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Urban Flooding: Study of Bangalore

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Abstract: ***Climate Change has brought an unprecedented change in the meteorological parameters, affecting the urban habitat. Uncontrolled growth, cravings for Urban dwellings, and inhibiting the areas which were once the sponge for urban floods have caused massive hardships for urban governance and the controlling authorities. 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 the youth from across the country. The demand for housing is met by the haphazard construction of residential apartments often encroaching on the water-logged low-lying land. Many lakes visible 40 years ago have vanished from the map. They are now in residential & 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.***

Keywords: Urban Flooding, Silicon Valley, Lakes, Urban Infrastructure.

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 to take away the surface runoff (Miller & Hutchins, 2017). Urban densification and inadequate drainage design have been the primary cause of Urban flooding(Ofwat, 2011). Choked drains are the additional reason for surface runoff not being carried away by storm drains. Increased built-up area and hard paving of surfaces, lead to blocking the passage between the rainwater and the groundwater creating a large surface runoff. Global warming has paved the way for increased frequency and intensity of rainfall (Giorgi et al., 2011).

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Bangalore (Bengaluru) is the capital of Karnataka state of India and one of the largest cities in Southern India. The accounted population of Bengaluru as per the 2011 Census is 8.4 million in the Municipal Corporation area. The Corporation area is 741 square km with 198 wards. Population density comes to be 113 persons per hectare which is less than given by Urban and Regional Development Plan Formulations and Implementation (URDPFI) guidelines (125-175 persons per hectare)

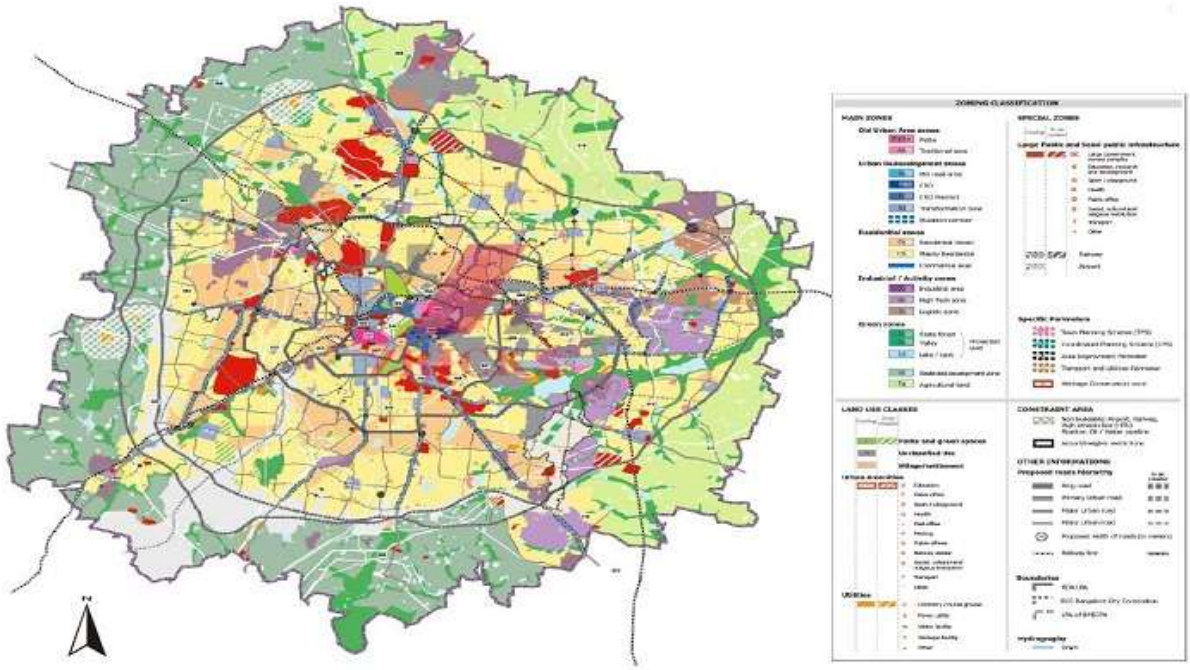

Figure 1. Bangalore Land use/ Land cover map

Source: *Mahanagar Palika* Master Plan 2015

Since 1980, Bangalore emerged as the preferred destination for Software Industry after India opened its market with lighter regulations and integration with the global economy(Parthasarathy, 2004). Bangalore with pleasant weather and lakes is at an elevation of 900 m which makes it a comfortable climate. The National Building Code of India marks Bangalore as a Temperate Climate zone. In a study (Anshu et al., 2023) conducted among the top 15 cities in India for climatic comfort, Bangalore ranked second after Mumbai.

