PLANNING STORMWATER INFRASTRUCTURE FOR MUMBAI (1136)

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Abstract. The study focuses on investigating of stress faced by the stormwater infrastructure in Mumbai, a megacity prone to urban floods and waterlogging. The main objective is to assess the effectiveness of the existing urban drainage systems, examine the various stress factors that contribute to their inefficiency, identify international best practices, and propose urban planning solutions to mitigate flood impacts. The study emphasizes the crucial role of infrastructure, especially in reducing the city's vulnerability. It highlights the challenges encountered by Mumbai, including rapid urbanization, haphazard development, and the dense population, which intensifies the flood risk. The research incorporates relevant theories, models, and cases to formulate comprehensive recommendations. Ultimately, the study aims to contribute to the sustainable development goals and enhance the overall well-being of Mumbai's residents.

Keywords: Stormwater infrastructure, Extreme rainfall events, High tides, Urban floods, Drainage system.

1. Introduction

Stormwater infrastructure plays a critical role in managing rainwater flow and preventing flooding in urban areas. It encompasses various systems such as storm drains, detention ponds, and green infrastructure. Proper management of stormwater infrastructure is essential for maintaining functionality, reducing flooding risks, and safeguarding water quality. However, waterlogging issues in urban areas stem from deforestation, inadequate watershed maintenance, and the construction of infrastructure that hampers natural drainage. Rapid urbanization and high population density further strain infrastructure, leading to inadequate drainage and choking. To address these challenges and ensure effective stormwater management, proper maintenance and planning are necessary. Coastal cities in India, in particular, face vulnerability to floods, emphasizing the importance of proactive prevention and mitigation measures for building resilience. Recent floods in several Indian cities have caused significant damage and economic impact. A study published in November 2019 by The New York Times predicts that rising sea levels could submerge approximately 40 square kilometers of land in Mumbai, India's largest city and financial capital, including critical infrastructure and densely populated areas, within the next three decades. This prediction highlights the urgent need for the Indian government and local authorities to address climate change and protect residents and assets from the detrimental effects of rising seas.

2. Literature Review

China has witnessed a significant increase in urbanization, with the urban population growing from 170 million in 1978 to over 850 million in 2020. Municipalities like Beijing, Tianjin, Shanghai, and Chongqing are key drivers of regional development due to their dense populations and high demand for urban infrastructure. The resilience of their infrastructure directly impacts surrounding areas. To assess urban infrastructure resilience, the Pressure-State-Response (PSR) framework was used, analyzing the dynamic characteristics of infrastructure in these municipalities from 2002 to 2018. The study found that factors like highway length and drainage network density significantly influenced infrastructure resilience. Measures such as enhancing public transport facilities and improving drainage capacity were identified as essential for a better urban environment. Additionally, the G-Cans project in Kasukabe, Japan, has effectively reduced water damage during heavy rainfall, while the Netherlands and Chennai, India, have implemented measures like floodgates, drainage systems, and stormwater drains to combat flooding.

3. Methodology

3.1 Study area

Greater Mumbai, India's most populous city and a major financial hub, faces challenges due to limited land availability and high population density. The sewerage system collects 63% of the generated 2,680 MLD, as reported in the City Development Plan by MCGM. The MTPD collected for solid waste and construction, demolition, and silt has also increased over the years. Effective management of these systems is crucial for sustainable development in the city. The stormwater drainage system is impacted by unauthorized dumping, which reduces the capacity of nullahs/drains to carry stormwater runoff, leading to flooding in certain areas of the catchment, caused by slum dwellers, hawkers, construction, and demolition.

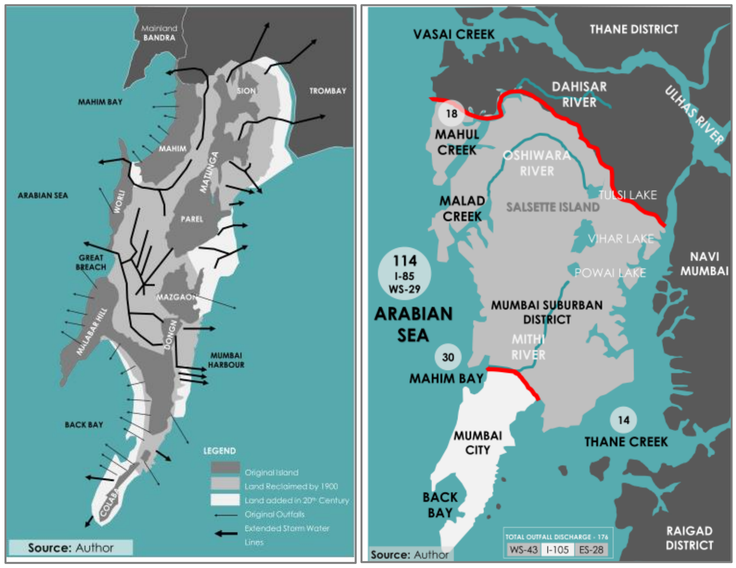

Figure 1. Showing the evolution of reclaimed land and the water bodies and outfalls in MCGM Boundary

