

Research Paper



Urban flooding: a study of Bangalore

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ABSTRACT

Climate change has brought an unprecedented change in meteorological parameters, affecting the urban habitat. Uncontrolled growth, cravings for urban dwellings, and the occupation of areas which were once the sponge for urban floods have caused massive hardships for urban governance and the controlling authorities. The sufferers are the common masses, especially the marginal sections of society, mostly the urban poor. Bangalore, the Silicon Valley of India, is facing a burning problem of urban mismanagement in terms of traffic, urban land use, and water availability. Bangalore is the hub of India's software revolution, which employs youth from across the country. The demand for housing is met by the haphazard construction of residential apartments, often encroaching on water-logged low-lying land. Many lakes visible 40 years ago have vanished from the map and are now in residential and commercial use. The natural channels are all modified and blocked, so the water cannot find its path to drain, thereby choking the city and low-lying areas. This paper explores how Bangalore, once a sustainable city, transformed into a city with multiple urban problems, and why it is still a widely accepted residential preference among the youth equipped with innovative technologies and upcoming start-ups.

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1. INTRODUCTION

Urban flooding is mostly pluvial flooding caused by high-intensity short-duration (HI-SD) rainfall when ground infiltration and storm drainage are not capable of taking away the surface runoff [1]. Urban

densification and inadequate drainage design have been the primary causes of urban flooding [2]. Choked drains are an additional reason for surface runoff not being carried away by storm drains. Increased built-up area and hard paving of surfaces block the passage between rainwater and groundwater, creating a large surface runoff. Global warming has paved the way for increased frequency and intensity of rainfall [3].

2. STUDY AREA

Bangalore (Bengaluru) is the capital of Karnataka state of India and one of the largest cities in Southern India. The population of Bengaluru as per the 2011 Census is 8.4 million in the Municipal Corporation area. The Corporation area is 741 km² with 198 wards [4]. Population density comes to 113 persons per hectare, which is less than that given by the Urban and Regional Development Plan Formulation and Implementation (URDPFI) guidelines (125–175 persons per hectare) [5].

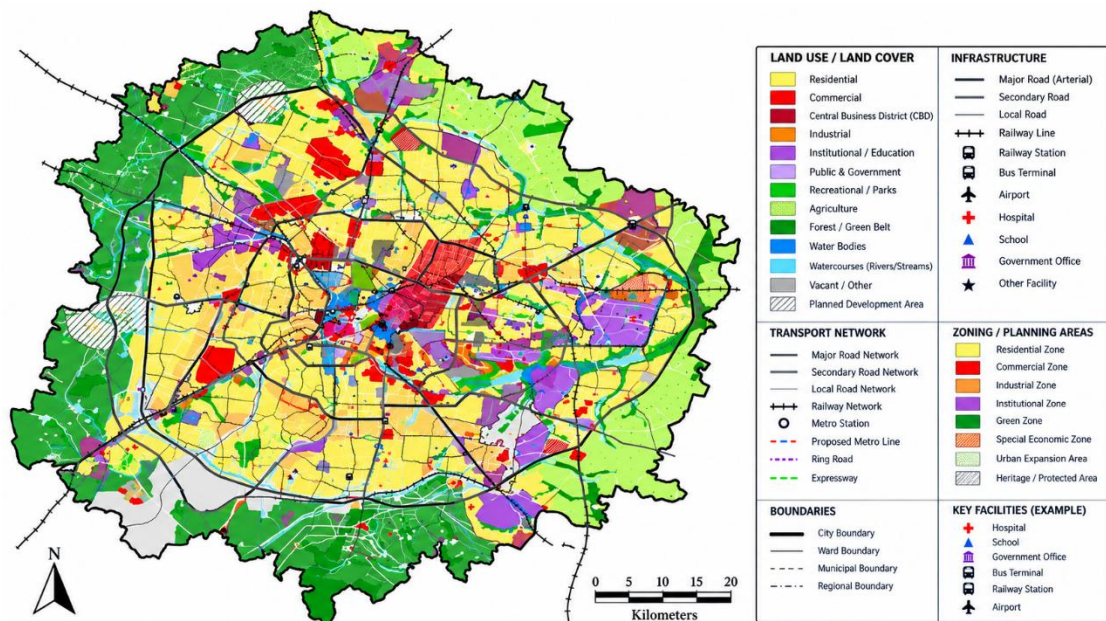


Figure 1. Bangalore Land Use/Land Cover Map

[6] Since 1980, Bangalore has emerged as the preferred destination for the software industry after India opened its market with lighter regulations and integration with the global economy [7]. Bangalore, with pleasant weather and lakes, is at an elevation of 900 m, which gives it a comfortable climate. The National Building Code of India marks Bangalore as a temperate climate zone. In a study conducted among the top 15 cities in India for climatic comfort, Bangalore ranked second after Mumbai [8]. The climate data of Bangalore are given in Table 1 and the monthly rainfall distribution in Figure 2 [9].