Table 1. Climate data of Bangalore

Source: Indian Meteorological Department (IMD)

Climate data for 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	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

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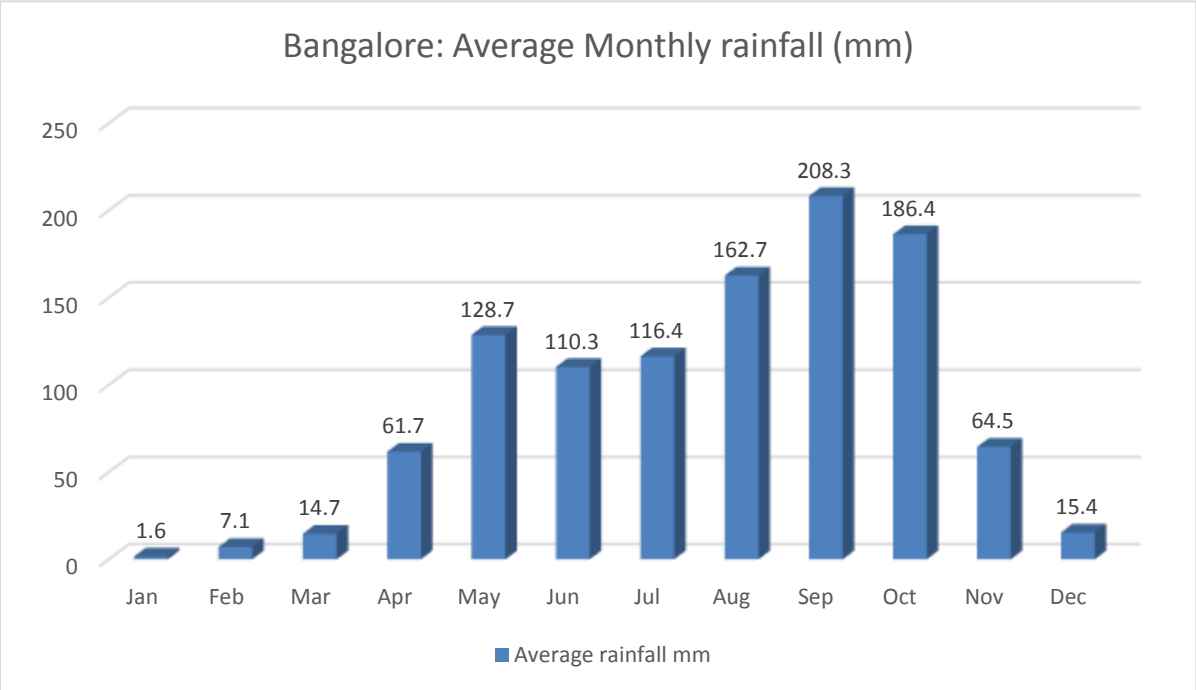
Average low °C	16.1	17.6	20.2	22.1	21.8	20.6	20.1	20	20	19.8	18.3	16.4	19.4
Record low °C	7.8	9.4	11.1	14.4	16.7	16.7	16.1	14.4	15	13.2	9.6	8.9	7.8
Average rainfall mm	1.6	7.1	14.7	61.7	128.7	110.3	116.4	162.7	208.3	186.4	64.5	15.4	1,077.80
Average rainy days	0.2	0.3	1.1	4	7.5	6.8	8	10.2	9.5	9.6	4.2	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	241.1	136.8	111.8	114.3	143.6	173.1	190.2	211.7	2,360.90
Average ultraviolet index	10	12	12	12	12	12	12	12	12	12	10	10	12



As per Bangalore Mahanagar Palika Master Plan 2015, the land use distribution in Bangalore is listed below.