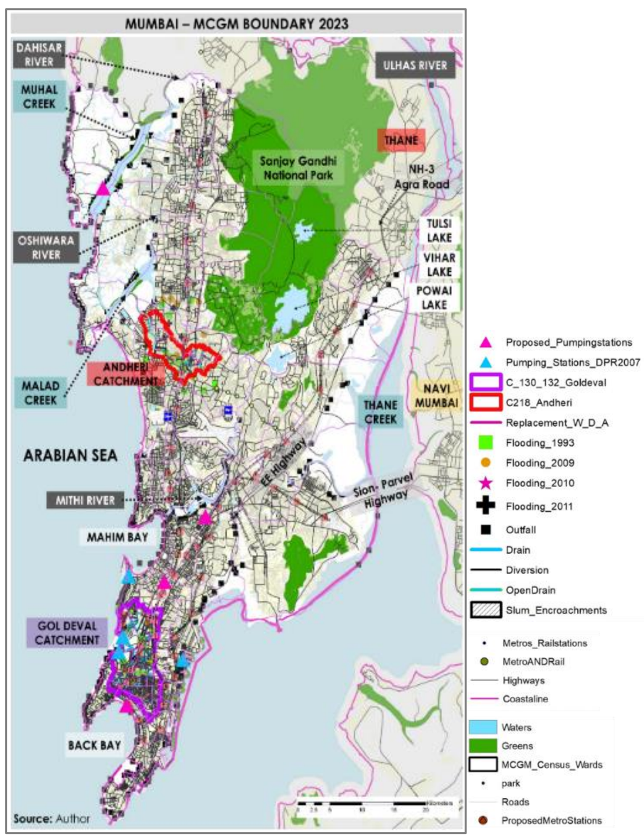

Figure 52 Showing Overview Mumbai City - MCGMC Boundary

The drainage network length-to-road length ratios in Mumbai's different regions reflect their development priorities. The western suburbs prioritize drainage infrastructure, with a ratio of 3:1, while the island city shows balanced development with a ratio of 1:1. In contrast, the eastern suburbs focus more on road development, resulting in a ratio of 1:0 for drainage infrastructure. These ratios highlight the varying stages of development and infrastructure priorities in each region.

Table 1. Showing the types of systems in the stormwater Infrastructure

TYPE	TOTAL KM	ISLAND CITY KM	WESTERN SUBURBS KM	EASTERN SUBURBS KM
Major Nallas >1.5 M width	215.07	23.37	101.50	90.20
Minor Nallas < 1.5 M width	156.50	48.00	42.10	66.40
Arch/ Box Drains	174.28	82.35	51.93	40.00
Roadside open drains	1986.98	20.00	1297.50	669.48
Closed pipe or dhapa drains	565.23	443.00	86.03	36.20
No. of water entrances	34972	32657	1706	609

Researchers often use non-probabilistic sampling techniques, such as the snowball method, to collect data from a specific group with common characteristics. This method enables them to reach a diverse group of participants. A household survey is conducted with a sample size of 90 or 100 individuals, depending on the research objectives. The participants are selected based on their willingness to participate and relevance to the research topic. The selection criteria for catchment areas are determined through consultations with stakeholders and perception surveys at the household level in critical areas. After careful consideration, Andheri Subway in K Ward and Goldeval Temple in C Ward were selected for further action.

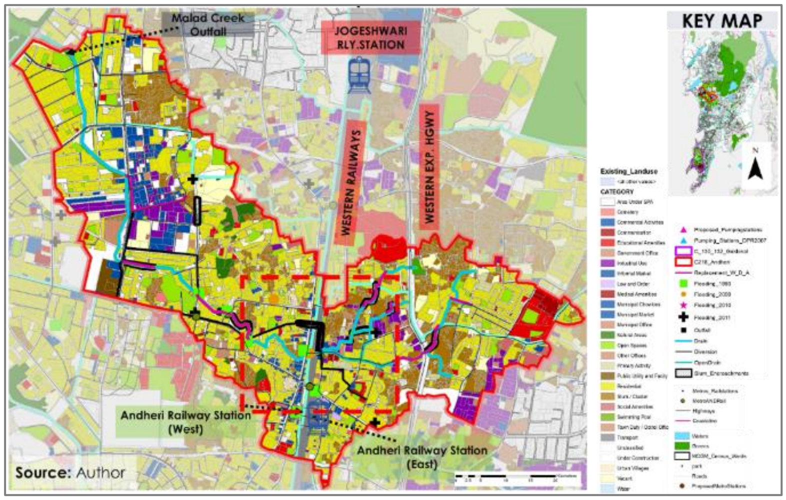

Figure 3. Showing Land use Map of Catchment 218

Catchment 218, located in Andheri (K) Ward, includes Andheri East (K/E) and Andheri West (K/W). The main waterlogging concern is the Andheri subway, a crucial transportation link between the two areas. Residential land comprises the majority of the catchment, with 61 out of 173 hectares allocated for residential use. Slum clusters cover 26 hectares, while the remaining land includes vacant plots, commercial areas, industrial zones, open spaces, and under-construction sites. Encroachment issues affect the open drain (nallah) in the area due to the presence of slums. Historical flooding data from 2009 to 2011 has been collected, highlighting a significant rainfall spike on 27 July 2005, with 944.20 mm recorded in a 24-hour period.

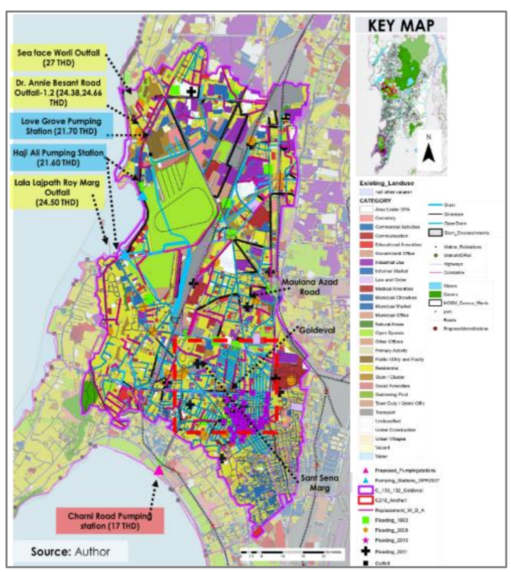

Figure 53. Showing Land use Map of Catchment 130, 132, City Nallah

Catchment 130 is the largest in Mumbai, spanning multiple wards from Fort to Parel and Byculla to the Western Coast. It includes low-lying areas near Maratha Mandir Road, Sankla Lane, Mahadev Palav Road, and BDD Chawls that are prone to waterlogging. The catchment has various outfalls, with the main one positioned below the lowest low tide level. Catchment 132, which includes Cumballa Hill, has been merged with Catchment 130. The Gol Deval Temple catchment covers an area of 1,370 Ha with ground levels ranging from 74.93 to 26.39 m THD. It consists of underground drains and open nallah, with a length of 168,280 m and dimensions ranging from 0.230 m to 30 m. Waterlogging primarily occurs during heavy rainfall between June and September, especially in July. The catchment is predominantly residential, with significant commercial and industrial areas. The Arabian Sea acts as the water-receiving body, and various outfalls drain into it, including the proposed Charni Road Pumping Station.

3.2 Data

3.2.1 Autocorrelation

BRIMSTOWAD-II Report, MCGM Engineering Hub, and climate data from the Regional Meteorological Centre Mumbai, IMD.