Table 1. Climate Data of Bangalore, 1991–2020 (extremes 1901–present)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high (°C)	32.8	35.9	37.3	39.2	38.9	38.1	33.3	33.3	33.3	32.4	33.0	31.1	39.2
Average high (°C)	28.4	30.9	33.4	34.1	33.1	29.7	28.3	28.1	28.6	28.5	27.4	26.9	29.8
Average low (°C)	16.1	17.6	20.2	22.1	21.8	20.6	20.1	20.0	20.0	19.8	18.3	16.4	19.4
Record low (°C)	7.8	9.4	11.1	14.4	16.7	16.7	16.1	14.4	15.0	13.2	9.6	8.9	7.8

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average rainfall (mm)	1.6	7.1	14.7	61.7	128.7	110.3	116.4	162.7	208.3	186.4	64.5	15.4	1,077.8
Average rainy days	0.2	0.3	1.1	4.0	7.5	6.8	8.0	10.2	9.5	9.6	4.2	1.3	62.7
Average relative humidity at 17:30 IST (%)	41	32	29	35	47	62	65	67	64	65	61	53	52
Average dew point (°C)	13	12	13	17	19	19	19	19	19	18	17	15	17
Mean monthly sunshine hours	262.3	247.6	271.4	257.0	241.1	136.8	111.8	114.3	143.6	173.1	190.2	211.7	2,360.9
Average ultraviolet index	10	12	12	12	12	12	12	12	12	12	10	10	12

