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Enhancing Urban Resilience – A Nature Based Solution Approach To Mitigate Urban Flooding. A Case of Kolkata.

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***Abstract*— Global climate change results in changed weather patterns and increased episodes of high-intensity rainfall events occurring in short periods. Kolkata, a linear coastal city spread on the banks of river Hooghly, is the 3rd most flood-prone city in the world with a large population exposed to urban flooding. Over-topping of the Hooghly River, change in land use patterns, diminishing retention water bodies, the failed capacity of sewerage and canal networks, shrinkage of wetlands, and failed grey infrastructures are a few catalysts of urban flooding. The most vulnerable are the poor inhabitants of the city due to the unplanned, densely spread informal settlements with less attention to environmental issues. Thus a holistic and sensitive approach towards urban flood mitigation is the need of the hour. The project focuses on understanding the role of urban water bodies such as ponds, wetlands, etc in one of the identified vulnerable area. The outcome of the projects explores a nature-based solution approach in terms of its sustainable management, preserving and restoring the natural as well as modified ecosystem. The proposed spatial planning and design guidelines would effectively and adaptively help to mitigate issues of urban flooding providing both human wellbeing and environmental benefits.**

***Keywords*— Global climate change; Urban flooding; Nature-based solution**

I. INTRODUCTION

A. Background - Global Scenario

The IPCC and the Asian Development Bank specifically identify the heavily urbanized mega-cities in the low-lying deltas of Asia as hot spots for climate risks (ADB 2008; IPCC AR4 2007). The phenomenon of climate change and urban flood has in recent times engaged the attention of planners, governments, and other authorizations worldwide due to the increase in the threat of climate change which has origins in anthropogenic activities. Flooding in urban areas can be caused by flash floods or coastal floods or river floods but there is also a specific flood type more appropriately identified as water logging which is called urban flooding. According to the National Disaster Management Authority of India, the most notable cities of India that are severely affected by the increasing trend of urban flooding are Hyderabad in 2000, Ahmedabad in 2001, Delhi in 2002 and 2003, Chennai in 2004, Mumbai in 2005, Surat in 2006, Kolkata in 2006,2016, Jamshedpur in 2008, Delhi in 2009 and Guwahati 2010. Studies by NDMA reveals that urbanization leads to developed catchment areas, the urban flood peaks from 1.8 to 8 times and flood volumes up to 6 times. The peak discharge of floods is influenced by unplanned land use and other human activities, which change how precipitation is stored on the land surface and flows off into streams, water bodies, and low-lying regions. Poor inhabitants of these cities are among the most vulnerable, because large and densely populated conglomerations of informal settlements in most of these cities are located in areas of unplanned and unregulated development with less attention to environmental issues (World Bank 2010b; UNFCC 2008).

Figure 1 – Climate change scenarios

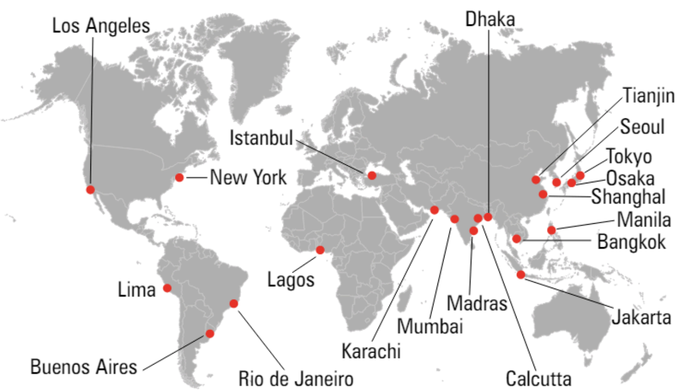


Figure 2 – Cities vulnerable to climate risks,
Source - Roadmap for low carbon and climate resilient, Kolkata