3.2.2 Contour, slope, basin and flow accumulation Maps

Cartosat DEM and USGS Earth Explorer (SRTM) as the primary sources.

3.2.3 Land Use and Land Cover LULC

USGS data from 1993, 2003, and 2023, using Landsat-4, Landsat-5, and Landsat-8 satellites, respectively, with a false-color composite created by changing the symbology of bands to 5/4/3, and employing supervised classification for image analysis.

3.2.4 Groundwater Recharge Potential Zones

Digital Elevation Model (DEM) and Geology data were obtained from USGS, while the SOIL-Fos Soil was used for assessing the matrix consistency ratio, which was set at 0.1 for large matrix constraints exceeding 5X5.

3.2.5 Pressure State Response Model

District Census Handbook of Maharashtra, Regional Plan of Mumbai, MMRDA, Brihanmumbai Municipal Corporation (BMC)/Municipal Corporation of Greater Mumbai (MCGM), and the Draft Development Plan 2034/MCGM Engineering Hub.

4. Results

4.1 Autocorrelation

Table 2. Showing the Autocorrelation - Date of Occurrence of Events, their Rainfall and Hightide data

Date of Occurrence	24-hr Rainfall in mm	Tide Height (mm)	Tidal Coefficient	Lunar Calender	Lag	AutoCorrelation-Rainfall	AutoCorrelation-Tides
05 July 1974	575.6			FM	0	1.00	1.00
30 July 1975	417.2			NM	1	-0.09	-0.35
31 July 1984	544.3			FM	2	0.17	-0.13
16 June 1990	421.2			FM	3	0.16	0.23
10 June 1991	477.6			NM	4	-0.07	-0.43
23 August 1997	346.2			FM	5	0.14	0.28
17 July 2000	351.5			FM	6	-0.08	-0.08
27 July 2005	944.2	4.7		FM	7	0.12	-0.17
16 July 2009	179.0			waning gibbous moon phase	8	-0.11	0.15
26 July 2011	375.0	3.5	54.0	FM	9	-0.09	
1 September 2011	283.0	4.7	88.0	waxing crescent moon phase	10	-0.11	
15 July 2014	200.0	4.5	96.0	FM	11	-0.24	
19 June 2015	283.0	4.5	75	waxing crescent moon phase	12	-0.07	
02 August 2015	265.0	4.9	104	FM	13	-0.08	
29 August 2017	315.0	3.3	46.0	waxing crescent moon phase	14	-0.08	
02 July 2019	375.0	4.5	89.0	waxing crescent moon phase	15	-0.05	
05 August 2020	331.8	4.5	81.0	waning gibbous moon phase	16	-0.03	
18 July 2021	250.0	3.7	60.0	waning gibbous moon phase	17	-0.05	

The table presents rainfall data along with the corresponding dates and tidal height overlapping with the lunar calendar. By applying the autocorrelation method, the graph demonstrates a stationary autocorrelation, indicating a dependence between the variables.

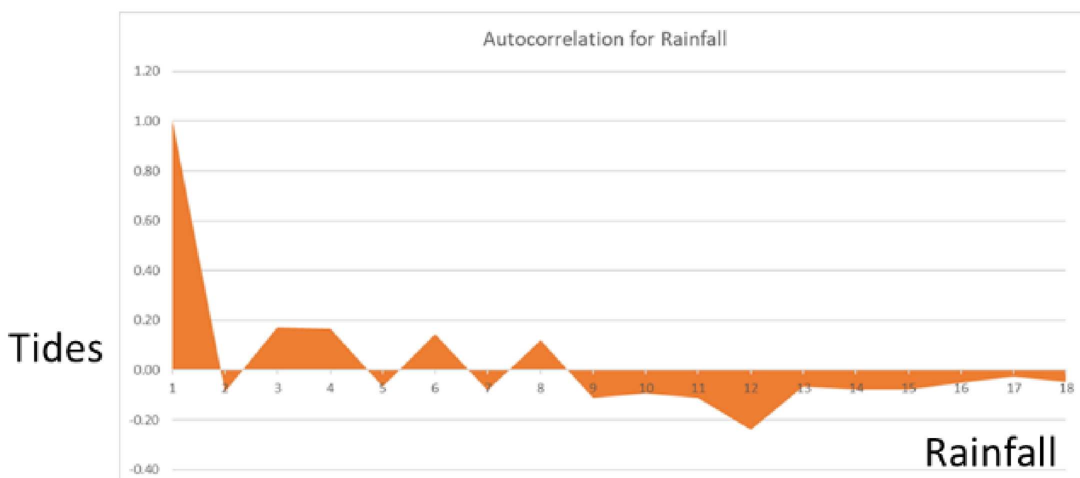

Figure 5. Showing Autocorrelation- Date of Occurrence of Events Rainfall Intensity

By applying the autocorrelation method, the graph demonstrates a stationary autocorrelation, indicating a dependence between the variables.