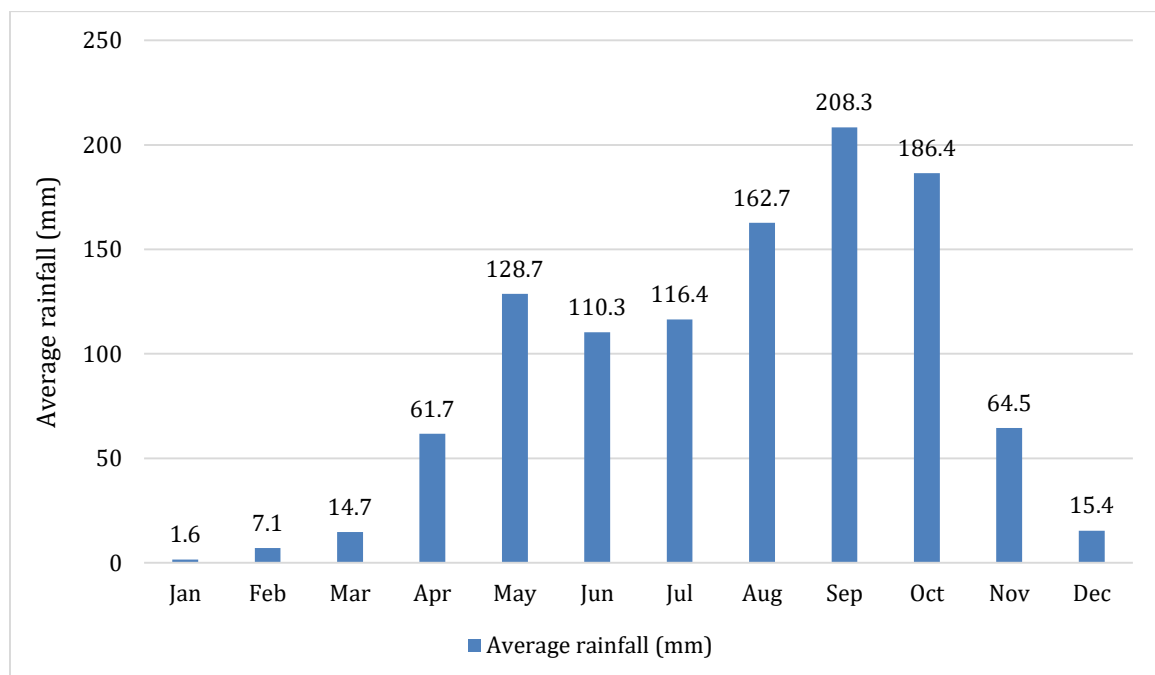


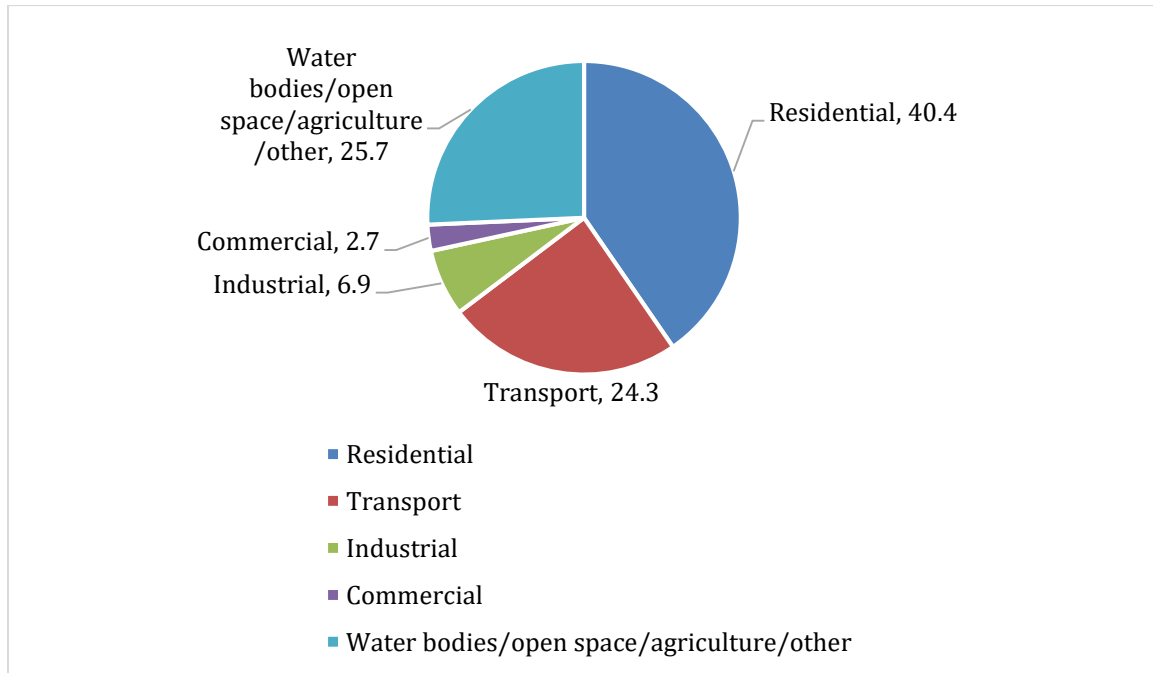
Figure 2. Average Monthly Rainfall of Bangalore

3. LAND USE AND LAKE DYNAMICS

As per the Master Plan 2015 [6], the land use distribution in Bangalore is listed in Table 2 and shown in Figure 3.

Table 2. Land use (LU)/Land Cover (LC) of Bengaluru

Land use/land cover	Percentage (%)
Residential	40.4
Transport	24.3
Industrial	6.9
Commercial	2.7
Water bodies/open space/agriculture land/other	25.7

**Figure 3.** Bangalore Land Use/Land Cover, 2015

3.1 Change in Land Use/Land Cover in Recent Years

Bangalore is known as the city of lakes. In 1962 about 262 wetlands existed, and these reduced to 110 wetlands in 2007. The numbers of active wetlands and lakes in 1973 were 51 and 159 respectively, which decreased to 17 active wetlands and 93 lakes in the year 2007 [10]. There has thus been a significant loss of wetlands and lakes during these periods. Lakes also collect the treated water discharged from sewage treatment plants (STPs); a lake now has two sources of water, namely the runoff from its catchment area during rain and the water discharged from the STP [11]. The land use/land cover changes of Bengaluru during 1973–2020 are shown in Figure 4 [12], and the prominent lakes converted to other uses are listed in Table 3.