B. Regional scenario - Understanding Kolkata

1) Location

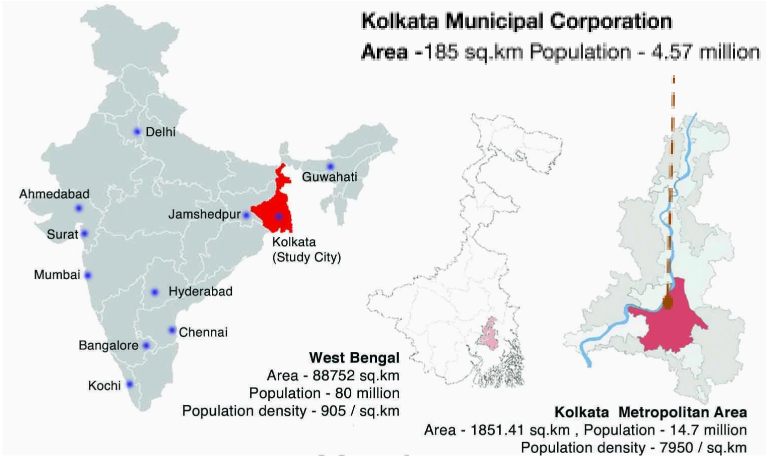


Figure 3 – India map showing all the vulnerable cities facing urban flooding & location map of Kolkata

2) Climate

Kolkata has a Tropical wet-and-dry climate (per Koppen climate classification) with an annual mean temperature of 24.8 C. Summers are hot and humid. Early summer experiences spells of thunderstorms and heavy rains. Rains are brought by the Bay of Bengal branch of South-West monsoon between June and September, supplying the city with most of its annual rainfall of 2020 mm (2006). Winter lasts only about two and a half months between December and January. (Mukherjee & Bardhan, 2017-18)

3) Demography

The KMC, which covers 185 km2 and is divided into 141 wards, is the core component of the KMA (KMC 2010). The land use pattern in the KMC is more urban, reflecting 300 years of organic growth. With almost nonexistent land-use planning or control, residential and non-residential land use is co-mingled in most areas, with little or no demarcations. The KMC accounts for 31% of the KMA's population. More than a third of the KMC's population lives in slums. (Dasgupta, Gosain, Rao, Roy, & Sarraf, 2012)

4) Urban Flooding scenarios

The flood proneness of different areas within KMA is shown in Fig 4.The south east region majorly covering the KMC area has the highest proneness to flood of 94%. (Bardhan, 2017)

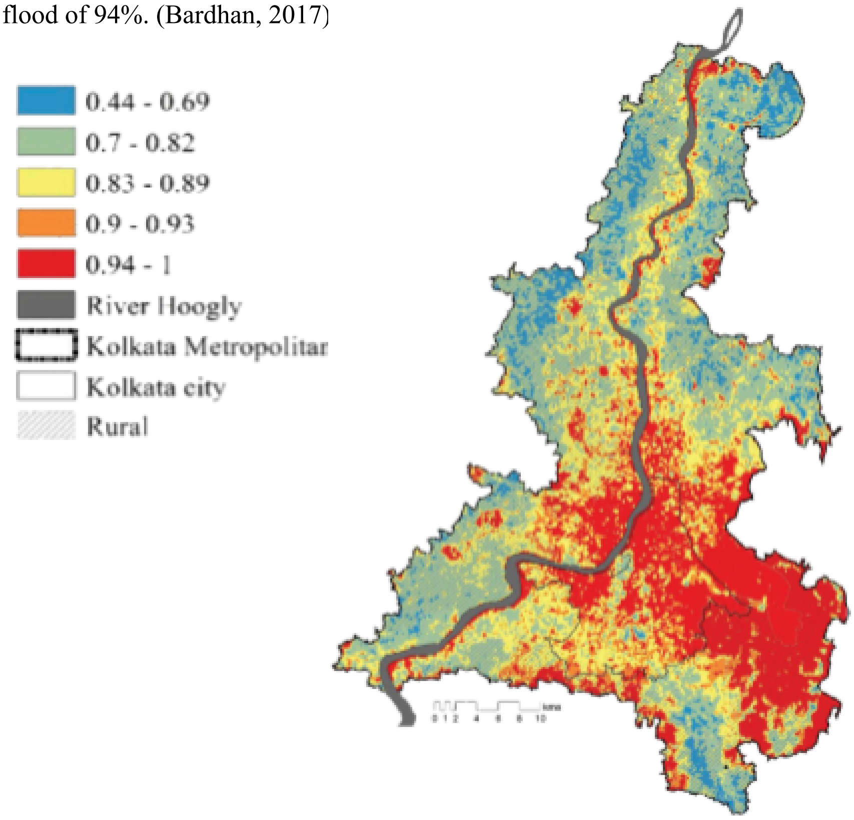


Figure 4 – Flood proneness map of KMA, Source - (Bardhan, 2017)

Certain portions of the city stays waterlogged for more than three days, with a depth ranging from 1.5 to 3 feet. Over the years, not only has the depth and length of water logging increased in certain places, but there has also been a major growth in the size of the land inundated as indicated in Fig 5.