4.2 Physiography

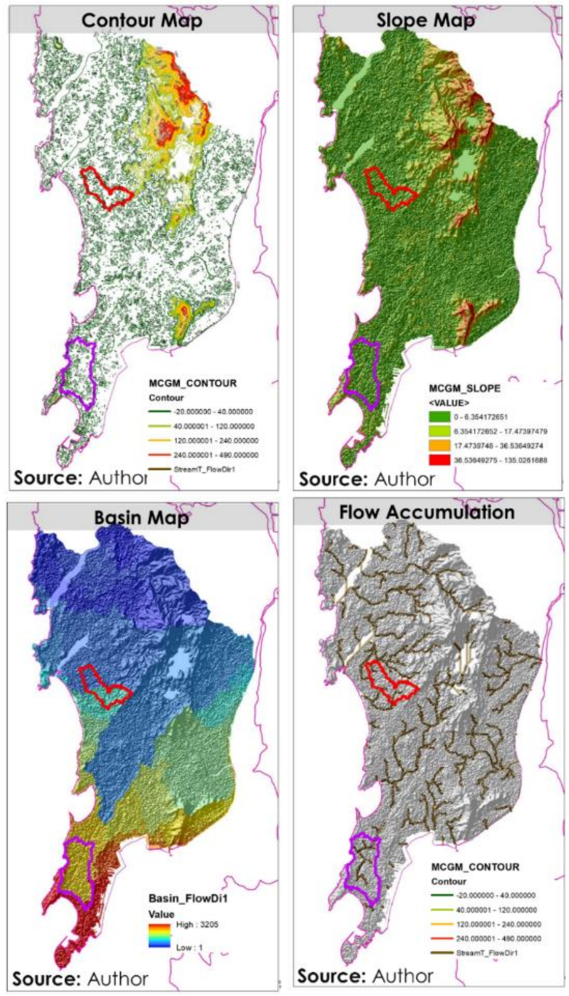

Figure 6. Showing Catchment boundary 218, Mogra Nallah and 130,132, City Nallah

The topography of catchment areas is determined by contour and slope maps, with a contour interval of 20 meters ranging from -20 to 490 meters and a slope range of 0 to 135 meters. The flow direction of water is determined by basin maps, with catchments 218 lying in the low to medium-range basins and catchments 130 and 132 in the medium to high range. Flow accumulation analysis is used to identify the topographic ridges where water accumulates.

4.3 Land use and land cover maps for the years 1993, 2003, 2013, and 2023

The analysis of land use and land cover indicates a consistent increase in built-up area, corresponding with population growth due to migration, while water bodies have steadily decreased due to slum encroachments, leading to disrupted water flow and increased flooding.

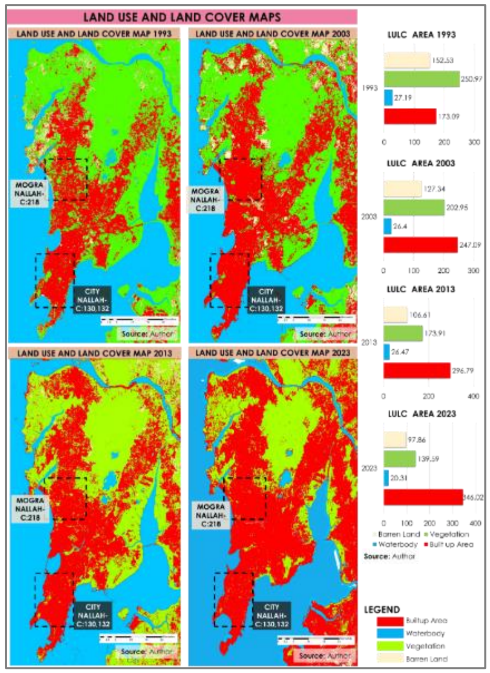

Figure 7. Showing Land Use and Land Cover Maps- 1993, 2003, 2013, 2023

Additionally, vegetation has significantly declined, reducing groundwater recharge capacity and disrupting the city's ecological balance, while barren land has experienced a gradual decrease over time.

4.4 Groundwater Recharge Potential Zones

The Weighted Overlay Method is employed to determine groundwater potential zones, while the Analytic Hierarchy Process (AHP) is used to identify and map these zones using remote sensing techniques. Rank-assigned scale values are derived from field surveys, stakeholder consultations, expert opinions, and existing reviews.

Table 3. Showing Weighted Overly Method for Groundwater Potential Zones

	Matrix	Rainfall	Geology	Slope	Drainage density	LULC	Lineament density	Soil	Normalized Values
		1	2	3	4	5	6	7	
1	Rainfall	1	3	3	5	5	5	7	38%
2	Geology	1/3	1	3	3	5	5	5	25%
3	Slope	1/3	1/3	1	1	3	3	5	13%
4	Drainage density	1/5	1/3	1	1	2	3	3	9%
5	LULC	1/5	1/5	1/3	1	1	1	3	6%
6	Lineament density	1/5	1/5	1/3	1/2	1	1	1	5%
7	Soil	1/7	1/5	1/5	1/3	1/3	1	1	4%

A Matrix Consistency Ratio of 0.1 is assessed for large matrix constraints (> 5X5) to ensure accuracy. Ultimately, the Weighted Overlay Method is applied to establish the final groundwater potential zones.

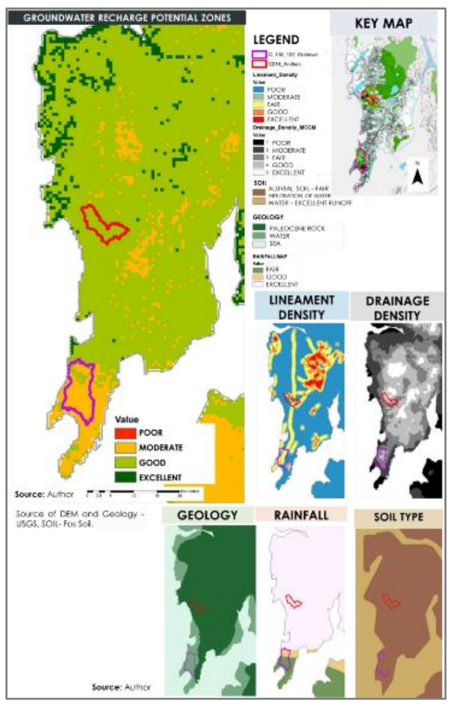

Figure 8. Showing Groundwater Recharge Potential Zones

The survey coordinates are noted and plotted for spatial analysis by Cross tabulation Method. A Survey questionnaire is prepared after careful observation on the site by rekey survey. And the survey area is 500 mts is selected from the point of conflict the Andheri subway 2.5%, 54% of it from Andheri East and 44% from Andheri West.