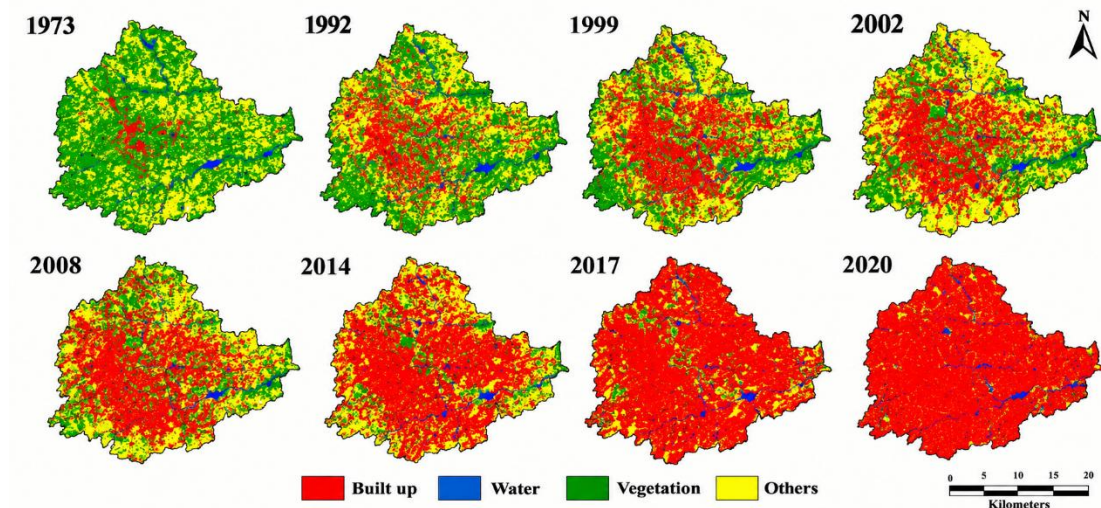


Figure 4. Land use/Land Cover Changes in Bengaluru, 1973–2020

Table 3. Prominent Land Cover Changes: Lakes Converted to Other Uses

Prominent Lake	Converted to
Dharmambudhi lake	Kempegowda bus stand (Majestic Bus Stand) (1960)
Shoolay lake	Football Stadium (1967)
Sampangi lake	Sports Stadium (1946)
Akkithimanahalli lake	Hockey Stadium (1970)
Sunkal lake	KSRTC regional workshops
Koramangala lake	National Dairy Research Institute (1923)
Hennur lake	HBR Layout (2014)
Jakarayana kere	Krishna Flour Mill (1928)
Vijinipura lake	Rajarajeshwari Layout (1960)

Table 4. Larger Lakes under Rejuvenation

Large Lake	Area (HA)
Bellandur lake	364.00
Yelahanka lake	121.68
Kalkere lake	75.68
Doddanekkundi lake	45.29
Hulimavu kere	44.26

Table 5. Smaller Lakes under Rejuvenation

Smaller Lake	Area (Ha)
Devarakere lake	0.28
Kariyobbanahalli kere	0.31
Golaratti lake	0.31
Halagadevarahalli kere	0.44
Srigandadakaval lake	0.45

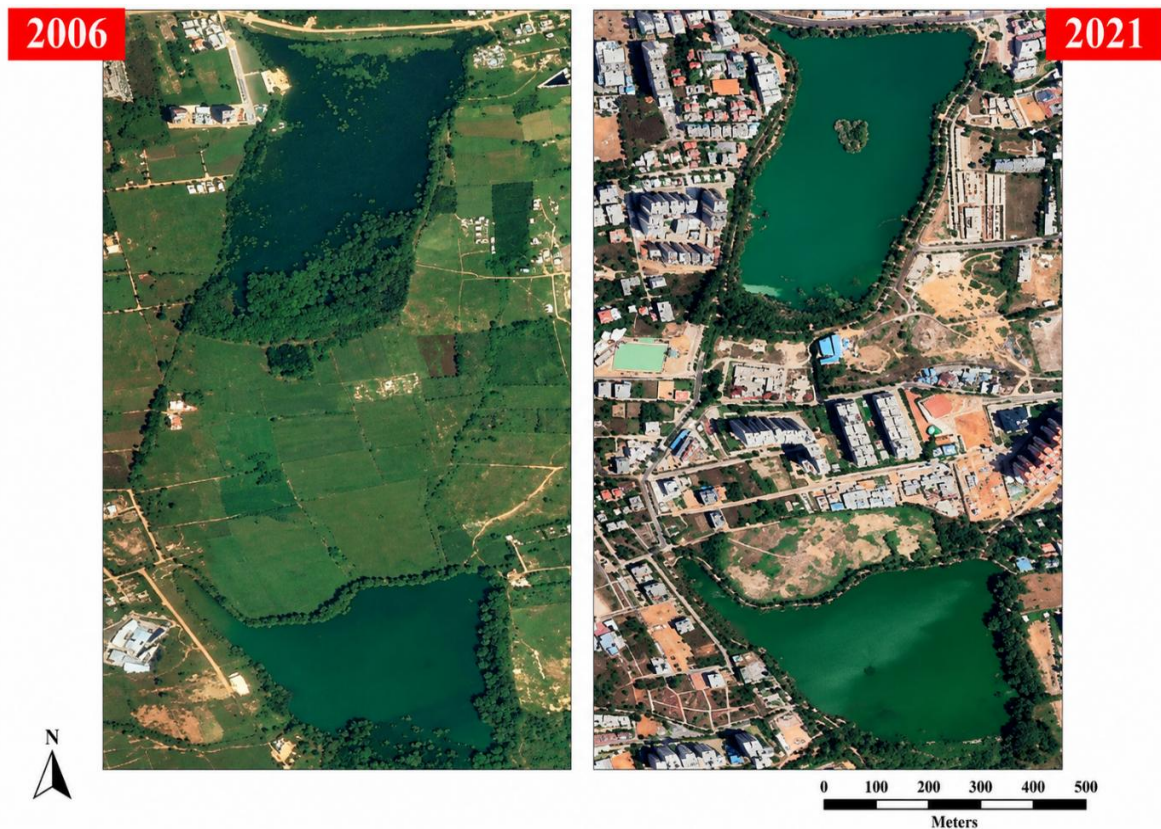


Figure 5. Land use/Land Cover Changes in the Agara–Bellandur Wetlands, 2006 and 2021

