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GOVERNMENT OF INDIA
MINISTRY OF HOUSING AND URBAN AFFAIRS

17th Urban Mobility India Conference & Expo 2024

Impact of Urban Floods on Transport Infrastructure: A Case Study of Kochi, Kerala

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INTRODUCTION

According to the Global Climate Risk Index 2021, **India is ranked 7th out of 180 countries** affected by climate change, implying extremely high exposure and vulnerability.

Over **300 of extreme climate events** have occurred in India in the past 60 years, leading to a monetary loss of **6.5 lakh crore in the last 20 years.**

Floods impact and threaten the transportation systems making it difficult to provide **crucial services** to the community, individual, and critical systems.

Transportation infrastructure which includes the road network, footpaths, public transport systems are **crucial** for various city level functions. They are the **first to bear** the brunt of weather events

30% to 55% of the direct flood damages would be suffered by the infrastructure sector, while **35% to 85%** of business losses were caused by **disruption to the transportation** and electricity supply and not by the flood itself (OECD,2018)

Cities such as Delhi, Gurugram, Chennai, Kochi, Bangalore, etc. are **silent on the need for climate resilient transport infrastructure** in cities in their Comprehensive Mobility Plans.

NEED OF THE STUDY

1.68 BILLION AFFECTED
267,000 KILLED
US$127 BILLION LOSS

Source: World Bank (1990-2019)

45% INCREASE India's economic losses from disaster

Source: World Bank (1990-2019)

20 times greater loss in GDP due to disasters in developing countries

Source: MHA, 2012

+1 INCREASE IN VERY SEVERE RAINFALL SCENARIOS PER DECADE

2/3 INDIVIDUALS ARE EXPOSED TO EXTREME FLOOD EVENTS

1/4 INDIVIDUAL IS EXPOSED TO EXTREME CYCLONE AND RAINFALL

Brazil, 2024

Dubai, 2024

Kochi, 2018

Chennai, 2015

There is a **need to systematically integrate climate risks in transport projects** to ensure the climate resilience in the transport to quickly rebound during and after disasters.

From recent cases in **Chennai,** the time taken to restore to basic services was **10 to 33 days (upto 14 to 21 days in some areas)** and upto to **3 months** to restore to normal economic scenario (University of Madras, 2017 & Middle East Institute, 2017)

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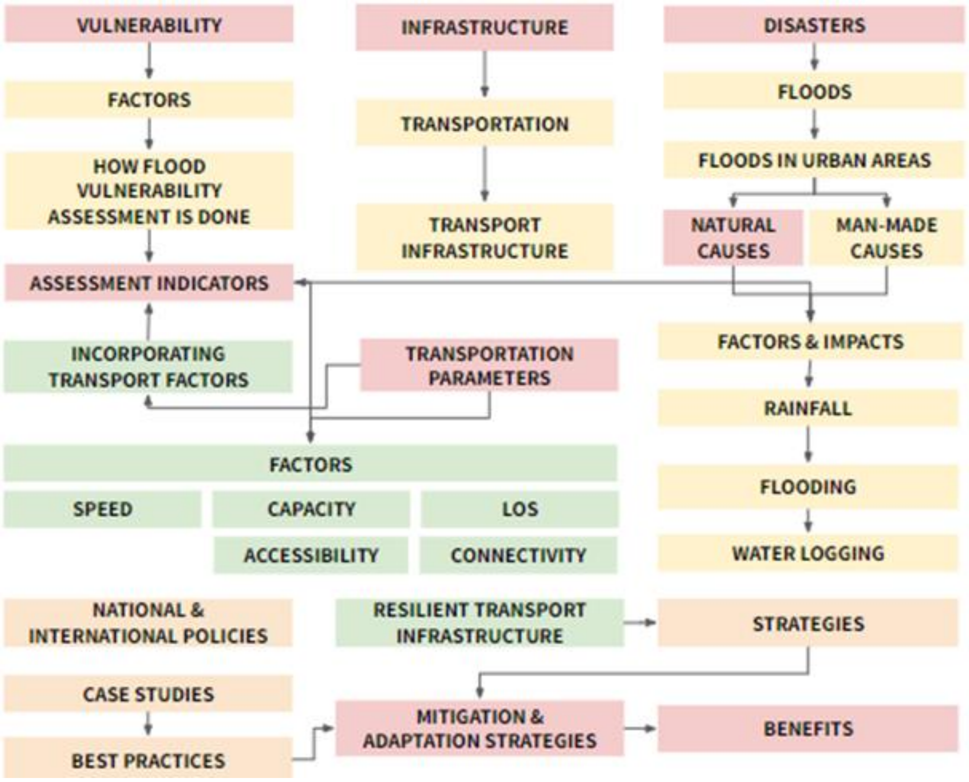
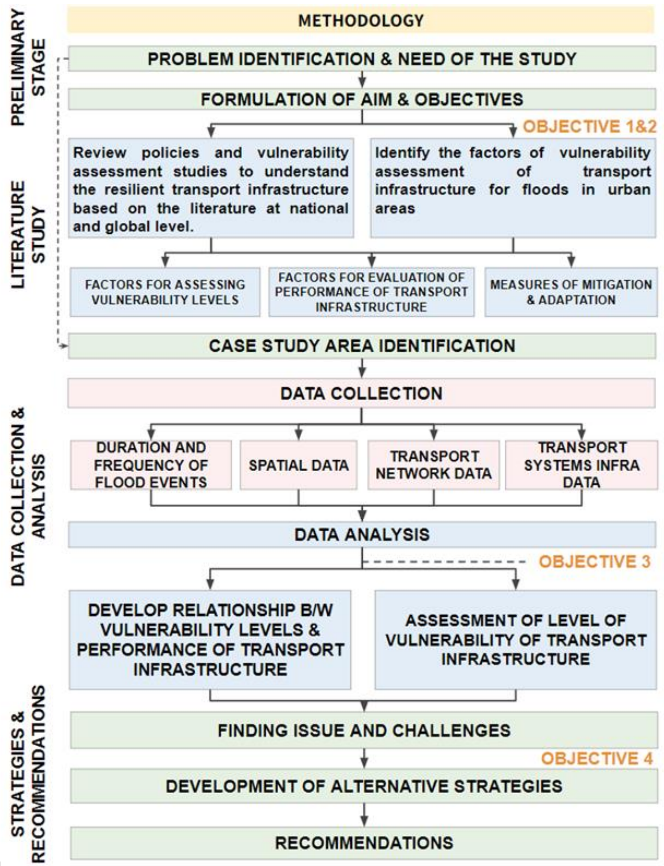
FINDINGS FROM LITERATURE