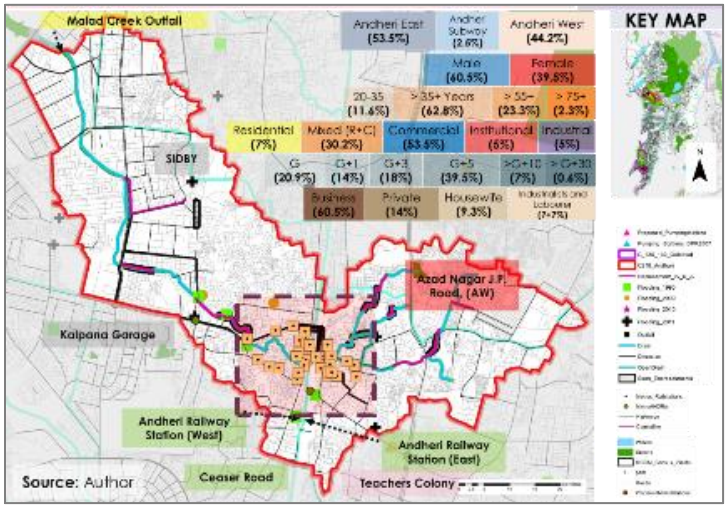

Figure 9. Showing Stormwater Drains Map of Catchment 218 - 43 Surveys

The survey data reveals that 61% of the participants were male, while 39% were female. The age distribution of the participants was as follows: 20-35 years (11.6%), >35 years (62.8%), >55 years (23.3%), and >75 years (2.3%). The survey also considered the land use categories, including residential (7%), mixed (residential and commercial) (30.2%), commercial (53.5%), institutional (5%), and industrial (5%). The height of the buildings was categorized as ground floor (20.9%), G+1 (14%), G+3 (18%), G+5 (39.5%), >G+10 (7%), and >G+30 (0.6%). In terms of occupational status, the participants were categorized as business (60.5%), private (14%), housewives (9.3%), and industrialists/laborers (7% each).

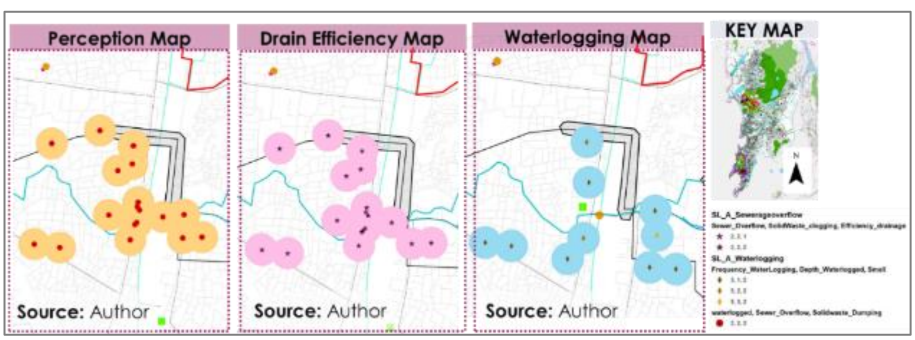

Figure 10.54 Showing Perception, Drainage Efficiency, Waterlogging

The perception Map determines the Current status where Waterlogged Sewerage overflow and Solid waste Dumping are considered. Drain Efficiency determines the Map of Sewerage overflow, Solid waste clogging, and Drain Efficiency (Not at all, Somewhat) critical Points Mapped. Waterlogging Map determines the Frequency of waterlogging, Depth, and Smell are considered and critical Points are Mapped.

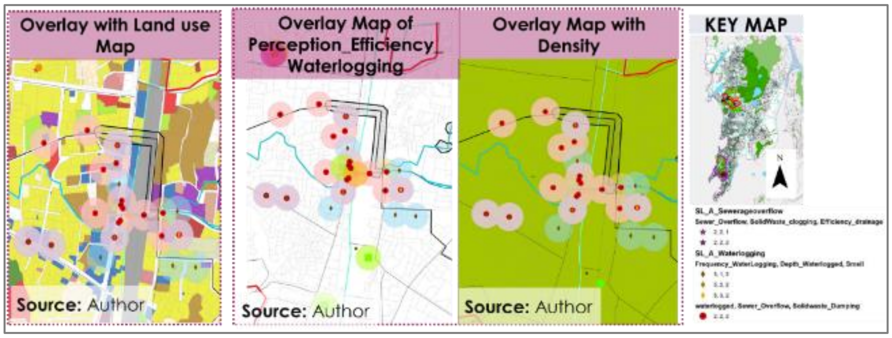

Figure 55. Showing Overlay of Perception, Drainage Efficiency, Waterlogging- Land use and density

Overlay with Land use Map determines Most waterlogging can be seen along the road with the critical points being similar. Overlay Map of Perception, Efficiency, Waterlogging, and Overlay Map with Density determines Overlaying all three considerations and with the previous history of flooding we can determine the terrain is a reason and waterlogging is due to the dumping of solid waste and inefficient drainage and Density ranges from 200-400 pp sq. km.

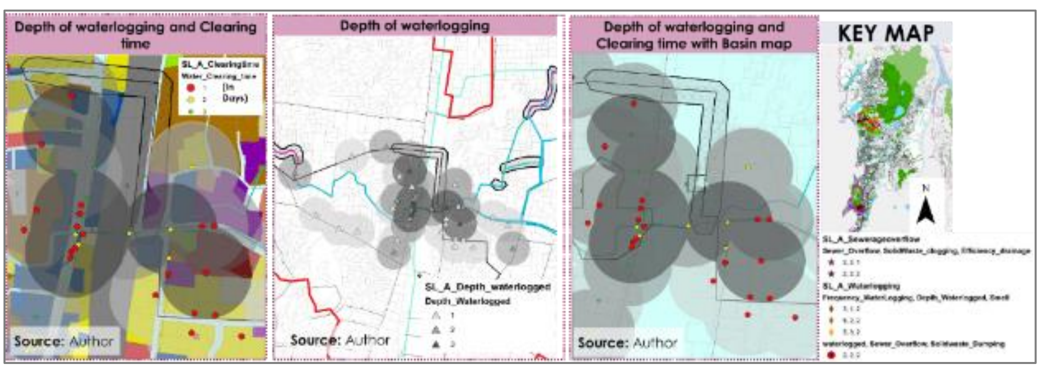

Figure 12.56 Showing Depth of waterlogging and Clearing time - Land use

The depth of waterlogging and clearing time are visualized using color-coded symbols, with red dots and dark grey buffers representing critical points with significant waterlogging and slow clearing. Yellow indicates moderate cleaning time within a day, while green represents areas that clear in less than 12 hours. Commercial and industrial land use, slum encroachments on drains, and an institution are primarily affected. The depth of waterlogging map highlights severe flooding depths exceeding 5 meters. The overlay of waterlogging and clearing time with the basin map shows the constrained terrain. Spatial analysis using the cross-tabulation method is performed based on survey coordinates, and a survey questionnaire is prepared after careful site observation through rekey survey.