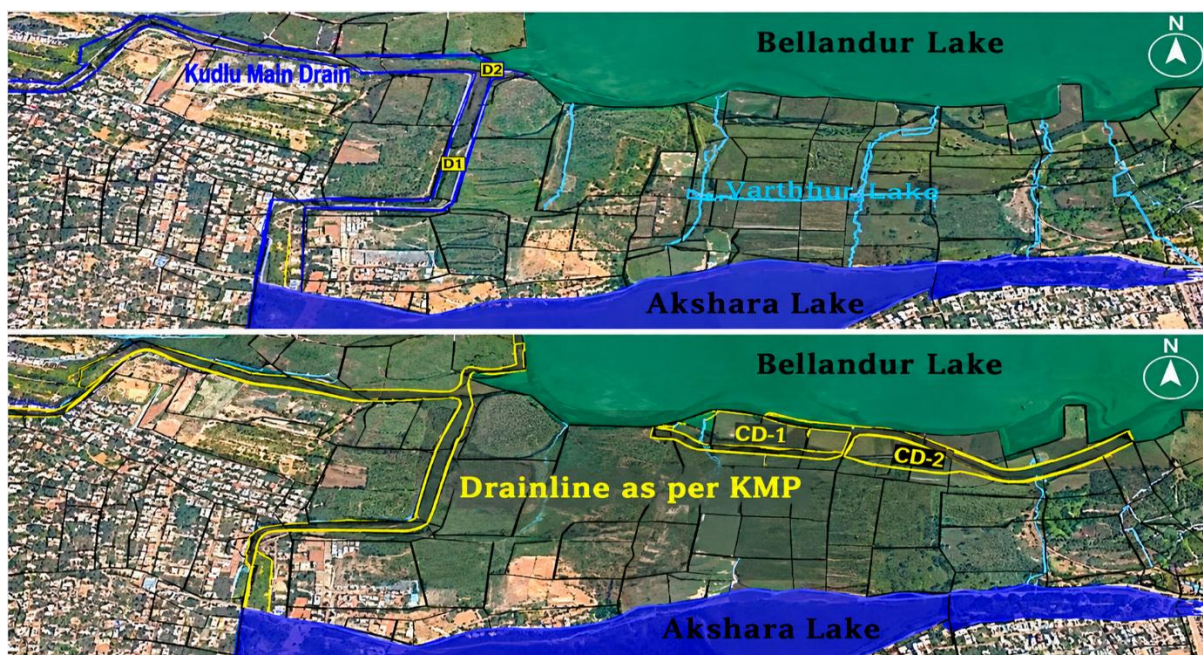


Figure 6. Mapping of Existing Rajakaluves in the Agara–Bellandur Wetlands

3.2 Landscape Dynamics and Alterations in Rajakaluves (Collecting Drains)

Wetlands in Bangalore are interconnected, and these interconnected systems facilitate the transfer of water from one lake to another. Figure 6 highlights the interconnected lake system in the Agara–Bellandur region with rajakaluves and a stream network. The figure also indicates the narrowing down of the rajakaluves during the period 2000 to 2015 (cross sections A, B, C and D) [13].