- Impact of heavy precipitation in the operation of the road network, it has been mostly assessed as **speed drop, ranging in freeways from low impact drops of 2%–6% to higher impact between 20% and 25%**
- After **5 MM of rainfall, increase in every 1 MM rainfall there will be 2mins additional travel time increases** in the network. (SPA, 2017)
- A transport system that has low resilience to actual and expected climate change can impose high costs for maintenance and repair. World Bank, 2015
- Considering that after extreme events some places are less accessible than others (Bono and Gutiérrez 2011; Balijepalli and Oppong 2014), the concept of accessibility arises as an important indicator of the transportation network performance (Páez et al. 2012).



METHODOLOGY & INDICATORS



Demographic

- Population
- Economic aspect
- Employment
- Education

Environment

- Temperature
- Precipitation
- Tide

Physical

Most Used (>5)

- Inundation areas
- Elevation & Topography
- Slope

Vulnerability Assessment

- NDVI
- NDWI
- WRI
- TWI
- Proximity to Water Bodies

Transport

Most Used (>5)

- Network Criticality
- Connectivity
- Accessibility
- Travel time/speed/
- Trip Length

Least Used

- Network Density (2)
- Network Capacity (1)

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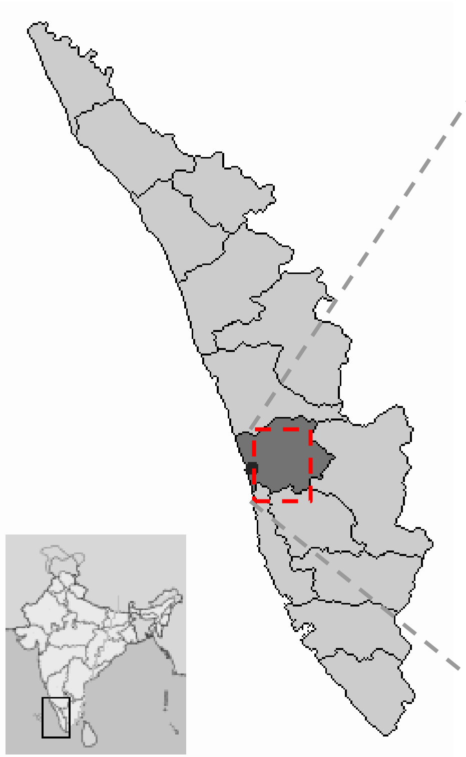
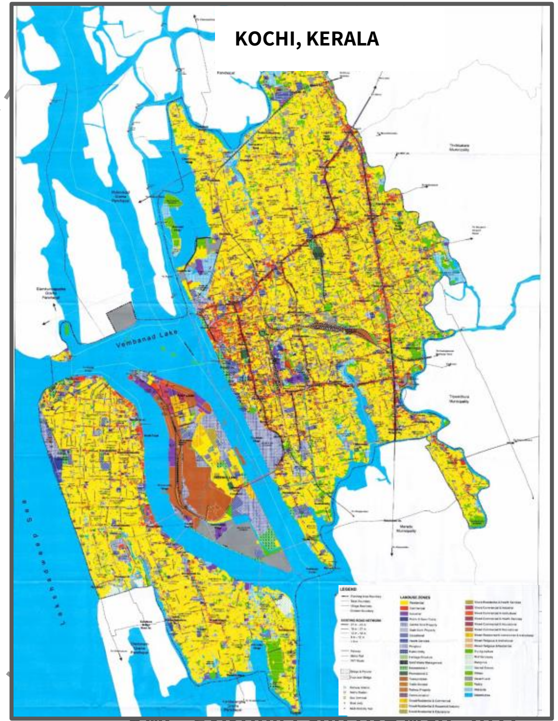
CASE STUDY AREA PROFILE: KOCHI





KMC, Existing Land Use Map, 2021

TOTAL STUDY AREA 94.88 SQ. KM	**POPULATION 8.98 Lakhs (est.)**	**DISTRICT ERNAKULAM**	**DENSITY 6346 PPL/Sq.km**
SEX RATIO 1027	**NETWORK DENSITY 11.4 km/sq.km**	**PT DENSITY 2.81 km/sq/km**	**TOTAL WARDS 74**

City	Population (2023)
Estimated Population (2024)	**1,53,32,793**
Male Population (2024)	**755,906**
Female Population (2024)	**777,372**
Population Density (2024)	**6346**
Annual Growth Rate (CAGR %)	**3%**
Household Size (2011)	**4.4**
Literacy Rate (2011)	**88.5 %**
WFPR (2011)	**38%**
Total Workforce	**58,00,000**
Male Workforce	**28,72,000**
Female Workforce	**29,54,000**

TIMELINE OF EVENTS

1924
Periyar Great Floods
Continuous rain for 3 weeks, parts of Munnar and Alleppey were severely affected, Connectivity to various areas completely destroyed

