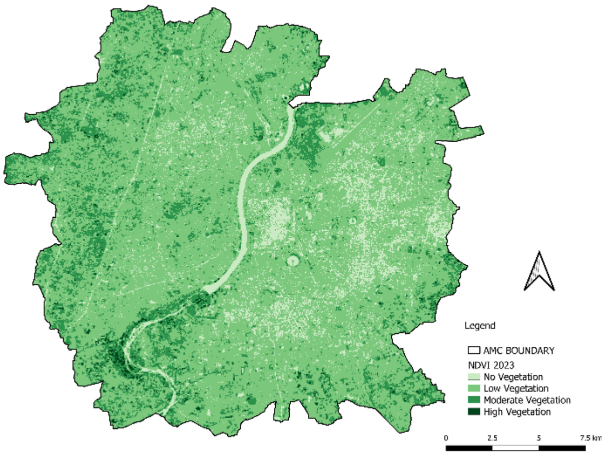

Figure 9: NDVI Ahmedabad City 2023 (Source: Landsat 8 OLI- processed by authors)

Table 1: Area classification and differences of NDVI (Source: Landsat 7 and 8 processed by the authors)

Class	NDVI areas-2001 (sq.km)	NDVI areas-2023 (sq.km)	Difference (sq.km)
No vegetation	142.75	25.97	-116.78
Low Vegetation	224.21	351.58	127.37
Medium Vegetation	62.73	66.84	4.11
Dense Vegetation	19.96	4.47	-15.49

The analysis shows that the low vegetation and medium vegetation have increased, however, the dense vegetation has substantially reduced over the study period of twelve years. The surface runoff and flooding issues may increase because of the same.

The reason for the selection of the area is to enquire and propose an analysis methodology to mitigate such flood-like situations, which may have arisen due to the lowering of dense vegetation as well as poor urban planning.

3) Selection of the area of interest

As per Amdavad Municipal Corporation (AMC), the city of Ahmedabad is divided into 6 administrative zones namely–Central, East, South, North, West, and New West Zones which are further divided into wards. As per various news reports in 2018 and 2022 from The Times of India and Times Now, the western zone of Ahmedabad city is highly vulnerable to floods. In 2022, with just 60 minutes of rain, the West Zone areas saw severe waterlogging and traffic movement issues. In the western zone, there are a total of 9 wards and out of which, parts of Vasna, Paldi, Navgangpura, Stadium, and Naranpura come under very high flood vulnerability. The population density map shows that the Vasna ward in the West zone has the highest population density. Therefore, the authors have further narrowed down their study area to the Vasna ward.

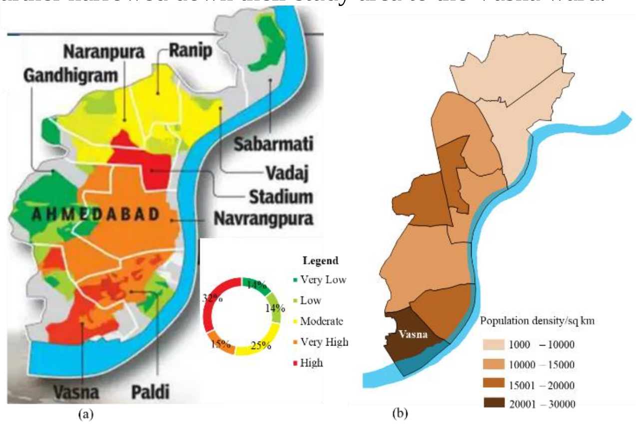

Figure 10: (a) Flood vulnerable areas in the western zone (The times of India, 2018)(b) map population density of the western zone (Source: AMC and Census 2011)

The total area of the Vasna ward is 5.5 sq. km. The authors have, for study purposes, divided the ward into three zones named Zone A, Zone B, and Zone C, based on its physical characteristics and urban growth, ascertained through a site visit during the month of June 2022. Zone C was selected as an Area of Interest, due to its proximity to the river, the presence of the BRTS route, the highway, and the area having old and dense residential development.