Table 6. List of STPs of BWSSB, Bengaluru

Sl. No.	Name	Capacity (MLD)	Location Near to	Level of Treatment	Process for Treating Sewage
1	K&C Valley	248	Belur Nagasandra (near Challaghatta)	Secondary	Activated sludge process (ASP)
2	K&C Valley	60	Belur Nagasandra (near Challaghatta)	Secondary	ASP with power generation
3	Lalbagh	1.5	Lalbagh kere	Tertiary	Activated aeration + plate settlers + UV disinfection
4	Cubbon Park	4	Cubbon Park (upgraded)	Tertiary	Membrane bioreactor
5	K.R. Puram Ph-I	20	Tambuchetti Palya Road	Secondary	UASB + extended aeration
6	Yelemallappa Chetty kere	15	Yelemallappa Chetty kere	Secondary	Sequential batch reactor
7	Bellandur Amani kere	90	Varthur kere	Secondary	Activated sludge process (ASP)
8	Kadabeesanahalli Ph-I	50	Marathahalli Outer Ring Road	Secondary	Extended aeration
9	Kadugodi	6	Kadugodi	Secondary	Sequential batch reactor
10	Halasuru	2	Halasuru lake	Secondary	Sequential batch reactor
11	Rajacanal Ph-I	40	Geddalahalli near Hebbal	Secondary	Extended aeration
12	Hebbal	60	Nagavara kere	Secondary	Activated sludge process (ASP)
13	Jakkur	15	Jakkur kere	Secondary	Upflow anaerobic sludge blanket (UASB) + extended aeration
14	Yelahanka Ph-I	10	Allalasandra kere	Tertiary	ASP + filtration + chlorination
15	Rajacanal	40	Geddalahalli near Hebbal	Secondary	Sequential batch reactor
16	Horamavu Agara	20	Between Kalkere and Horamavu Agara kere	Secondary	Sequential batch reactor
17	Nagasandra Ph-I	20	Near Madavara kere (Tumkur Road)	Secondary	Extended aeration
18	Mallathahalli	5	Mallathahalli kere	Secondary	Sequential batch reactor
19	Nagasandra	20	Near Madavara kere (Tumkur Road)	Secondary	Sequential batch reactor
20	Chikkabanavara	5	Chikkabanavara kere	Secondary	Sequential batch reactor
21	Mailasandra Ph-I	75	Mailasandra	Secondary	Extended aeration
22	V. Valley	180	Mysore Road	Secondary	Two-stage high-rate trickling filter
23	Kempambudhi	1	N.R. Colony	Secondary	Extended aeration

Sl. No.	Name	Capacity (MLD)	Location Near to	Level of Treatment	Process for Treating Sewage
24	Doddabele	20	Doddabele	Secondary	Sequential batch reactor
25	Kengeri	60	Near Kengeri bus stand	Secondary	Activated sludge process
26	Doddabele	40	Doddabele	Secondary	Sequential batch reactor
27	Sarakki lake	5	Near Sarakki lake	Secondary	Sequential batch reactor
Total		1112.5			

[14] Table 6 lists the STPs and collection points in the city, to understand how and why the STPs' capacity is not adequate to sort out the issues of stormwater flooding in recent times. The highlighted are the points where it is most vulnerable to getting water-logged during intense rainfall. Major flood-prone areas have been identified below after multiple surveys over the areas in monsoon periods and non-monsoon sudden outpours. The intensity of the waterlogging amplifies with the time it remains waterlogged; the economic loss is massive and variable, and since Bangalore's real estate is at an all-time high due to the upsurge in IT and start-ups, property damage and the rent and pricing of both residential and commercial properties account for massive losses. Though the rajakaluves and the STPs are well spread out in the city, they fail to collect the excess storm water in the affected areas, as per the observations and surveys, leading to urban flooding.

4. URBAN FLOODING IN BENGALURU

4.1 Major Flood Areas of Bengaluru

Altogether, 209 areas have been identified as flood-prone in Bengaluru; of these, 58 areas are hyper-sensitive and 151 areas are sensitive. Some of the flood-prone areas are Veerannapalya and HRBR Layout in eastern Bengaluru; the Industrial Area of Rajajinagar in West Bengaluru; Bannerghatta Road, Nayandahalli Junction, Silk Board junction, Gali Anjaneya Swamy Temple junction, Jayadeva flyover, Magrath-Brigade Road junction and Wilson Garden PWD Quarters in South Bengaluru; Sarjapur Road, Varthur, Panathur, Belagere and Hoodi in the Mahadevapura zone; and LBS Nagar in the Yelahanka zone. The zone-wise severely vulnerable areas are listed below and mapped in Figure 7.

4.1.1 Zone-Wise Severely Vulnerable Areas

- **Mahadevapura Zone:** Sarjapur Road, Gunjur, Varthur, Panathur, Belagere, Hoodi.
- **Kr Puram:** Pai Layout, Ambedkar Nagar, Vaddara Palya, Talacauvery Layout and RR Layout.
- **Bommanahalli Zone:** HSR Layout Sectors 2, 3 and 6, BDA Layout-Hulimavu, Someshwara Layout, Arekere, Anugraha Layout, Doddakanneli, NS Palya, Garvebhavipalya.
- **Rr Nagar Zone:** BEML 5th Stage, Pattanagere Main Road, Andanappa Layout, DIAT College, Bhavani Nagar.
- **Yelahanka Zone:** Kariyammanapalya Bridge, Rachenahalli lake inlet, LBS Nagar, near Manpho Convention Centre.
- **South Zone:** Sri Gali Anjaneya Swamy temple, Kempapura Agrahara, Nayandahalli Junction.
- **East Zone:** Nanda Gokula, HRBR Layout, Broadway Junction Road, Veerannapalya.
- **Koramangala Valley:** Bannerghatta Road (SPAR supermarket/Oakyard Apartment), Jayadeva Flyover, Silk Board Junction, Sony Signal-Maharaja Signal, Magrath-Brigade Road Junction, Siddapura Gate, Wilson Garden, PWD Quarters.
- **West Zone:** Rajajinagar Industrial Area, Binnymill Road, KP Agrahara.