2018
348 mm — KERALA FLOODS
Largest floods in Kerala. **483 dead, damage ₹40,000 crore, 10,000km** of highways and roads destroyed

2019
313 mm — FLOODS
Flooding in major parts of Kochi city due to heavy rain .**121 reported dead** in Kerala

2020
173 mm — CYCLONE AMPHAN
Major parts of Kochi city flooded, **104 Reported dead** in Kerala

2022
202 mm — CYCLONE TEJ
Major parts of Kochi city flooded, **Red alert issued 2 times. 32 Reported dead in Kerala**

2017
CYCLONE OCKHI
Flooding in major parts of Kochi city, damage to infrastructure. Transportation to standstill

2018
REBUILD KERALA INITIATIVE
Rebuilding kerala's road network and other infrastructure with climate resilience

2019
OPERATION BREAKTHROUGH
Urban flood mitigation project for Kochi city

2021 — 450 mm
HEAVY RAIN & FLOODS
Red alert issued 2 times in Kochi. 67 reported dead in Kerala

2023 — 157 mm
CYCLONE BIPARJOY
Red alert issued 3 times in Kochi. Floods in some parts of the city

Source: Author, Compiled from NEWS articles 2024

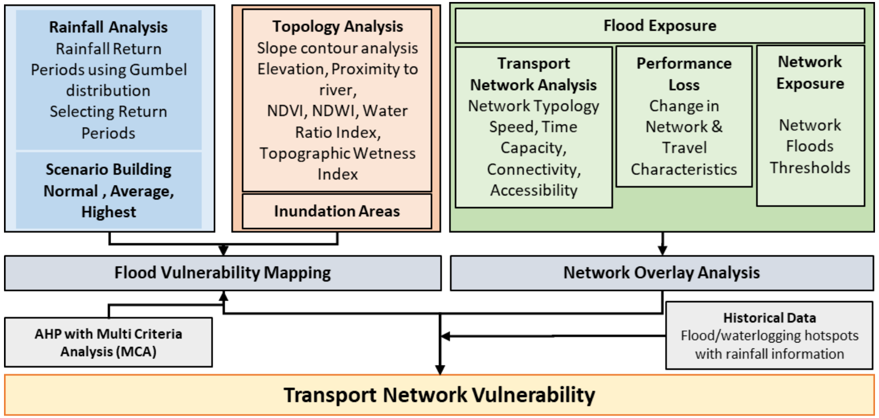
2018

BUS STAND, 2020

MG ROAD, 2023

ASSESSMENT OF FLOOD VULNERABILITY LEVELS USING AHP

A Multi-Criteria Analysis (MCA) was conducted using the specified parameters to prepare a Flood Vulnerability Map, which was then scaled from 1 to 5 considering the AHP values.



- Of the total area of Kochi, 16.2% and 18.2% of the area come under high flood vulnerable areas.
- To validate this data, Rainfall data, flood data from newspaper articles, and flood vulnerability data are combined to create geographical data.
- Random sampling of locations are taken and the number of location with data on flooding in the past 5 years and the model does not are calculated to get the accuracy level.
- The accuracy level came out to be 84%.

Indicator	Definition	Criteria	Value	Weightage
Slope	When the slope angle is less, the probability of flooding increases (Rahman et al. 2019). Runoff from rainfall accumulates and inundates areas with gentle slopes due to the low flow velocity in these areas (Lee and Kim 2021).	<0.93 0.93 - 2.14 2.14-3.74 3.74-6.56 >6.56	5 4 3 2 1	**14**
Elevation	Areas having lower elevation compared to surrounding areas are highly likely to be in risk of flooding than highly elevated areas.	<2 2-4 4-6 6-9 9-25	5 4 3 2 1	**15**
Water Resource Index (WRI)	WRI with a value greater than 1 for waterbodies. WRI values less than or close to 1 (especially values closer to and below zero) indicate that the soil moisture content is higher, making the area more vulnerable to flooding.	-10.1 - -7 -7 - -3.5 -3.4 - 0.16 0.16 - 3 3 - 6	5 4 3 2 1	**18**
NDVI	Flooding is more likely in built-up areas because water cannot infiltrate and generate surface runoff (Islam et al. 2021). Increased forest and vegetation cover enhances water infiltration and reduces runoff depth, thus lowering the chance of flooding (Swain et al. 2020b)	-0.22 - -0.11 -0.11 - 0.01 0.01 - 0.08 0.08 - 0.13 0.13 - 0.32	5 4 3 2 1	**16**
NDBI	Urbanization increases the amount of impervious surface area in a location, slowing the hydrologic system's response time and thereby increasing the risk of flooding (Feng et al. 2021).	-0.22 - -0.11 -0.11 - 0.01 0.01 - 0.08 0.08 - 0.13 0.13 - 0.32	5 4 3 2 1	**14**
Topographic Wetness Index	Identify rainfall runoff patterns, areas of potential increased soil moisture, and ponding areas, also considers slope as factor	-13.1 - -6.9 -6.9 - -3.5 -3.4 - 0.16 0.16 - 2.6 2.6 - 9.3	1 2 3 4 5	**15**
Proximity to River	Areas closer to streams considered to have a higher flood risk (Ravi Kumar.)	0 - 30 03 - 60 60 - 100	5 3 1	**8**