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2. Land Use (LU)/ Land Cover (LC) of Bengaluru

Land use/ Land Cover	Percentage (%)
1. Residential	40.4
2. Transport	24.3
3. Industrial	6.9
4. Commercial	2.7
5. Water bodies/ Open Space/ Agriculture land/ other	25.7

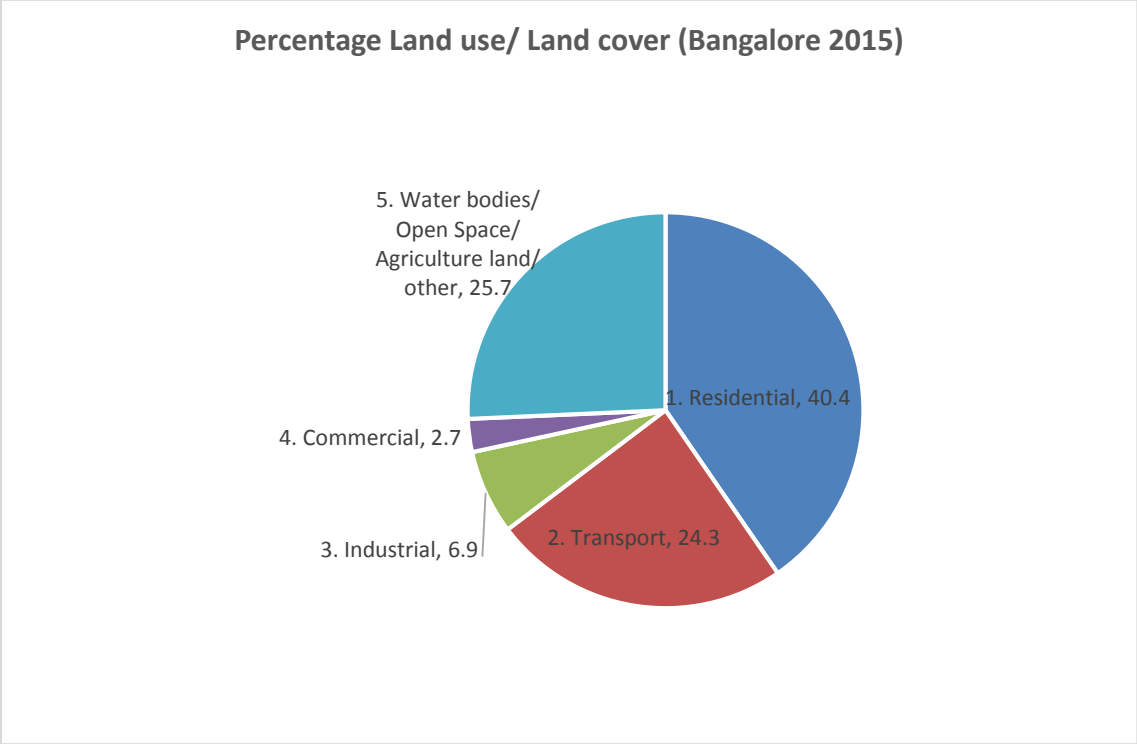

Figure 2 Bangalore Land use/ Land cover

Change in Land Use/ Land Cover in Recent Years

Bangalore is known as the city of lakes. In 1962 about 262 wetlands existed and it reduced to 110 wetlands in 2007. The number of active wetlands and lakes in 1973 was 51 and 159 respectively which decreased to 17 active wetlands and 93 lakes in the year 2007. We observe that there is a significant loss of wetlands and lakes during these periods. Lakes also collect the treated water discharged from Sewage Treatment Plants (STP). The lake has now two sources of water namely the runoff from its catchment area during rain and the water discharged from the STP.