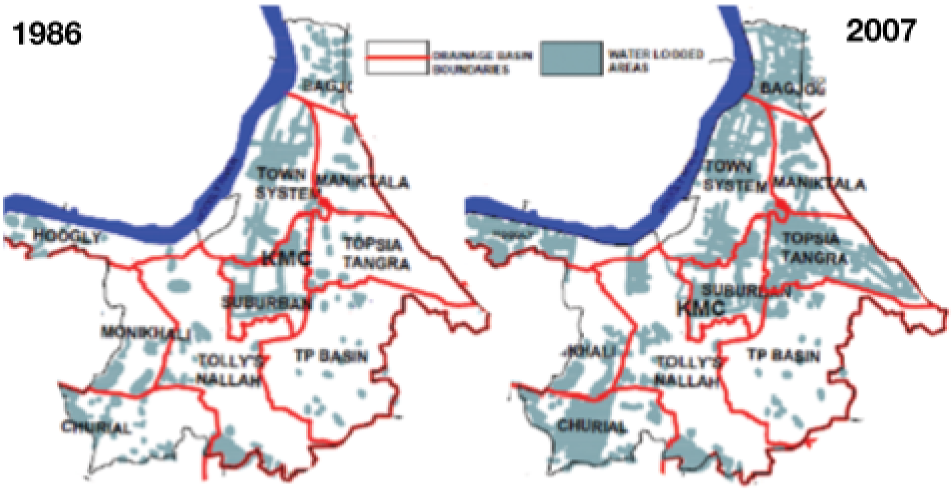


Figure 5 – Comparison of Water-logged Areas 1986, 2007, Source - (Mukherjee & Bardhan, 2017-18)

A study conducted by Kolkata Municipal Corporation and British Deputy High Commission in 2015 presented the pluvial flood maps which show the extent of flooding under extreme situations like 300 mm and 400 mm rainfall in 24 h. In such scenarios, almost the entire city is likely to get flooded as indicated in Fig 6.

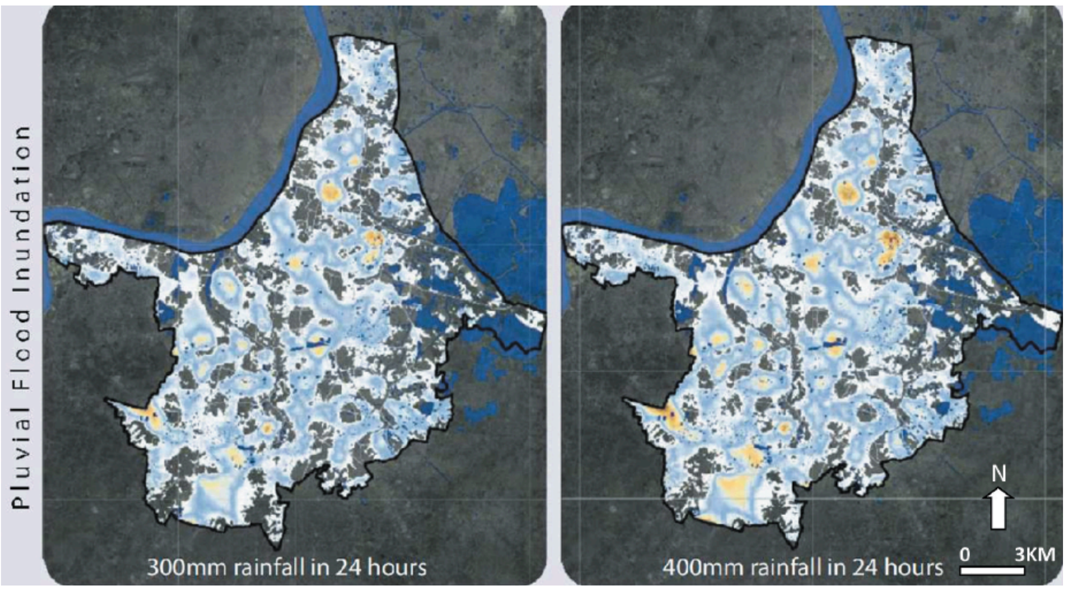


Figure 6 – Flood maps of KMC showing the projected extent of flooding under various extreme situations like 300 mm rainfall and 400 mm rainfall in 24 h, Source - (Kolkata Municipal Corporation (KMC), 2017)