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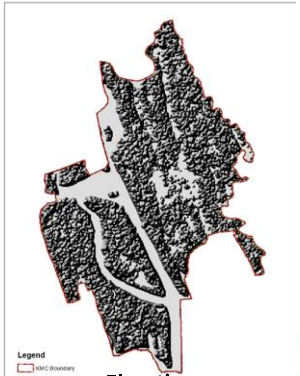
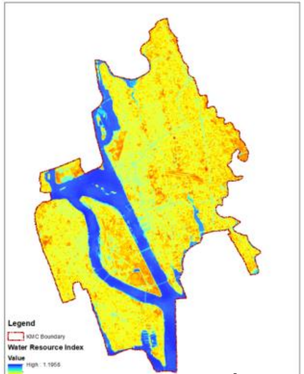
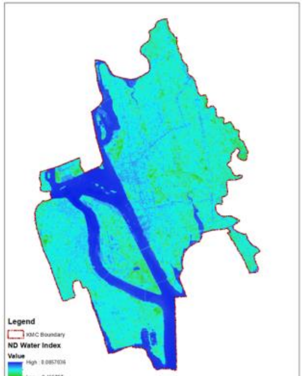
ASSESSMENT OF FLOOD VULNERABILITY LEVELS USING AHP

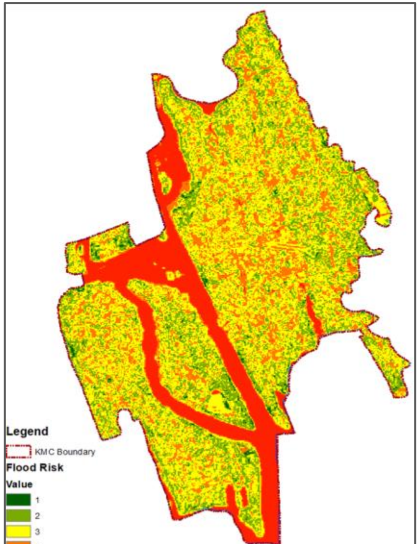

Slope


Elevation

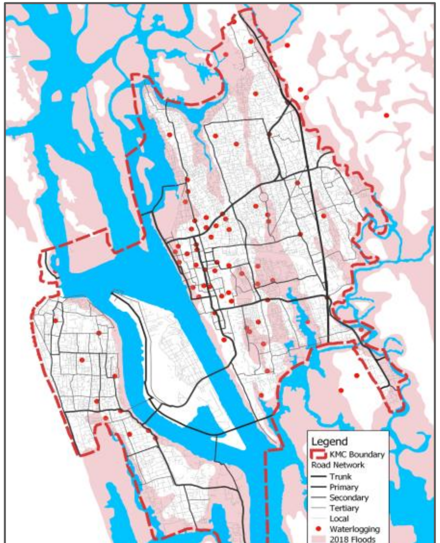

Water Resource Index


NDWI


Topographic Wetness Index



Flood Vulnerability Map



Flooding Data Validation

- This geographical data shows how much rainfall is required for a particular flood-vulnerable area to get flooded.
- The combination of data is done by overlapping the minimum daily rainfall with the rainfall in the city on the same day.
- The process is repeated for all 100 locations. These points are converted into polygons using the Voronoi polygon method.
- This method ensures each point gets an independent polygon, highlighting different vulnerability values where differences exist.
- These polygons are assigned a rainfall threshold value, above which the area would experience flooding.

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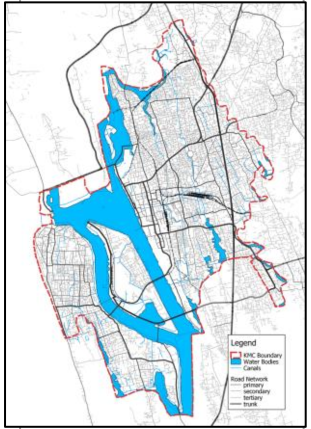
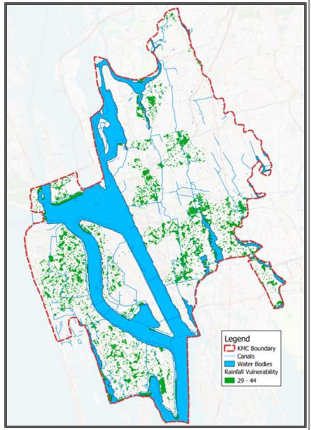
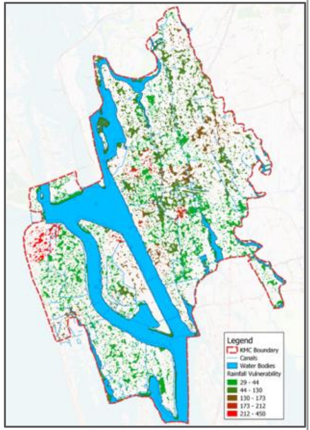
SCENARIO DEVELOPMENT & ANALYSIS

Normal Day	Average Day	High Rainfall Day
Assumed that there is no rainfall in the city. All the transportation factors would have a normal character.	Assumption of an average rainfall of 27 mm. This rainfall level is imputed to the flood vulnerability model.	The high rainfall scenario is the scenario at which the highest rainfall reported in the past 5 years. This rainfall level is imputed to flood vulnerability model.