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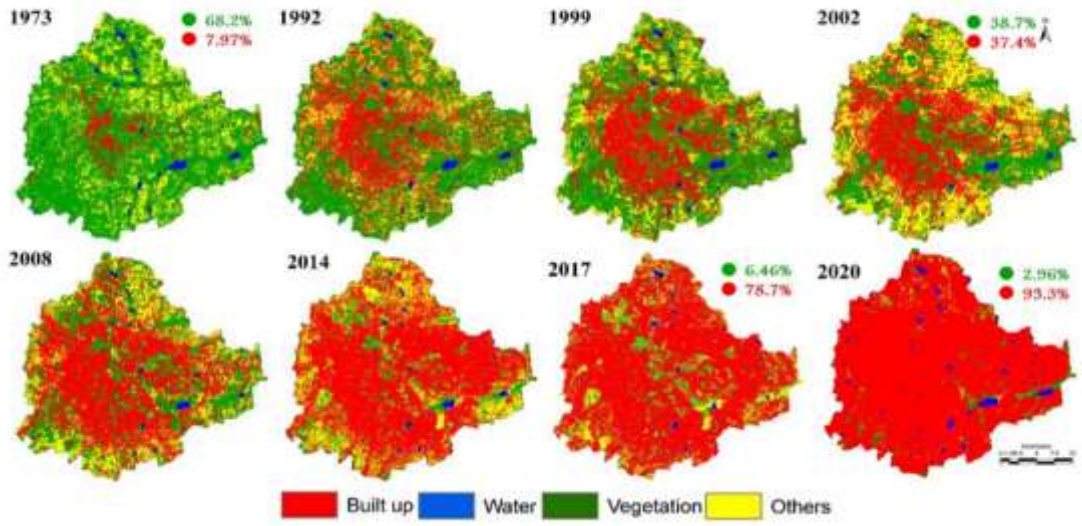

Figure 3. Land use/ Land Cover Changes in Bengaluru (1973-2020)

Source: (Akshatha & Shankar, n.d.)

Table 2. Prominent Land cover change

Prominent Lakes	**Converted to**
1. Dharmambudi lake	Kempegowda bus stand (Majestic Bus Stand) (1960)
2. Shoolay lake	Football Stadium (1967)
3. Sampangi lake	Sports Stadium (1946)
4. Akkithimannahalli lake	Hockey Stadium (1970)
5. Sunkal Lake	KSRTC Regional workshops
6. Kormangal lake	National Dairy Research Institute (1923)
7. Hennur lake	HBR Layout (2014)
8. Jakarayana kere	Krishna Flour mill (1928)
9. Vijinipura lake	Rajarajeshwari layout (1960)

Larger Lakes under rejuvenation

Large lakes	**Area (ha)**
1. Bellandurl lake	364.00
2. Yelahanka lake	121.68
3. Kalkere lake	75.68
4. Doddanekkundi lake	45.29
5. Hulimave Kere lake	44.26

Smaller Lakes under rejuvenation

Smaller lakes	**Area (ha)**
1. Devarakere lake	0.28
2. Kariyobbanahalli kere lake	0.31
3. Golaratti lake	0.31

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4. Halagadevarahalli kere	0.44
5. Srigandadakaval lake	0.45

Figure 4. Land use/ Land Cover Changes in Bengaluru (2006-2021)Agara-bellandur wetlands
Source:Google maps