TABLE I

HISTORICAL FLOOD EVENTS IN KOLKATA, Source - (Bank, 2011)

Years	Effects
1986	Flooding due to heavy rains in some areas of Kolkata
1999	Torrential rain-affected areas of Kolkata
2006	Heavy rain, large parts of Kolkata city underwater, 2000 people evacuated from the cit y

2007	51 people lost their lives, 3.2 million people affected

The recent flood scenarios has resulted in increase of water borne diseases, and inaccessibility to safe and clean drinking water. The entire transportation network comes to a pause adversely affecting the commerce and livelihood for a large mass of the population.

Figure 7 – Flood scenarios 2018, 2020, 2021. Source – The Independent,The Telegraph, India TV

The climate change scenarios by IPCC [2] show inundation of the city in scenarios such as 100-year return period storm and A1FI (temperature increase in Kolkata of about 1.8℃ and increase in the precipitation extremes of about 16 percent in 100-year return period storm). It is concluded that the largest affected area belongs to the two depth categories 0.25 – 0.50 m and 0.50 – 0.75 m for the baseline scenarios and 0.50 – 0.75 m and 0.75 – 1.00 m accounting for the largest affected areas in climate change scenarios as shown in Fig 8. (Bank, 2011)

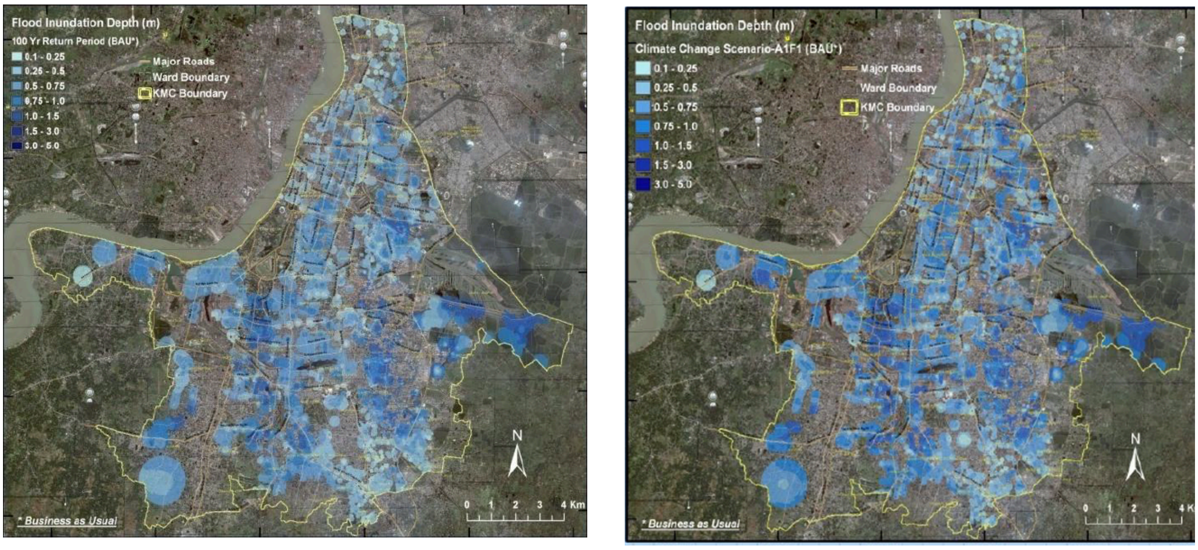


Figure 8 – Flood inundation depth scenarios for 100-year return period storm baseline and climate change scenarios. Source - (Bank, 2011)

TABLE II

EFFECT OF VARIOUS STORM RETURN PERIOD SCENARIOS, Source - (Bank, 2011)

	Storm return period scenarios			
	30 yr	**50yr**	**100yr**	**A1F1 (added to 100 yr)**
Area affected	33.7%	36.4%	38.5%	41%
Population affected (%)	38.9%	42.2%	44.9%	47.4%