Catchment 130 and 132 are major areas of concern for waterlogging, particularly during the heavy rainfall months of June to September, with July being crucial. The Gol Deval Temple is a key location that connects traffic from South Bombay to North Bombay. The survey area, selected within a 500-meter radius of the conflict point, includes various locations such as Gol Deval Temple (27.7%), MS Ali Road (21.3%), Zohar Chowk (17%), and Ducan Road (23.4%). The survey participants consist of 40.4% males and 59.6% females, distributed across different age groups. Land use categories considered in the survey include residential, mixed (residential and commercial), commercial, institutional, and industrial.

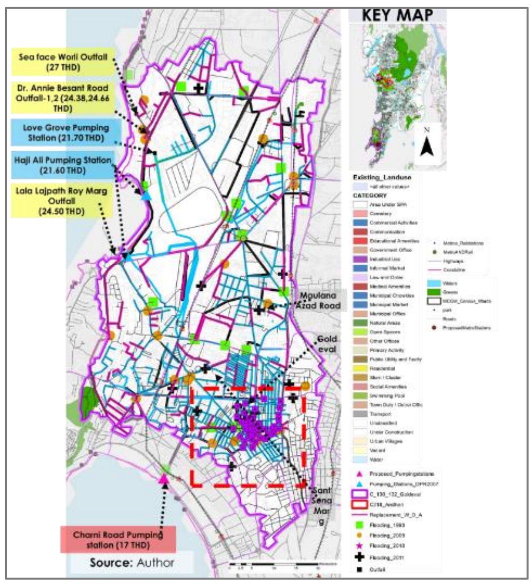

Figure 5713. Showing Stormwater Drainage Map of Catchment 130, 132, City Nallah- 47 Surveys

The height of buildings, including street hawkers, is also taken into account, with various categories such as G+1, G+3, G+5, >G+10, and >G+30, determining the depth of potential losses. The occupational status is Business (21.3%), Private (19.1 %), Housewife (29.8 %), Industrialists and Laborers (10.6+10.6 %), and Students (8.5%).

Figure 58. Perception, Drainage Efficiency, Waterlogging

The perception Map is to know the Current status where Waterlogged Sewerage overflow and Solid waste Dumping are considered. Drain Efficiency Map- Sewerage overflow, Solid waste clogging, and Drain Efficiency (Not at all, Somewhat) critical Points Mapped. Waterlogging Map- Frequency of waterlogging, Depth, and Smell are considered and critical Points are Mapped.

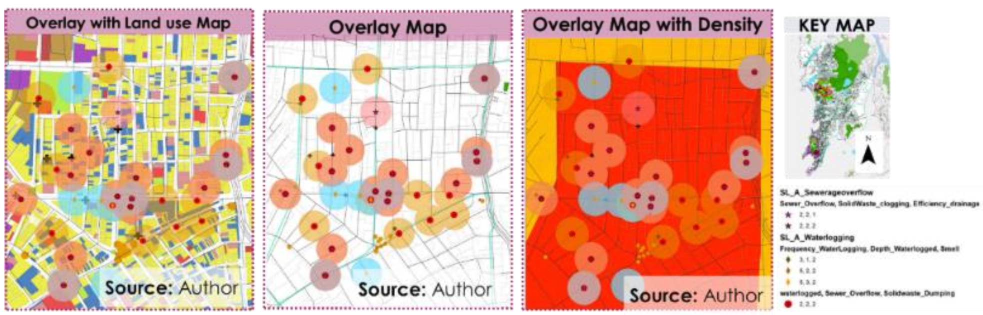

Figure 15. Overlay of Perception, Drainage Efficiency, Waterlogging- Land use and density

Overlaying all three considerations and with the previous history of flooding we can determine reasons for waterlogging is due to the dumping of solid waste and inefficient drainage most Residential Followed by commercial are majorly affected most of the ground floor, Density ranges from 600- 870 pp sq.km which is the most critical is in the city.

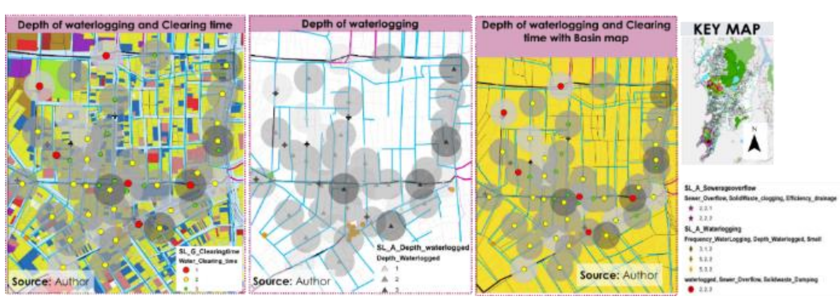

Figure 16. Showing Depth of waterlogging and Clearing time - Landuse and Basin

Depth of waterlogging and Clearing time - Critical points were red dots and dark grey buffers. Where major depth of waterlogging and less clearing. Yellow is a moderate cleaning time of less than a day and Green is those which takes less than 12 hours to clear. Commercial, and industrial land use, and an Institution are majorly affected. Depth of waterlogging - The dark greys show a severe flooding depth of more than 5mts of height. Depth of waterlogging and Clearing time with Basin map- On overlaying with the basin and contour shows the terrain being constrained.

4.5 PSR Model- Pressure, State and Response Model

Comprehensive Evaluation Index System (Urban Infrastructure Resilience Evaluation)

The Three-stage Resilience Level Assessment involves evaluating the pressure, state, and response stages. A higher score on the stress index (Upressure) indicates a greater risk to the infrastructure, while a higher score on the state index (Ustate) indicates a healthier state of the infrastructure. Similarly, a higher score on the response index (Uresponse) indicates a more timely and effective response to any crises or risks, which contributes to the overall health of the infrastructure system.