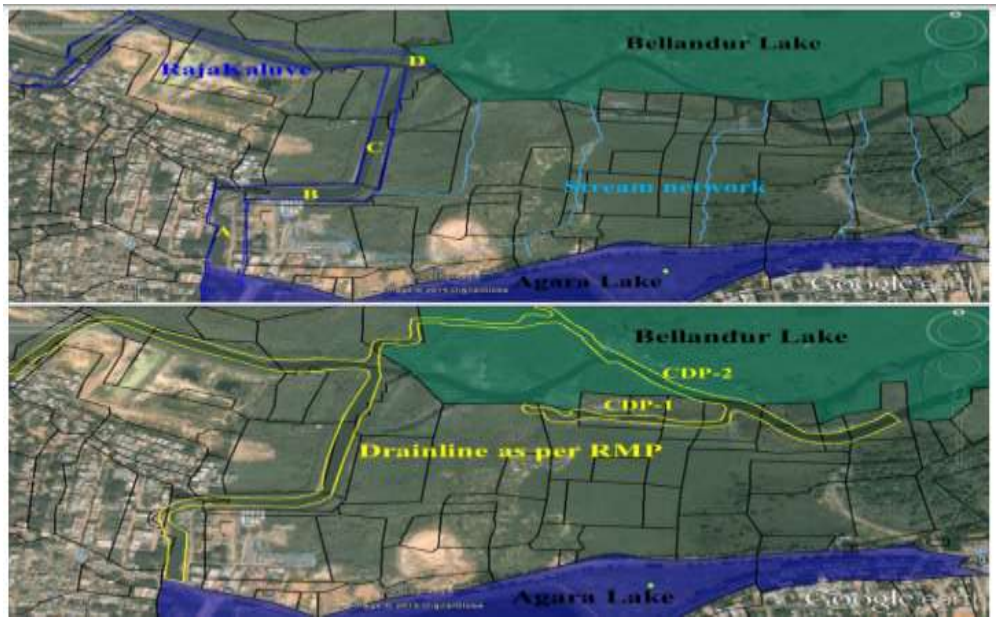

Figure 5. Mapping of existing Rajakaluves in Agara-Bellandur wetlands

Source: Ramachandra, T.V., Kiran, R., & Ahalya, N. (2002). Status, conservation and management of wetlands.

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Landscape Dynamics & Alterations in Rajakaluves (Collecting Drains)

Wetlands in Bangalore are interconnected and these interconnected systems facilitate the transfer ofwater from one lake to another via wetlands. Figure 11 highlights the interconnected lake system in the Agara-Bellandur region with rajakaluves and a stream network. The figure also indicates the narrowing down of rajakaluves which is explained for the period 2000 to 2015, (for the cross sections A, B, C, D are marked respectively).

Source: Bangalore Water Supply and Sewerage Board, Govt. of Karnataka

Table 3 List of STPs in BWSSB Bengaluru

Sl.No	Name	Capacity in MLD	Location near to	Level of Treatment	Types of 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 Bio Reactor
5.	K.R.Puram Ph-I	20	Tambuchetti playa Road	Secondary	UASB + Extended Aeration
6.	Yelemallappa Chetti kere	15	Yelemallappa Chetti kere	Secondary	Sequential Batch Reactor
7.	Bellandur Amani kere	90	Vartur kere	Secondary	Activated Sludge Process **(ASP)**
8.	Kadabeesanahalli Ph-I	50	Marathalli 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

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12.	Hebbal	60	Nagavara kere	Secondary	Activated Sludge Process **(ASP)**
13.	Jakkur	15	Jakkur kere	Secondary	Upflow Aerobic Sludge Blanket (UASB) + Extended Aeration
14.	Yelahanka Ph-I	10	Allalasandra kere	Tertiary	Activated sludge Process **(ASP)** + filtration + Chlorination
15.	Rajacanal	40	Geddalahalli near Hebbal	Secondary	Sequential Batch Reactor
16.	Horamavu Agara	20	In between Kalkere and Horamavu Agara kere	Secondary	Sequential Batch Reactor
17.	Nagasandra Ph-I	20	Near Madavara kere (near Tumkur Road)	Secondary	Extended Aeration
18.	Mallathahalli	5	Mallathahalli kere	Secondary	Sequential Batch Reactor
19.	Nagasandra	20	Near Madavara kere (near 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 process
23.	Kempambudhi	1	N.R.Colony	Secondary	Extended Aeration
24.	Doddabele	20	Doddabele	Secondary	Sequential Batch Reactor
25.	Kengeri	60	Near Kengeri bus stand	Secondary	Secondary-Activated Sludge Process

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26.	Doddabele	40	Doddabele	Secondary	Sequential Batch Reactor
27.	Sarakki Lake	5	Near Sarakki Lake	Secondary	Sequential Batch Reactor
	TOTAL	1112.5			

The table 3, is a list of STPs & collection points in the city to get an understanding of how & why the STP's capacity is not adequate to sort out the issues of stormwater flooding in recent times. The highlighted are the points, where it's most vulnerable to getting water-logged during intense rainfall. Later in the paper major flood-prone areas have been identified after multiple surveys over the areas in monsoon periods & non-monsoon sudden outpours. The intensity of the waterlogging amplifies with the amount of time it's still waterlogged, the amount of economic loss is massive & variable, and since Bangalore's real estate is on an all-time high due to upsurge in IT & start-ups, property damage, rent & pricing of properties both residential & commercial account to massive losses due to this. Though the Rajakaluves and the STPs are well spread out in the city, yet fail to collect the excess stormwater in the affected areas as per the observations and survey leading to the urban flooding

Major Flood Areas of Bengaluru

All together 209 areas have been identified as flood prone in Bengaluru. Out 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, 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, Wilson Garden PWD Quarters in South Bengaluru, Sarjapur Road, Varthur, Panathur, Belagere and Hoodi in the Mahadevapura zone and LBS Nagar in Yelahanka zone.