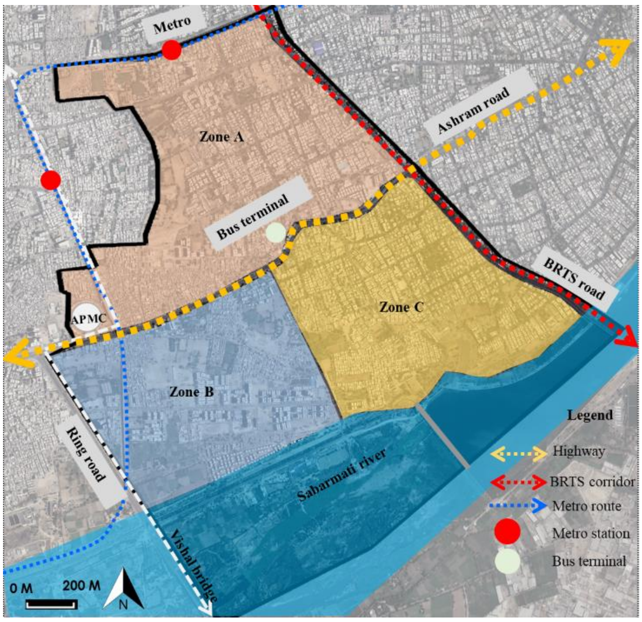

Figure 11: Map of Vasna ward showing zonal subdivisions (Source: author)

4) Existing situation analysis

The authors have further analyzed the existing situation of the selected zone through the following steps:

Step 1: Generation of Topography and natural drainage map using SRTM DEM data. The process follows the usage of SRTM DEM 1 Arc Second Void filled data available from the

USGS portal (www.earthexplorer.usgs.gov) and processing in QGIS v 3.28.2. The following sub-steps are used in the processing

- DEM clipped to the selected zone boundary of the Area of Interest using 'Clip raster by mask layer'.
- Contour tool used under Extraction of raster to generate the contour shape files of the Area of interest.
- Fill Sinks (Wang and Liu) tool under SAGA – Terrain analysis to generate the filled DEM
- Channel Network and Drainage basins under SAGA-Terrain analysis- Channel tools to generate the shape file of the natural drains.

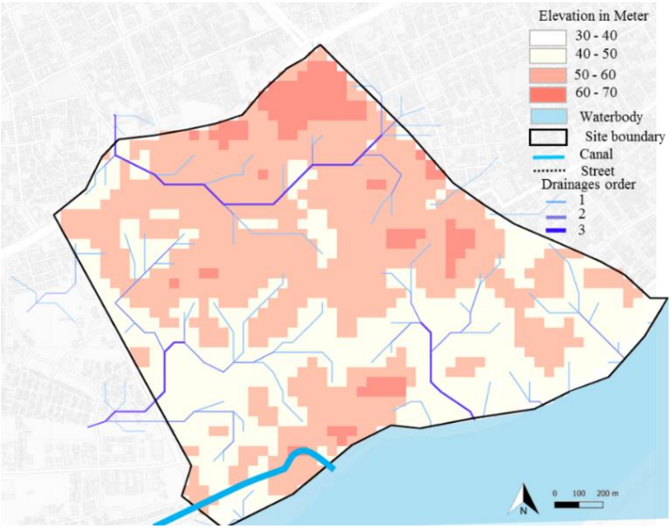

Figure 12: Step 1: Slope and drainage analysis (Source: Author)

The above map shows that the highest elevation of the site is in the range of 60-70m and the lowest elevation is in the range of 30-40m which is near the riverbed.

Step 2: This step consists of an overlay of the manmade drainage (obtained from the Amdavad Municipal Corporation) and a topography map of the study area to analyze whether the stormwater network follows the natural drainage pattern and slope.

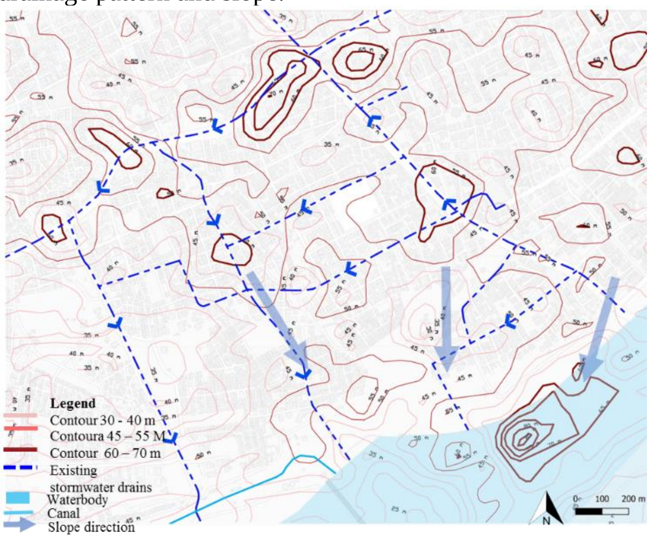

Figure 13: Step 2: Overlay of contours with man-made drainage network (Source: Author)

The study shows that the man-made drainage is along primary and secondary roads with its outfall in the river and canal, coinciding with the natural slope.