Table 4. Showing Urban Infrastructure Resilience Evaluation - Functional Parameters

Function Layer	Criterion Layer		Factor Layer	Description	Properties	A_Values	G_Values	A_Hij	G_Hij	A_Wj	G_Wj	A_U_pressure _state _Response	G_U_pressure _state _Response
Pressure	Natural Pressure		Torrential rain days	Number of days of rainfall above 50mm for 24 h	Negative	6.23	6.23	0.09	6.23	0.08	0.08	0.48	0.48
			Extremely hot days	Days with maximum temperature above 32 °C	Negative	1.89	1.89	0.04	1.89	0.06	0.06	0.11	0.11
			Magnitude of near-source earthquakes for city	Risk of earthquake disaster	Negative	0.86	0.86	0.02	0.86	0.06	0.06	0.05	0.05
			Days above strong gale	Days with wind speed between 3.7 m/s to 11 m/s	Negative	1.52	1.52	0.04	1.52	0.06	0.06	0.09	0.09
			High Tides	Average tide height 2.7 m to 3.2 m	Negative	6.66	6.12	0.09	6.66	0.08	0.08	0.53	0.54
	Human Pressure	Catchment Data	Population Density	The degree of population aggregation in limited land	Negative	5.09	5.09	0.08	3.54	0.07	0.06	0.36	0.23
			Urbanization rate	The degree of population aggregation to cities	Negative	3.25	3.25	0.06	3.95	0.06	0.07	0.21	0.26
		Land Use	Change in land use from agriculture to urban	Degradation of agricutureland and More concretization	Negative	1.52	1.52	0.04	1.52	0.06	0.06	0.09	0.09
			Increase in density of housing	Housing as a major factor of development	Negative	5.31	4.31	0.08	5.31	0.07	0.07	0.39	0.39
		Hydrogeology	Low transmissivity and storage of aquifer	The surface drainage systems	Negative	2.48	2.48	0.05	3.48	0.06	0.06	0.15	0.23
		Strom Water Drains Coverage	Percentage area Covered	Standard of Infrastructure	Negative	**2.54**	**2.46**	**0.05**	**2.46**	**0.06**	**0.06**	**0.16**	**0.15**
			Drain length (Open and Closed Pipe Lines Drains)		Negative	**1.32**	**1.26**	**0.03**	**1.26**	**0.06**	**0.06**	**0.08**	**0.07**
			Network		Negative	**1.52**	**1.52**	**0.04**	**1.52**	**0.06**	**0.06**	**0.09**	**0.09**
		Water Logging	Conflict Points Locations	Effectiveness of Infrastructure	Negative	**3.85**	**4.78**	**0.07**	**4.78**	**0.07**	**0.07**	**0.25**	**0.34**
			Number of Flood Prone Points (Ponding Points)		Negative	**2.66**	**3.87**	**0.05**	**3.87**	**0.06**	**0.07**	**0.16**	**0.26**
		Strom Water Drains Discharge	Outlets of Treated Waste water	Rate of Recycling and reuse of storm water	Negative	**1.87**	**1.87**	**0.04**	**1.87**	**0.06**	**0.06**	**0.11**	**0.11**
			Quality of Waste water		Negative	**3.55**	**1.75**	**0.06**	**1.75**	**0.06**	**0.06**	**0.23**	**0.10**
			Decrease in pipeline leakage	Risk of polluting ground water	Negative	**1.22**	**2.56**	**0.03**	**2.56**	**0.06**	**0.06**	**0.07**	**0.16**
State	Social Benefit		Per capita area of paved roads	Quality of life of urban residents	Positive	2.85	2.85	0.11	2.85	0.14	0.14	0.41	0.41
			Water coverage rate	Living standard of urban residents	Positive	1.5	1.5	0.08	2.1	0.12	0.13	0.18	0.27
			Gas coverage rate		Positive	0.88	0.88	0.05	0.99	0.12	0.12	0.10	0.12
	Economical Benefits		Losses by Flooding	Reduce disaster(accident) losses	Negative	2.93	2.93	0.12	2.87	0.15	0.14	0.43	0.41
			Losses by Death		Negative	1.22	1.22	0.07	1.22	0.12	0.12	0.15	0.15
			Density of drainpipe density in the built-up area	Long-term effectiveness of Infrastructure	Positive	4.03	4.03	0.13	4.03	0.17	0.17	0.70	0.70
			Length of highway		Positive	6.15	6.15	0.16	6.15	0.30	0.29	1.82	1.81
	Resource Environmental Benefit		Urban green space per capita	Resource possession of urban residents	Positive	4.22	4.22	0.14	1.35	0.18	0.12	0.76	0.16
			Water resources per capita		Positive	0.78	0.78	0.05	0.78	0.12	0.12	0.09	0.09
			Power consumption per capita	Resource consumption of urban residents	Negative	1.25	1.25	0.07	1.54	0.12	0.12	0.15	0.19
			Gas consumption per capita		Negative	1.5	1.5	0.08	1.5	0.12	0.12	0.18	0.18
Response	Recovery and adaptability		Sewage treatment rate	Ability to respond to the pressure of resources environment	Positive	3.25	3.25	0.15	3.25	0.23	0.23	0.73	0.73
			C&D Waste treatment rate		Positive	3.15	3.15	0.15	4.45	0.22	0.32	0.69	1.44
			Urban infrastructure maintenance and construction funds	Post-disaster emergency rescue	Positive	3.22	3.22	0.15	3.22	0.22	0.22	0.72	0.72
			Hospital beds per 10,000 population		Positive	2.87	2.87	0.15	2.87	0.21	0.21	0.59	0.59
	Learning ability		Mobile phone coverage rate	Ability of urban residents to acquire and learn information	Positive	1.23	1.23	0.09	1.23	0.16	0.16	0.19	0.19
			Internet coverage rate		Positive	1.46	1.46	0.10	1.46	0.16	0.16	0.24	0.24
			Research and Development (R&D)	Government investment in innovation and learning ability	Positive	4.17	4.17	0.17	3.11	0.29	0.22	1.22	0.68

A_Value / G_Value- Normalized Value (A_- Andheri/ G_- Gol Deval)

i-Value of the Area(Andheri/Gol Deval)/ j-Indicators

A_Hij/ G_Hij – Enthrophy of Indicators (A_- Andheri/ G_- Gol Deval)

A_Wj- Weight of Evaluation Indicators (A_- Andheri/ G_- Gol Deval)

U_Pressure, U_state, U_response -

R*- Urban Infrastructure Resilience levels (R*)