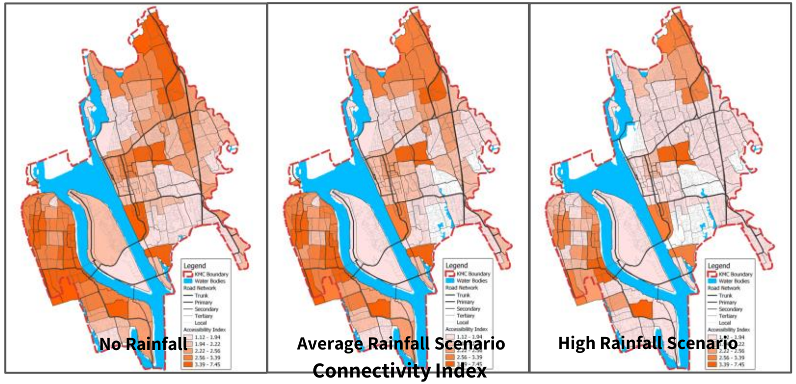




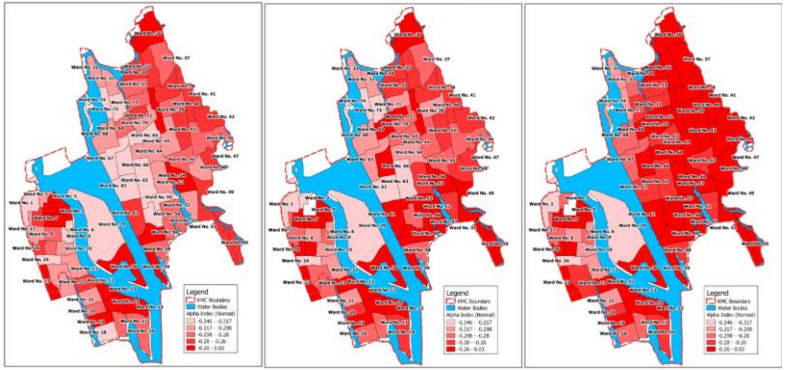
Transport System	No Rainfall	Avg Rainfall		High Rainfall	
	Length (m)/Number	Affected Length (m)/Number	% Affected	Affected Length (m)/Number	% Affected
Road Network	1082455	151399	**14.0**	289399	**26.7**
Primary	95084	18191	**19.1**	29191	**30.7**
Secondary	53696	7395	**13.8**	10395	**19.4**
Tertiary	109980	14083	**12.8**	28083	**25.5**
Local	823695	111730	**13.6**	221730	**26.9**
Bus Network					
Stations	7	4	**57.1**	4	**57.1**
Stops	575	126	**21.9**	167	**29.0**
Routes	164318		**0.0**		**0.0**
Metro					
Stations	13	7	**53.8**	7	**53.8**
Routes	14573	6026	**41.4**	6693	**45.9**
IPT stops	104	33	**31.7**	41	**39.4**
Rail Network					
Stations	4	1	**25.0**	2	**50.0**
Line	88223	30509	**34.6**	39152	**44.4**
Water Metro Stations	21	1	**4.8**	1	**4.8**

ANALYSIS

Public Transport Accessibility Levels



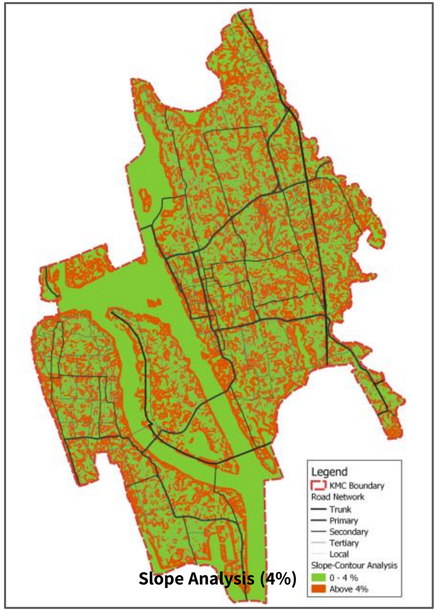
Connectivity Index



The **Public Transport Accessibility Level (PTAL)** is decreasing from increasing rainfall. This is due to the increase in waiting time for public transport and well as difference in networks which are unusable due to flooding/waterlogging.

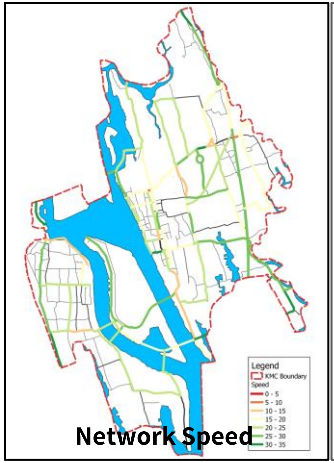
Connectivity Index	Normal (No rainfall)	Average Rainfall Scenario	High Rainfall Scenario
Alpha Index	0.27	0.25	0.22
Beta Index	0.44	0.49	0.54
Gamma Index	0.15	0.17	0.19

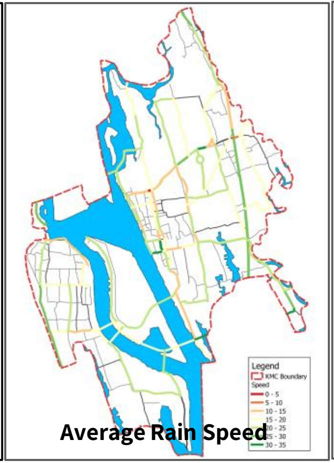
3 wards out of 74 are completely inaccessible during **high rainfall scenario** due to loss in connectivity. These wards are Thevara, Perumpadappu and Vaduthala

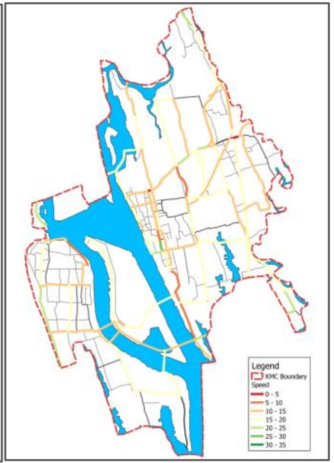


Document	Guidelines
IRC 86: 2018	A gradient of 4 per cent should be considered the maximum for urban roads
	Gradient should desirably not exceed 2 per cent for road carrying slow moving traffic
	At intersections, the road should be as near level as possible
	Minimum lengths of vertical curves for satisfactory aberrance and maximum grade change without a vertical curve