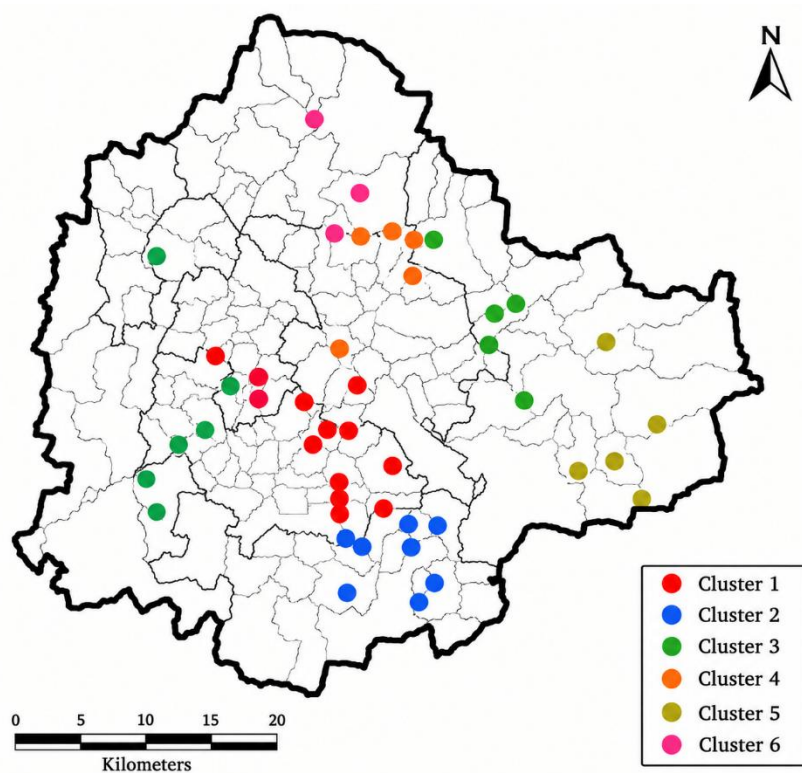


Figure 7. Flood-Prone Locations of Bengaluru by Zone



Figure 8. Flooding at Sarjapur and Bellandur, September 2022

4.2 Causes of Flooding and Analysis of the Low-Lying and Wetland Areas

[15] The causes of urban flooding in Bengaluru, grouped into natural factors and structural and management factors, are summarised in Figure 9. The elevation map and the major valleys of Bengaluru are shown in Figure 10 [16].