Step 3: Overlay of Built use, natural drainage, and manmade drainage. This step is essential to understand the extent of the natural drainage that is encroached upon by the built mass, as well as if the man-made drainage coincides with the natural drainage pattern.

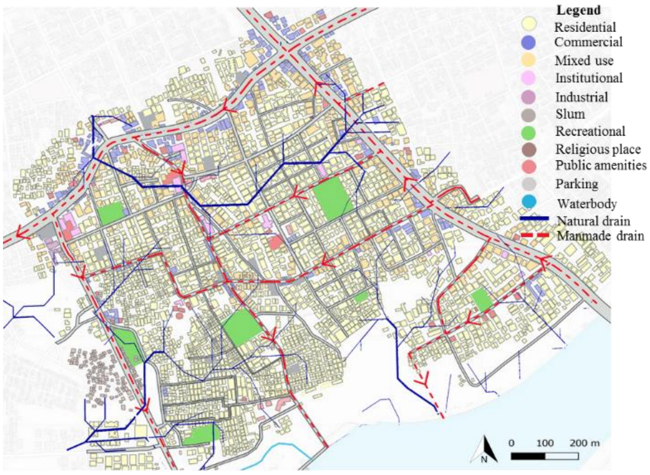

Figure 14: Step 3: Overlay of Built use, natural drainage, and manmade drainage (Source: Author)

The Built use of the area was mapped using a detailed site visit conducted during the month of June 2022. The built-use study shows 61% residential development and mixed-use occupying 15% of the area and commercial development occupying 6% of the area along the primary and secondary roads. 3% of the area is encroached by Slum dwellers. 1% area is developed as impervious open parking spaces.

The comparison of the built-use map with the natural and man-made drainage maps revealed that numerous buildings have been constructed obstructing the natural drainage patterns, and the man-made stormwater drainage system deviates from the natural flow path. Additionally, the southern region of Zone C exhibits a lower density of man-made stormwater drainage.

The presence of slums and other residential buildings in low-lying areas contributes to flood-like situations. Besides this, impervious open parking spaces in the area contribute to an increase in surface runoff.

Step 4: Overlay the building age map with the natural drains and the man-made drains to identify if the buildings encroaching on the natural drainage patterns are older than the usable life of the blocks and can be considered for replacement with newer blocks, with due consideration for open spaces and swales to utilize the natural drainage pattern. The building age map highlighted that 22% of the building are above 30 years old and 30% of buildings are between 15 to 30 years old and the rest are of relatively newer construction. This indicates that there is ample scope available for redevelopment to revitalize the natural drainage patterns. Further, after examining the overlap between building age maps and the natural/man-made stormwater drainage maps, it was clear that the encroachment upon natural drainage is not a recent occurrence, but rather has a historical timeline of 30 years or more.

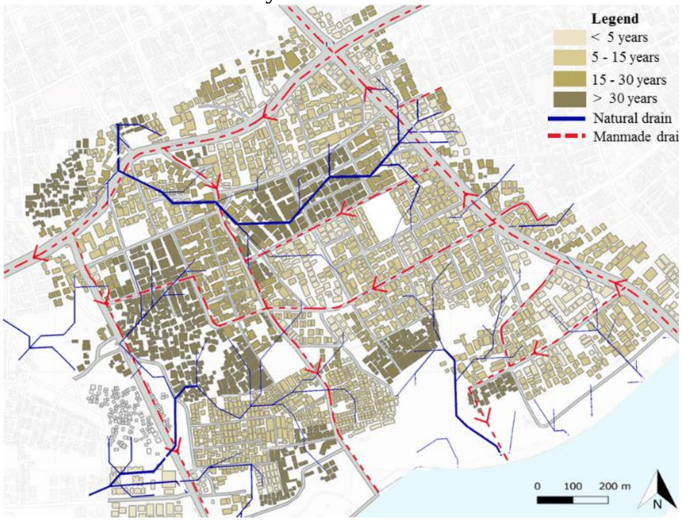

Figure 15: Step 4: Overlay of Building age, natural drainage, and manmade drainage (Source: Author)

Step 5: Overlay of open spaces of the study area with natural drainage and a manmade network to understand whether the open spaces are integrated with the natural drainages for effective water percolation and retention.