SPEED ANALYSIS





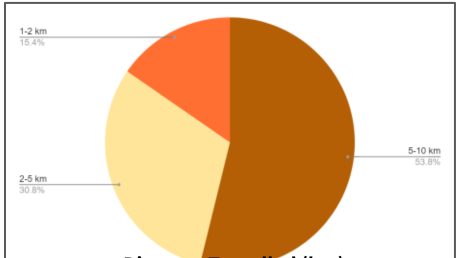


Vulnerability Interval	Decrease in Speed for 1 mm Rainfall (Kmph)	Source
0 -1	No change in speed	
1 -2	1.5%, 2.5%, 2.08% during light(2.5mm/h) moderate 2.5-7.6 mm/h) and heavy(more than 7.6) rainfall	SONU MATHEW (2021)
2-3	4.8%–6.4% reduction in free-flow speed	HCM
3-4	5%–6.55% reduction in the operating speed regardless of the intensity of rainfall.	Smith et al. (2004),
4-5	2.11 min. Increase in TT per mm rainfall after 5 mm initial rainfall	Climatrans, Sairam, Sanjay Gupta

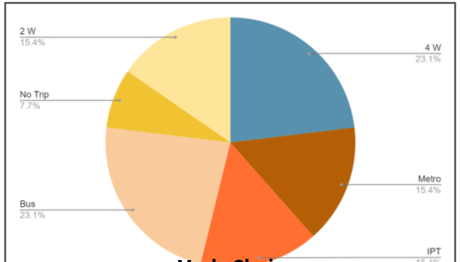
Speeds (kmph)	Rainfall Scenario		
	Normal Rainfall %	Average Rainfall %	High Rainfall %
Below 10	4.37	12.6	17.2
10-20	29.24	51.7	59.3
20-40	51.6	24.6	17.8
40-60	12	11.2	5.7
Above 60	2.8	0	0

- From literature, vulnerability value for an area observed using the Vulnerability Assessment is compared with the % deduction in value of speed.
- Each vulnerability interval is provided with an % speed deduction value
- It is assumed that during high rainfall and high vulnerability scenario the network will be unusable and speed will be zero.
- A difference in speed is observed during **average (27mm) and high rainfall** scenario in Kochi

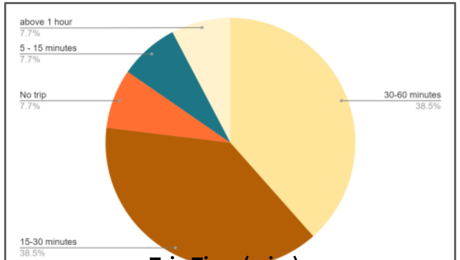
TRAVEL CHARACTERISTICS & FINDINGS



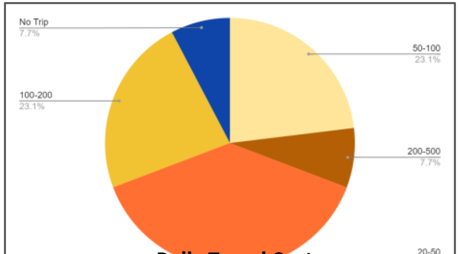
Distance Travelled (km)



Mode Choice



Trip Time (min.)



Daily Travel Cost

- Arage trip time is higher in users within the age group 75 to 84 followed by 25-34 and 65-74, whereas it is less in the age group, 5-14
- Daily Trip Frequency is higher in user in the age group 5-14 and for others its is between 1 and 1.5 trips per day
- Average monthly expenditure is above Rs. 1500 for all the age groups

Guidelines	Normal	During Rainfall
Average Trip Length (ATL)	4.3 km	5.1 km
Average Trip Time (ATT)	19.6 Min	28.8 Min.
Average Trip Expenditure	Rs. 54.2	Rs. 61.6

- **26% of the trips were cancelled** according to to the primary survey during the event of floods or heavy rainfall.
- The reason for this are said to be **safety issue, road closure, work from home, holiday etc.**
- **43% of the users** which responded have **changed their mode of transportation** to their work during the event.
- Around **20% changed to public transport** such as metro and **80% change to private transport modes**
- Reasons for this are, **comfort, ease to access, less travel time,** etc
- Around **16% of the users responded that their travel time doubled** during the event but for others there is **some difference or no difference.** Reason for change - **Absence of PT, Waterlogging, road closure, etc.**
- The daily travel expenditure of users have remained same in some cases but **in the case of users changing their mode to private modes, their costs have increased upto 10 times**
- There is **no much difference in the frequency of trips since most frequency were once daily.**

ISSUES

Indicator	Observations/Results
Multi-Criteria Analysis (Flood Vulnerability)	• **16.2 % of area under vulnerability level 5 and 18.2% of area under vulnerability level 4** within the city including water bodies. • Waterlogging and flooding reported in major road networks, bus stops and stations, railway stations etc.
Network Density	• Road Network Density is evenly distributed within the city in almost all the wards **(11.4 km/ sq.km)** • PT Network density is **2.8 km/sq.km** at the city level and the density is higher in the Marine drive area and MG road compared to other places.
Trips	• 26% of the trips were cancelled, 43% changed their mode of travel. 20% changed to public transport such as metro and 80% change to private transport modes • Increase in usage of private vehicles, especially 4W
Trip TIme	• Average trip time is higher in users within the age group 75 to 84 followed by 25-34 • 16% of the users responded that their travel time doubled during the event but for others there is some difference or no difference.
Accessibility	• Several bus stops and bus routes are inaccessible during average and heavy rainfall scenario • Road network are also affected which lead to taking an alternative route or a slower speed for the user
Connectivity	• Steady decrease in the alpha, beta and gamma connectivity indices in Kochi at the ward level during different rainfall scenarios
Network Speed	• Various literature show that a decrease in the travel speed occurs during i rainfall