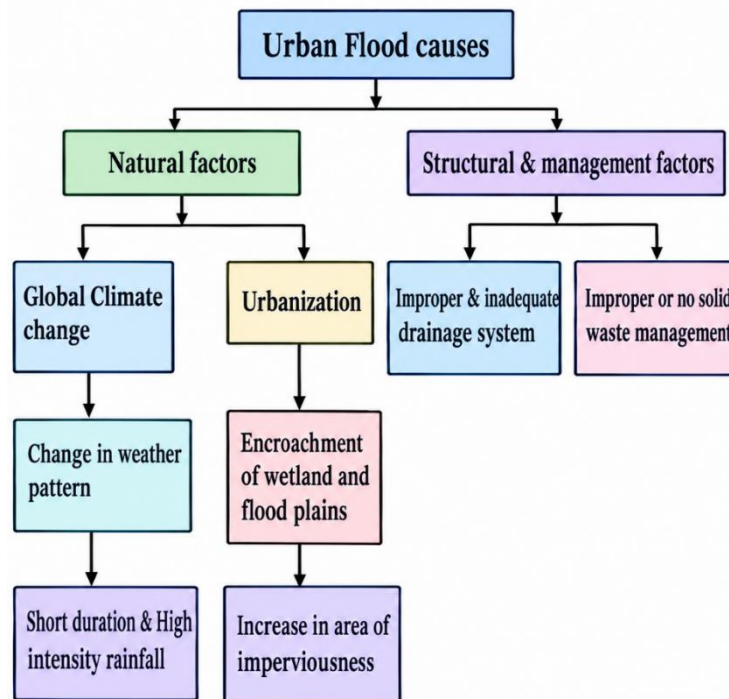


Figure 9. Causes of Urban Flooding in Bengaluru

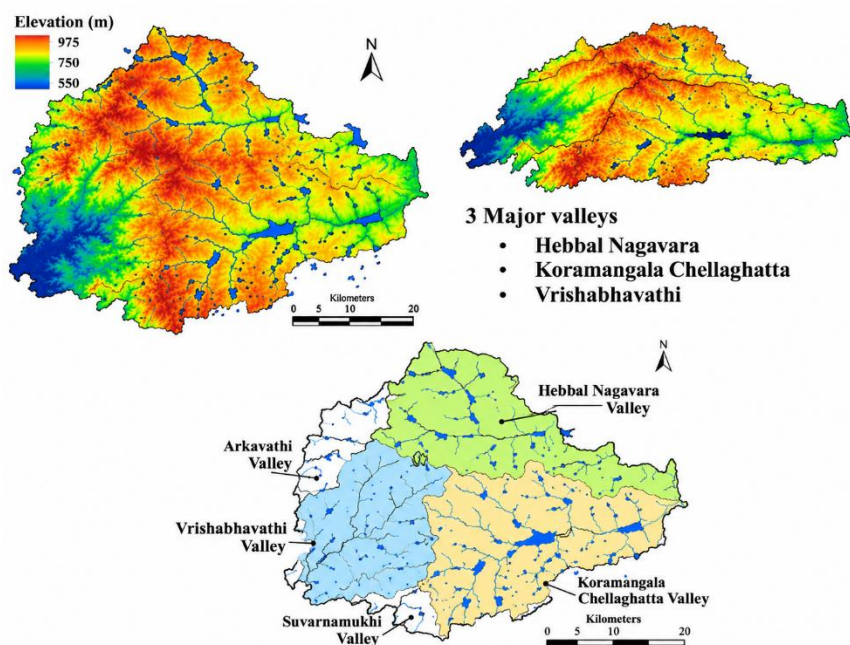


Figure 10. Elevation Map and Major Valleys of Bengaluru

Analysing the elevation maps of Bengaluru under the BBMP jurisdiction, it is clear that the city is inlaid with valleys and minor ridges, which have been converted into multiple lakes over the city. Due to urbanization, the lakes have been illegally encroached upon and converted into residential complexes,

SEZs, and even government buildings in the last two decades, as listed in Table 3 [12]. Moreover, the stormwater collecting channels known as rajakaluves have been narrowed down and blocked in certain areas. The major collecting channels present are inadequate in capacity to sustain the growing population's sewage treatment needs during the monsoon months with added rainwater storms. Previously the lakes were the absorbing areas for the excess downpours during the monsoon months [17], but unfortunately the connecting channels to these lakes have now been blocked, as seen in the imagery in Figure 5. More evidence related to the interruption of natural channel flow direction is visible in various low-lying areas of the city. Another reason for STPs not working to their full capacity is garbage litter and waste plastic accumulation, leading to clogging of the collection points of the STPs [18]. The multiple surveys done led to our understanding that the recognized flood-prone areas of the city either fall under unethically urbanized wetland areas or have blocked rajakaluves. Water-logging that stands for more than two days can cause considerable loss of properties and cars, as seen in the September 2022 Bengaluru floods [19].

5. CONCLUSION AND RECOMMENDATIONS

Sponge city concept: to increase infiltration, water permeability must be allowed by providing more open space. High-rise development should be promoted and built-up ground coverage must be minimized. Pavements should be metalled, but the footpaths and adjoining setback areas should be sponge-type to absorb rainwater. Collecting channels running underneath the footpaths around the city should be unclogged and made plastic-free.

5.1 Relevant Research Gap

- A lot of research, data collection surveys and mapping analyses have been done in the last 10 years under various research agencies, including significant and relevant work by T. V. Ramachandra and team, Centre for Ecological Sciences, Indian Institute of Science, Bangalore, to reveal the facts leading to floods every monsoon in Bangalore.
- Multiple actions by BBMP only work like a band-aid, which is not sustainable.
- The proposed solutions are not working and the issues come back every year at a larger scale, even though BWSSB and BBMP are seen de-silting all the stormwater drains before every monsoon.
- New lakes are being created as water-runoff collection points across Bangalore's affected areas to extend the sponge concept and reduce the impact and spread of urban flooding.

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Authors Contributions Statement

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Pallavi Mukhopadhyay	✓	✓	✓		✓	✓		✓	✓		✓		✓	
Bijay Kumar Das	✓			✓			✓			✓		✓		✓

C : Conceptualization

M : Methodology

So : Software

Va : Validation

Fo : Formal analysis

I : Investigation

R : Resources

D : Data Curation

O : Writing - Original Draft

E : Writing - Review & Editing

Vi : Visualization

Su : Supervision

P : Project administration

Fu : Funding acquisition

Conflict of Interest Statement

No conflict of interest.

Informed Consent

Not Applicable.

Ethical Approval

Not Applicable.

Data Availability

This study draws on publicly available data. No new datasets were created.

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