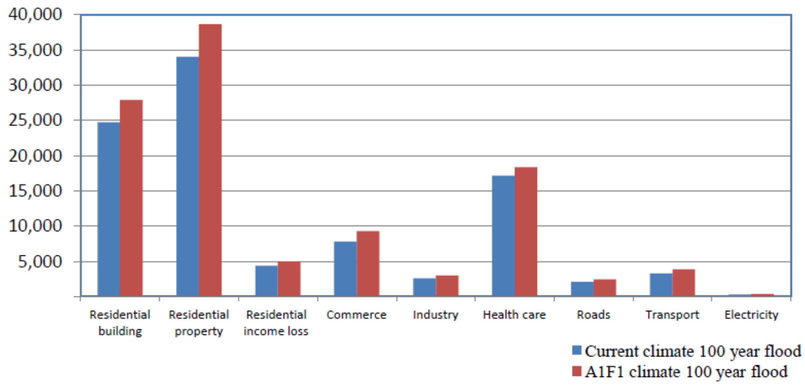


Figure 8 – Total losses in major sectors in KMC (Rs million in 2050). Source - (Bank, 2011)

C. Aim

To improve urban flood resiliency by enhancing the vulnerable blue infrastructure through a nature-based solution

D. Vision

The general vision is conceptualized as respecting the natural hydrogeological networks. Distinguishing and safeguarding watershed areas, neighborhood water bodies such as ponds, and open green spaces can act as sponges in high rainfall events, reduce the volume of rainwater runoff, and lower the risk of flood and waterlogging.

E. Objectives

1) *Macro level (City scale):* To understand the various factors leading to urban flooding in Kolkata

2) *Macro level (City scale):* To identify one of the most vulnerable areas by overlapping the layers of Topography, Hydrology, Geology, Land use land cover change, Flood vulnerability index & social vulnerability.

3) *Macro level (Watershed and ward scale):* To study the various approaches of nature-based solutions through case studies, best practices, and literature reviews and their applicability in the context taken up for study to be produced in terms of master plan and guidelines.

4) *Micro level (Pilot projects):* Landscape design proposals for identified potential pilot areas, increasing their capacity to delay store, and release the precipitation as well as creating opportunities for place-making interweaved with ecological enhancement.

F. Scope

1) Selection of a study zone in terms of low-lying areas within a particular watershed with the potential of creating a network to move and use the flood water from the adjacent neighborhood in the selected ward through Google satellite images, DEM, and Maps generated by Bhuvan and Arc GIS.

2) The demonstration project will be focused on the protection and enhancement of urban water bodies and green space around

3) Identification and analysis of suitable nature-based solutions needed for the study site and scenario through literature study for various standards and components, case studies for understanding the implementation in similar situations, and site conditions as per data collected through Google Street photos and site visits.

G. Limitation

1) The project doesn't cover the detailed study of all areas, limited to the highest vulnerability in terms of flood and societal threats seen in recent years

2) Nature-based solution study will be limited in terms of mitigation of flood-related issues and areas with the potential of acting as a sponge

3) The study will not be in-depth in terms of wastewater management systems and water supply of household