PROPOSALS

STRATEGY 1: NETWORK ALTERNATIVES DURING AVG. RAINFALL SCENARIO

Proposal | Road Network alternatives to continue transportation without disruption during the event of floods which have the needed capacity to handle the additional traffic capacity during average rainfall period

NETWORK SELECTION FACTORS

INTERSECTIONS FLOODED	NEXT AVAILABLE SHORTEST PATH	CONNECTING MAJOR LOCATIONS
HIGH CONGESTION NETWORKS	LESS VULNERABLE NETWORK	DEVELOPED OR DEVELOPABLE

STRATEGY 2 : MISSING LINKS FOR WARD CONNECTIVITY

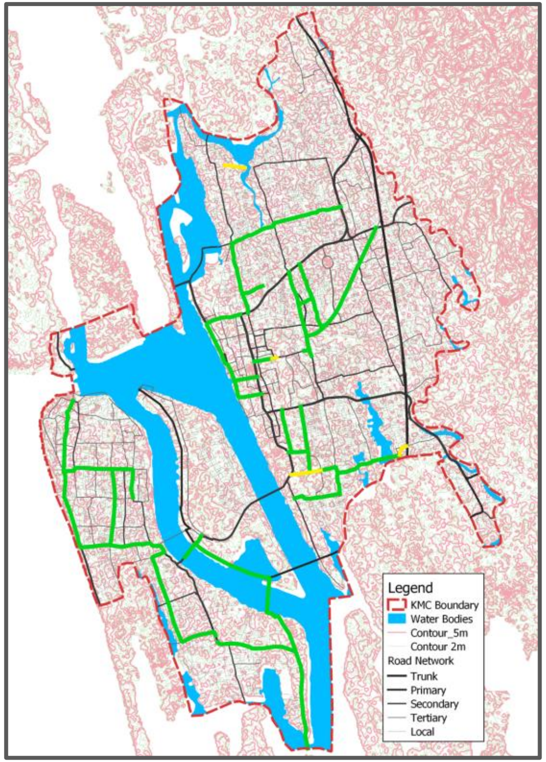
Proposal | The critical zones or wards which become isolated due to low accessibility of the network. Identify the missing links and identify a link to be used for emergency and basic transport accessibility

High congestion networks during average rainfall

Isolated wards during average rainfall scenario

ROAD CAPACITY AND CONDITIONS	NETWORK CONNECTIVITY	LAND AVAILABILITY
NETWORK ACCESSIBILITY →	TRAFFIC VOLUME →	LESS FLOOD VULNERABLE
SLOPE AND CONTOUR	ACCESS POINTS	DEVELOPABLE

NEW NETWORK LINKS



Proposed Alternative & New Network

PROPOSALS

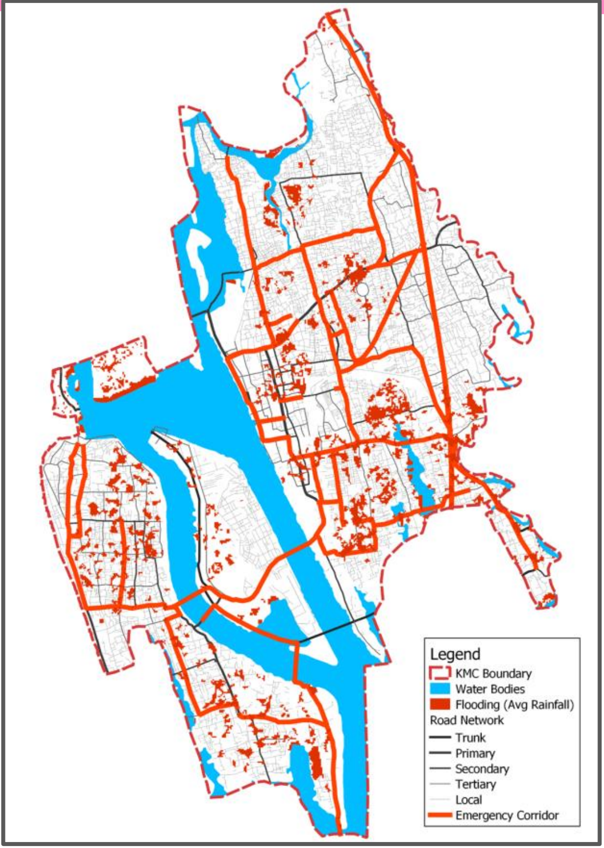
UPGRADED CONNECTIVITY INDICES

Indices	Normal Index	Avg Rainfall		
		BAU	Strategy 1	Strategy 2
Alpha	0.27	0.25	0.22	
Beta	0.44	0.49	0.54	0.46
Gamma	0.15	0.17	0.19	0.16

STRATEGY 3 : EMERGENCY ROUTE FOR EMERGENCY FACILITIES

Factor	Normal Day	Avg. Rainfall	
		BAU	Interventio n
Travel Time (Min.)	11 Minutes	19 Minutes	14.5 Minutes
Travel Length (Km)	2.3 Km	3.46 km	2.9 km

Proposal for identifying emergency corridors in the city in the event of floods, heavy rainfall or other disasters which are resilient to these effects for providing emergency operation



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PROPOSALS

PROPOSAL 3 : PLANNING AND POLICY RECOMMENDATIONS

RECOMMENDATION 1: FLOOD VULNERABILITY ACTION PLAN FOR URBAN TRANSPORT (FVAPUT)

Proposal | Aims to reduce the risks and impacts of flooding on transport infrastructure in a combined effort at regional level