Zone Wise Severely Vulnerable Areas:

- **Mahadevapura Zone**
  Sarjapur Road,Gunjur,Varthur, Panathur,Belagere,Hoodi
- **KR Puram**
  Pai Layout, Ambedkar Nagar, Vaddara Palya, Talacauvery Layout & RR Layout.
- **Bommanahalli zone**
  HSR Layout2,3&6 Sectors, BDA Layout-Hulimavu, Someshwara Layout Arekere,Anugraha Layout, Doddakanneli, NS Palya, Garvebhavipalya.
- **RR Nagar Zone**

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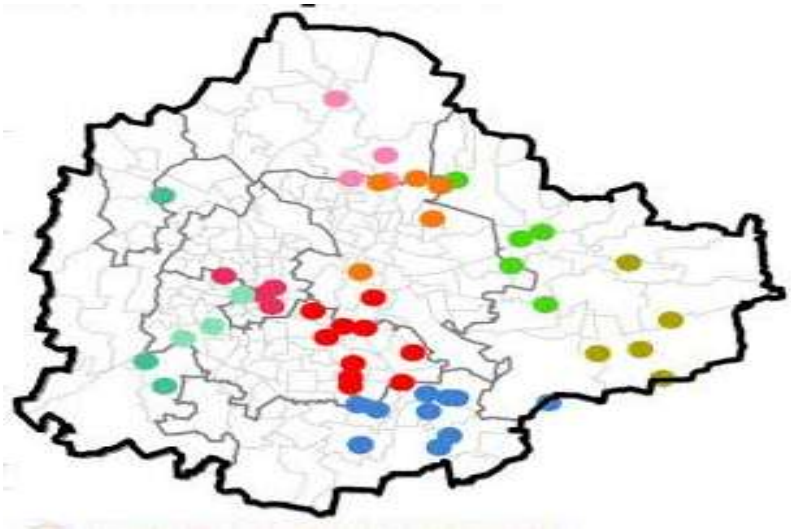

BEML 5th Stage, Pattanagere Main road, Andanappa Layout, DIAT College, Bhavani Nagar.

- **Yelahanka Zone**
  Kariyammanapalya Bridge,Rachenahalli Lake inlet, LBS Nagar, Near Manpho Convention centre
- **South Zone**
  Sri Gallanjaneya swamy temple, Kempapura Agrahara, Nayandahalli Junction
- **East Zone**
  Nanda Gokula, HRBR Layout, Broadway junction Road, Veerannapalya