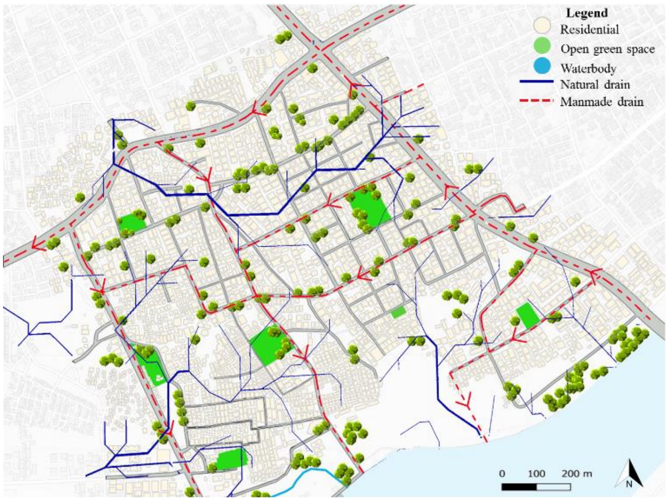

Figure 16: Overlay of open space, natural drainage, and manmade drainage (Source: Author)

The overlay of the open space network and the natural and man-made drains reveals a lack of integration, reducing the effectiveness of open spaces in absorbing and facilitating water percolation into the soil. These open green spaces, which should ideally function as sponges or retention areas, are not efficiently contributing to flood prevention in the study area.

Step 6: Overlay the existing road network with natural and man-made drains to understand if the roads are encroaching over the natural drainage patterns.

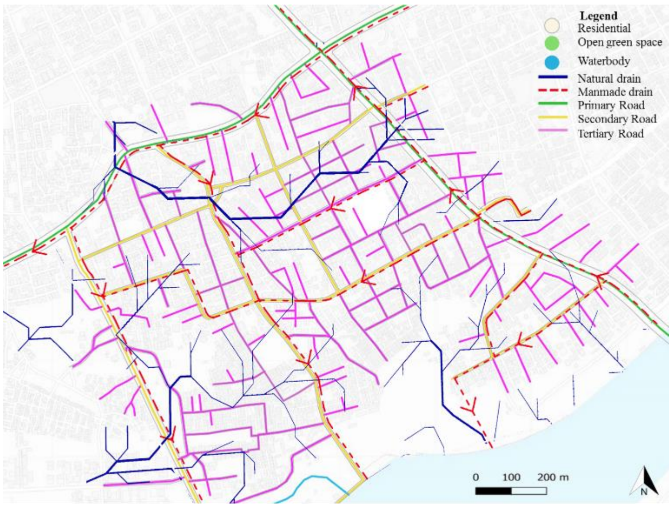

Figure 17: Overlay of existing roads, natural drainage, and manmade drainage (Source: Author)

The overlay study reveals that most of the roads are obstructing the natural drainage channels, thereby impeding the natural flow of water. Furthermore, the overlap between road networks and natural drainage, indicates that roads have been constructed over the natural drainage channels, disrupting the natural water flow direction.

Step 7: Summarizing the findings. The authors have compiled a comprehensive map of issue identification has been created, which shall form the basis of the preparation of a comprehensive set of guidelines for the revitalization of the area under reference.

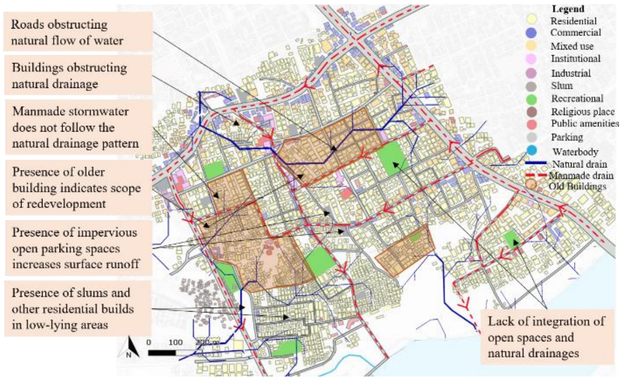

Figure 18: Summary of the findings

5) Development strategy and optimization guidelines

The optimization guidelines follow the overall analysis of the Area of Interest, which can be integrated into the development plan of the city for effective statutory implementation.