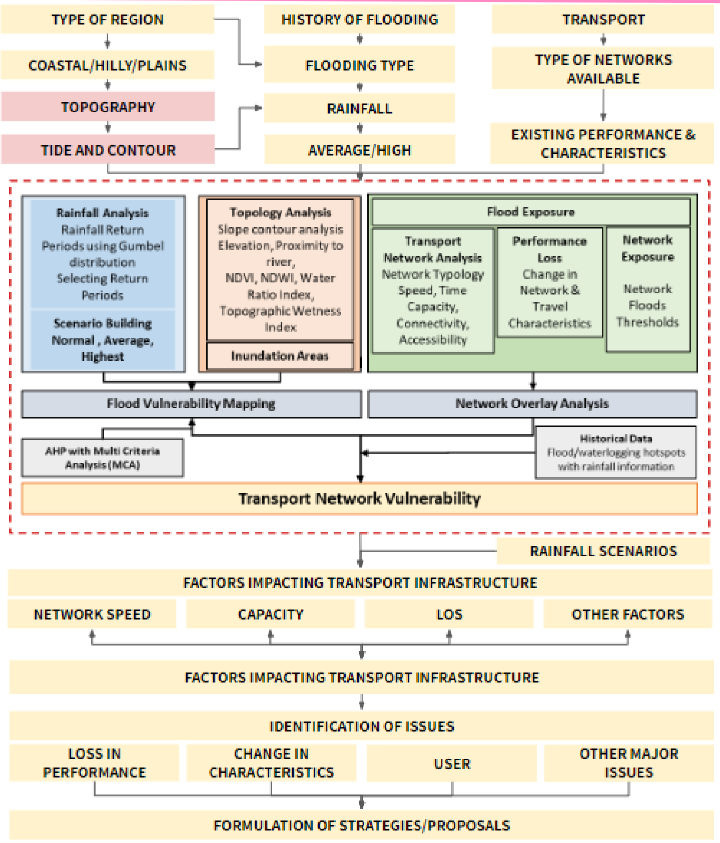
- Protocol for managing traffic, road network (closures), etc. and develop plans to reroute traffic and manage transportation disruptions based on precipitation within the city
- Resilient Emergency Services: Ensure that emergency services have reliable transportation during floods
- Evacuation routes and procedures for transporting people out of flood-vulnerable areas based on rainfall codes
- Plan for quickly restoring transportation infrastructure after a flood, focusing on clearing debris, repairing damage.

RECOMMENDATION 2 : FRAMEWORK FOR URBAN FLOOD VULNERABILITY ASSESSMENT FOR URBAN TRANSPORT

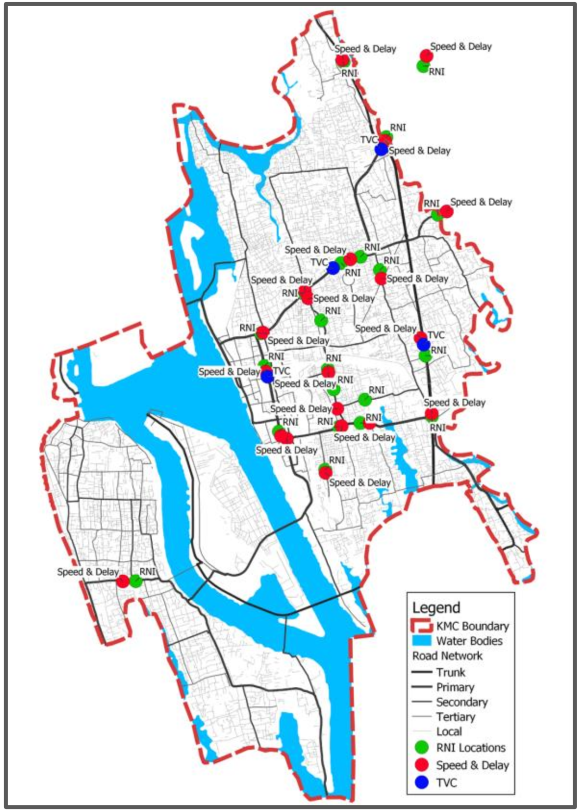
Proposal | Framework for a structured approach to assessing and mitigating flood vulnerabilities in urban transport networks.

RECOMMENDATION 3: REFORMS IN CITY'S NETWORK PLANNING

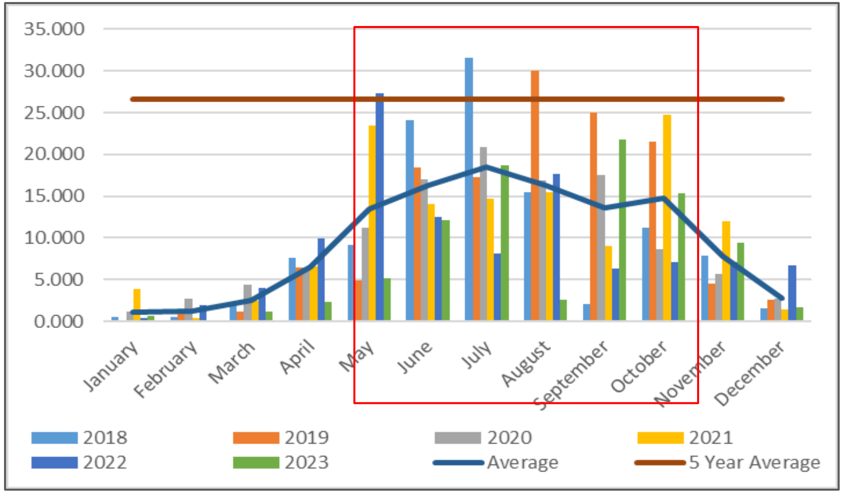
Proposal | Enforcement of network planning guidelines for mitigating impact of urban floods on transport networks



DATA COLLECTION



RAINFALL & TEMPERATURE



Source: IMD Data (2024)