SARJAPUR & BELLANDUR

Source: Times of India 15th Sept 2022 issue

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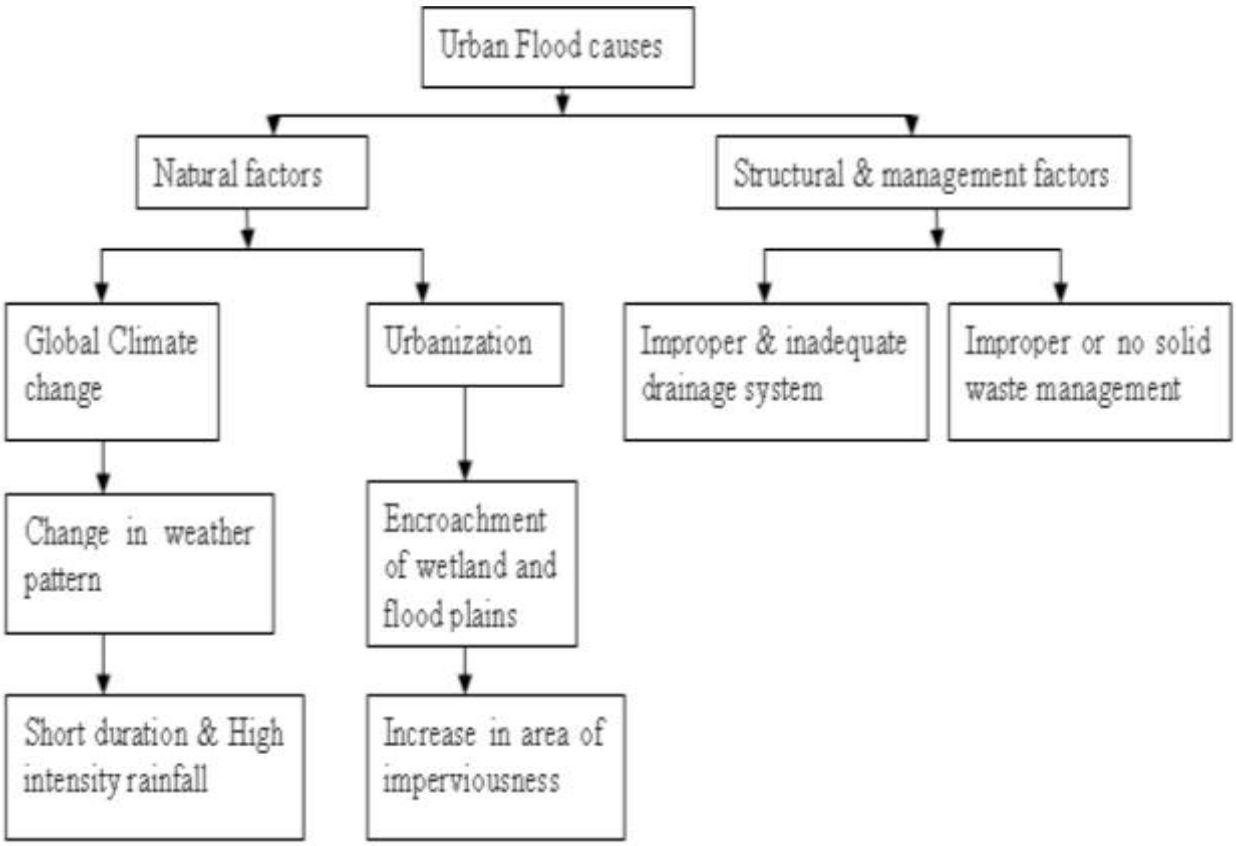
Major Causes of Flooding in Bengaluru

- **Koramangala Valley**
  Bannerghatta Road(SPAR super market/OakyardApartment)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 Agahara

Analysing the Low-Lying & Wetland Areas of Bengaluru

Source: Ramachandra, T.V., Kiran, R., & Ahalya, N. (2002). Status, conservation and management of wetlands.