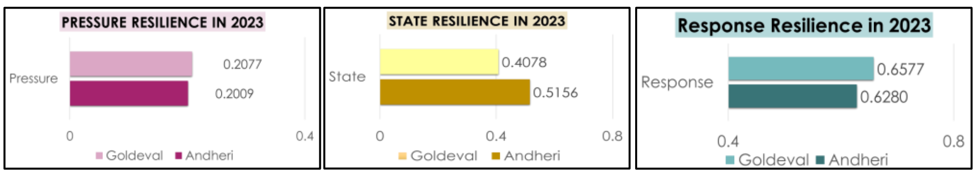

Figure 17. Showing Pressure, State and Response Resilience in 2023

The pressure is 0.2 for both areas where the stress is prevalent and in serious Pressure which is near to '0'. State Resilience in 2023 The state is 0.4 and 0.5 for Gol Deval and Andheri catchments respectively are Fragile. Response Resilience in 2023 The response is 0.65, 0.62 for Gol Deval and Andheri catchments respectively moderate response as initiatives are taken in BRIMSTOWAD Master Plan II.

Table 5. Urban Infrastructure Resilience levels - (PSR Model)

Category	[0, 0.3]	[0.3, 0.5]	[0.5, 0.7]	[0.7, 0.8]	[0.8, 1]
U_pressure	Serious	High	Moderate	Slight	Minor
U_state	Damaged	Fragile	Moderately healthy	Healthy	Very healthy
U_response	No response	Slight response	Moderate response	Somewhat positive	Strong response
R*	No resilience	low resilience	Medium resilience	Higher resilience	Highest resilience

The pressure generated is due to Natural which is rainfall 6.23 and High tides 6.6 followed by population density and Density of residential area. The state is influenced by social benefits and Economical benefits, the highway length, and the density of drainpipe density in the built-up area. And urban green spaces from environmental benefits. The response is by the recoverability and adaptability which are the treatment of sewerage deposition of C&D waste, and Hospitals available in case of emergency with 10,000-bed occupancy. Showing the importance of R&D.

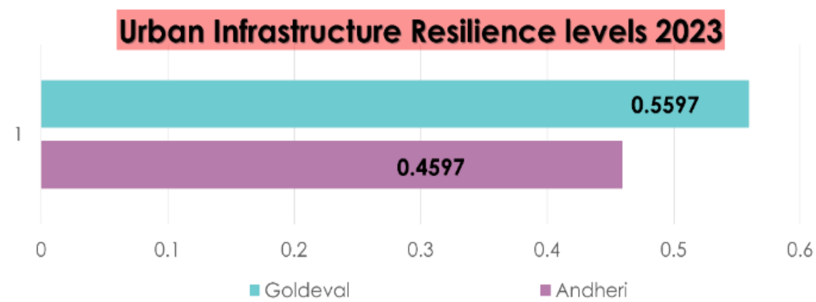

Figure 18. Showing Urban Infrastructure Resilience Levels 2023

Urban infrastructure Resilience levels of 0.55 and 0.45 for the Goldeval and Andheri catchments respectively Medium and Low resilience.

5. Discussion

The Mogra Nallah Catchment in Andheri Subway has the potential for an underground water reservoir project. Sea dike barriers can be planned to protect against flooding and high tides and rainfall situation. Waterbody rejuvenation and urban green spaces recharge groundwater and reduce water demand. Effective drainage systems manage stormwater runoff. Improved sanitation and waste management reduce waterborne diseases. Comprehensive solid waste and sewerage management plans are needed. These measures promote sustainable water management, protecting the environment and public health.

6. Conclusion

The study highlights challenges faced by Mumbai, including polluted drainage systems, population density, non-overlapping stream flow, inadequate sewerage coverage, waterlogging, pollution, vector-borne diseases, and climate change resilience. Recommendations involve constructing diversion drains and detention ponds, enforcing waste management regulations, improving sewerage treatment plants, and enhancing public health measures. In conclusion, this study provides valuable insights into the stress on stormwater infrastructure in Mumbai and proposes viable urban planning solutions. By implementing the proposed measures and considering policy interventions, Mumbai can enhance its drainage system, mitigate floods and waterlogging, protect critical infrastructure, and achieve sustainable development goals related to health, sanitation, and clean energy.

Acknowledgment. I would like to express my heartfelt gratitude and appreciation to all those who contributed to the successful completion of this research paper. First and foremost, I extend my deepest thanks to my esteemed supervisor for their invaluable guidance and unwavering support throughout the entire research process. I am also indebted to the participants who generously shared their time and insights, enabling me to gather crucial data for analysis. Furthermore, I would like to acknowledge the support and encouragement received from my family and friends, whose unwavering belief in me has been a constant source of motivation. Lastly, I extend my thanks to the academic community for providing a rich environment of learning and inspiration.

References

Beibei Liu 1, C. X. (2022). Effect of Land Use and Drainage System Changes on Urban Flood Spatial Distribution in Handan City: A Case Study. *MDPI*.

Chhabra, A. (2022, July 05). *NDTV*. Retrieved from NDTV: https://www.ndtv.com/india-news/why-does-mumbai-get-clogged-in-the-rain-here-are-5-factors-that-play-a-part-in-mumbai-monsoon-waterlogging-3130560

Dhankhar, V. (2017). "Urban Flooding in India: Lessons Learnt and Roadmap for Future". *Architecture Time Space and People* .

Hari Ilam Vazhuthi N.1, n. A. (2020). Causes and Impacts of Urban Floods in Indian Cities: A Review. *International Journal on Emerging Technologies 11(4): 140-147(2020)*.

Min Chen 1, Y. J. (2022). Measuring Urban Infrastructure Resilience via Pressure-State-Response Framework in Four ChineseMunicipalities. *Applied Sciences*.

Rahman, M. H. (2021). GIS- Based compactness Measurement of urban form. The Caswe of Dhaka, Bangladesh. *Journal of Urban Management*.

Sengupta, S. (2021, March 29). Haphazard and high-density growth can choke Hyderabad: Experts.

Shakti, M. J. (2017). Mumbai: Mo Jal Shakti.

Tripathi, S. (2017). RELATIONSHIP BETWEEN INFRASTRUCTURE AND POPULATION AGGLOMERATION IN URBAN INDIA: AN EMPIRICAL ASSESSMENT. *Asian Development Bank Institute*.