- The older buildings of the block which are expected to undergo redevelopment, should be developed following a cluster development scheme that considers the natural drainage and terrain patterns. All natural drains should be maintained and continued using bioswales, and cross drainages wherever roads are crossing. Mandatory regulations should be established regarding the cluster development scheme for the inclusion of open spaces, green roofs, permeable paving surfaces, percolation pits, and rainwater harvesting systems in all the new buildings while reducing the ground coverage of the buildings.
- All the green open spaces should be integrated with the natural drainage and stormwater flows, using swales and

additional underground drainage pipes, to facilitate water detention and absorption before reaching the outfalls. Besides this, all open green spaces the equipped with recharge pits and percolation pits to facilitate better groundwater recharge.

- All open parking spaces should be retrofitted using permeable paving blocks and recharge pits to allow for groundwater recharge.
- Roadside drainages, if not available, should be installed with bioswales with cross drainages as required,
- Any newer development should be incorporated as per the topography map and natural drainage pattern of the site and should incorporate detention ponds and natural drainage such as bioswales.
- Any additional infrastructure projects should be designed in a way that does not obstruct natural drainage or detention. This integration should be an integral part of the infrastructure planning process.

4. Conclusion

GIS proves to be a valuable tool for conducting an in-depth analysis of a developed city. It enables the examination of existing conditions without an extensive on-ground survey and, facilitates the development of context-specific, low-tech solutions.

Municipal corporations and Municipalities of cities which are characterized by heavy flooding and water retention can utilize GIS as a decision support tool for strategy formulation for low-tech and immediate solutions as well as mid and long-term strategies. The strategies can further be developed into specific projects with detailed project reports which can be executed through EPC or PPP modes.

While the present research is oriented towards the retrofitting of the existing city fabric, it also invariably points out the necessity of the incorporation of effective drainage systems with strategies that allow water for retention and absorption. GIS analysis can act as an effective decision support tool in identifying water catchment areas, and natural drainage patterns within the city, enabling the incorporation of sustainable urban drainage systems with rain gardens, recharge pits, and bioswales along the stream order of the watersheds, which can effectively reduce the occurrence of floods.

References

[1] Amdavad Municipal Corporation. (2023, 05 14). *Ahmedabad city.gov*. Retrieved May 2023, from ahmedabadcity.gov: https://ahmedabadcity.gov.in/portal/jsp/Static_pages/introduction_of_amdavad.jsp

[2] American Society of Landscape Architects. (2016, 01 25). *2016 Awards*. Retrieved 05 15, 2023, from ASLA Professional Awards: https://www.asla.org/2016awards/171784.html

[3] Charlesworth, S. (2010). A review of the adaptation and mitigation of global climate change using sustainable drainage in cities. *Journal of Water and Climate Change*, 165-180. doi:DOI: 10.2166/wcc.2010.035

[4] Cristiano , P., & Tassi, R. (2012). Sustainable Urban Drainage Systems. In P. M. Javaid (Ed.). InTech. Retrieved May 08, 2023, from http://www.intechopen.com/books/drainage-systems/sustainable-drainage-systems

[5] IPCC. (2023). *IPCC sixth assessment report (AR6) Climate Change 2023*. IPCC. Retrieved May 08, 2023, from https://www.ipcc.ch/site/assets/uploads/2023/03/Doc5_Adopted_AR6_SYR_Longer_Report.pdf

[6] Muthanna, T. M., Sivertsen, E., Kliewer, D., & Lensa, J. (2018). Coupling Field Observations and Geographical Information System (GIS)-Based Analysis for Improved Sustainable Urban Drainage Systems (SUDS) Performance. *Sustainability, 10*(12). doi:https://doi.org/10.3390/su10124683

[7] The New Indian Express. (2022, 07 12). *New Indian Express*. Retrieved from https://www.newindianexpress.com/nation/2022/jul/12/flood-like-situation-in-ahmedabad-after-heavy-rainfall-2475703.html

[8] The times of India. (2018, June 27). *The Times of India*. Retrieved from Times of India: https://timesofindia.indiatimes.com/city/ahmedabad/west-zone-is-flood-prone-study/articleshow/64754393.cms

[9] Times of India. (2022, 07 12). *Times of India*. Retrieved from Times of India: https://timesofindia.indiatimes.com/city/ahmedabad/only-a-trickle-spent-on-stormwater-drains/articleshow/92815991.cms