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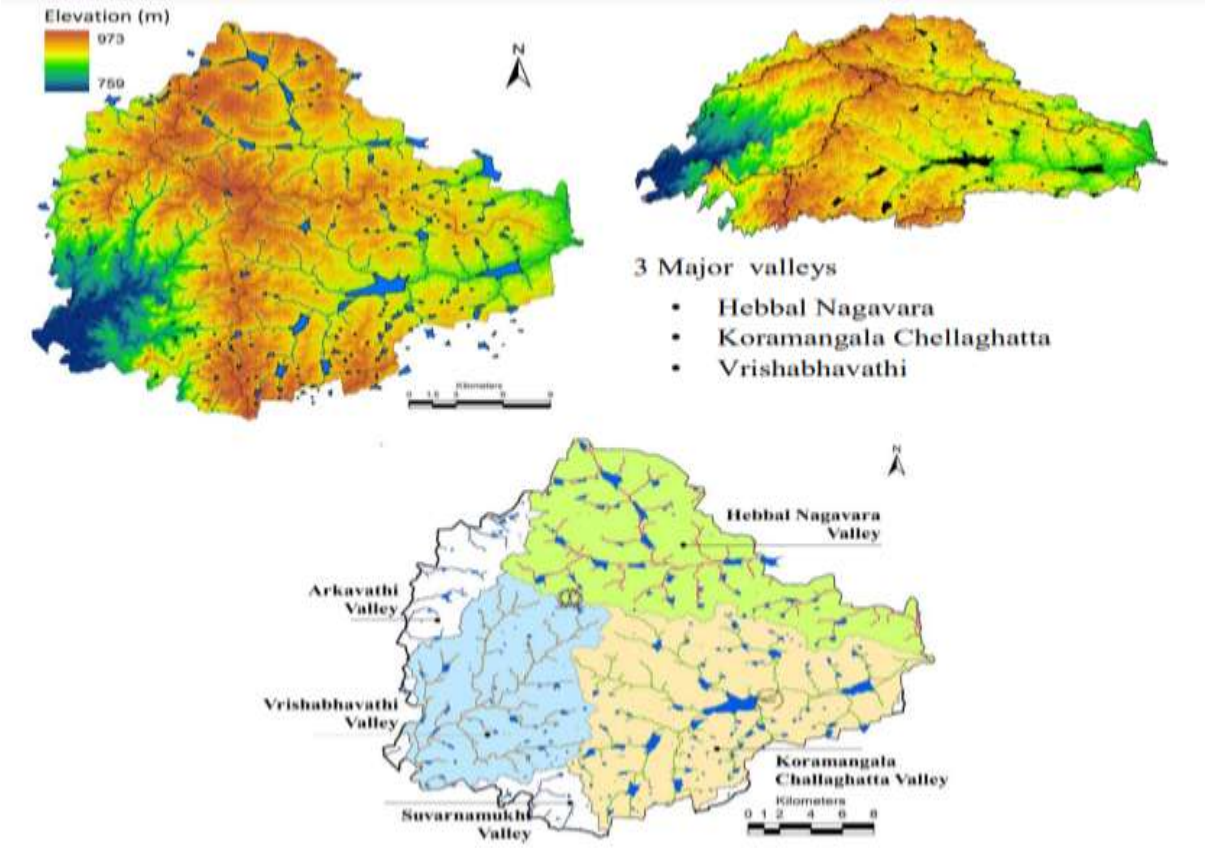

Analyzing the elevate on maps of Bengaluru under the BBMP jurisdiction it's clear that the city is inlaid with valley & minor ridges which have been converted into multiple lakes over the city. Due to urbanization the lakes have been illegally encroached on & converted into residential complexes & SEZs & even Government Buildings in the last two decades, as mentioned in Table 2.Prominent Land Cover Changes (Akshatha & Shankar, n.d.) Moreover, the stormwater collecting channels known as the RAJAKALUVES have been narrowed down & blocked in certain areas. The major collecting channels present are inadequate in capacity to sustain the growing population's STP needs during the monsoon months with added rainwater storms. Previously the lakes were the absorbing areas of the excess downpours during the monsoon months but unfortunately, now the connecting channels to these lakes have been blocked as seen in the Google images Fig. 4 of this paper. More evidence related to the natural channel flow direction interruption is visible in various low-lying areas of the city. Another reason for STPs not working to their full capacity is garbage litter & waste plastic accumulation leading to clogging of the collection points of the STPs The multiple surveys done led to our understanding that the recognized flood-prone areas of the city either fall under the unethically urbanized wetland areas or have blocked Rajakaluves. If the water-logging stands for more than two days can cause considerable loss of properties & cars as seen in last 2022 September Bengaluru floods.

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2. CONCLUSION & RECOMMENDATIONS

Sponge City Concept: To increase infiltration, water permeability must be allowed by providing more open space. The high rise should be promoted and built-up (ground coverage) must be minimized. Pavement should be metalled but the footpath and adjoining areas of setbacks should be sponge-type to absorb rainwater. Collecting channels running underneath the footpaths around the city should be unclogged & made plastic free.

Relevant Research Gap

- A lot of research & data collection surveys, and mapping analysis have been done in the last 10 years under the supervision of various research agencies including much significant & relevant research work IISC Bangalore's TV Ravichandran & team, CEO_Centre for Ecological Sciences Indian Institute of Science to reveal the facts leading to floods every monsoon in Bangalore.
- Multiple actions by BBMP only work like Band-Aid which is not sustainable.
- But why the proposed solutions are not working & the issues come back every year at a larger scale even though BSWB & BBMP are seen de-silting all the storm-water drains pre-monsoon every year.
- New lakes are being created as water–runoff collection points & across Bangalore urban's affected areas to increase the sponge concept to reduce the impact & spread of urban flooding.

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