H. Methodology

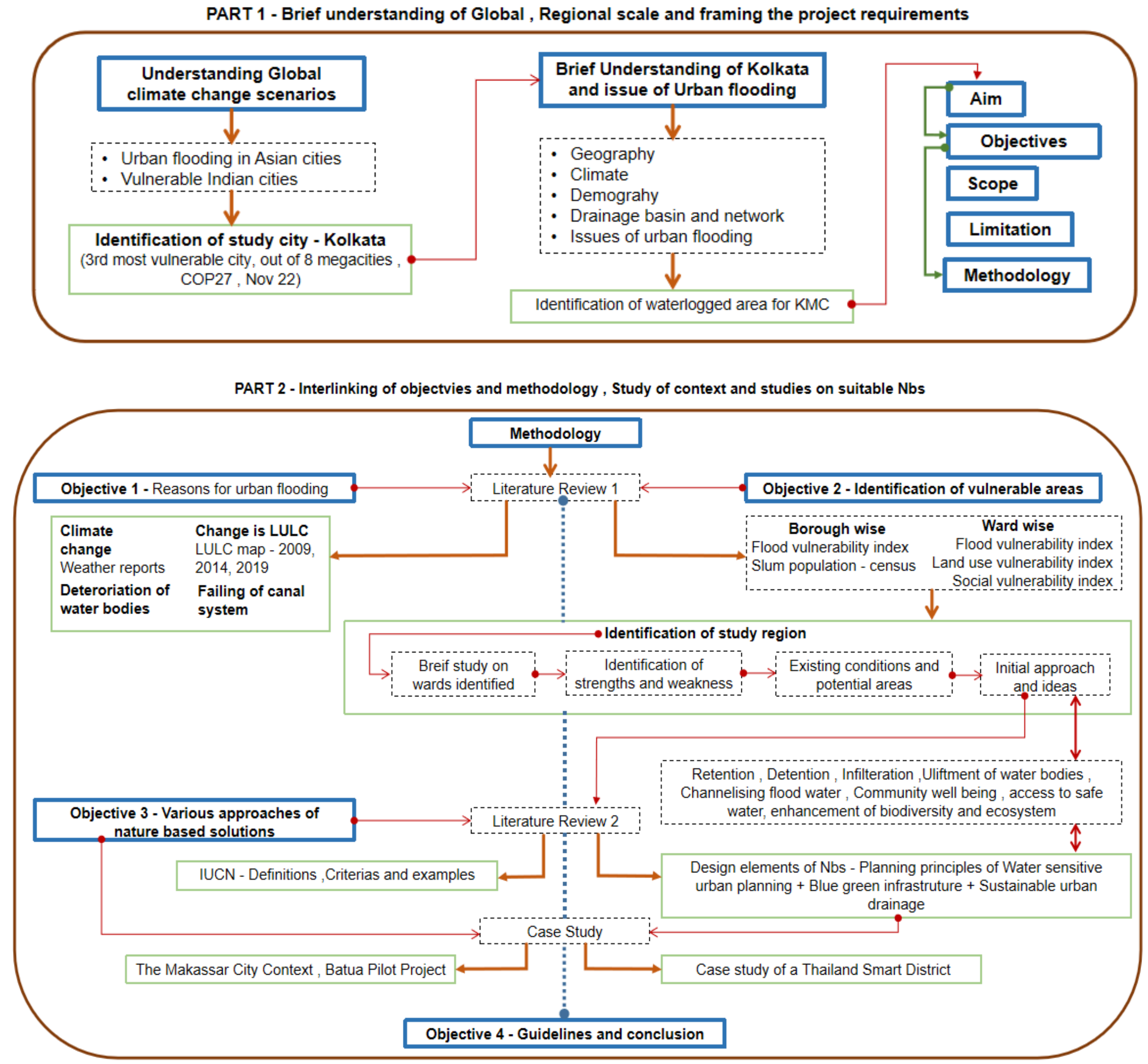
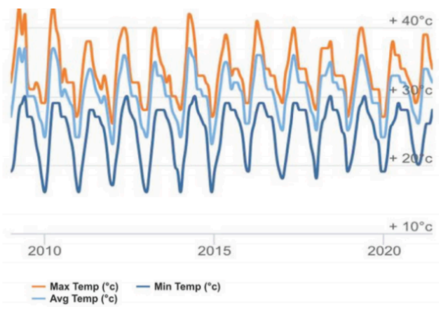


Figure 9 - Methodology for the project

II. UNDERSTANDING THE REASONS OF UBAN FLOODING IN KOLKATA

A. Climate Change

According to the Royal Meteorological Society the recent temperature graph (Fig 10), shows the maximum temperature remains almost the same but the lowest point of minimum temperature has kept rising over the past years. An increase in temperature also increases the potential for heavy rainfalls. The precipitation trends show an upward direction of the linear trend line, an increase in annual precipitation over the years in Kolkata as indicated in Fig 11.



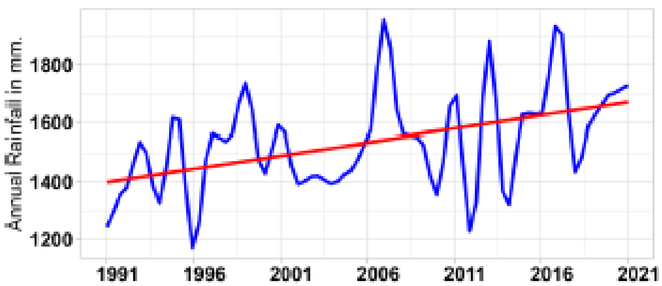


Figure 10 – Maximum, Minimum & Average Temperature trend, Source – Weather online 2021

Figure 11- Precipitation trend

B. Changing Landscapes over the centuries

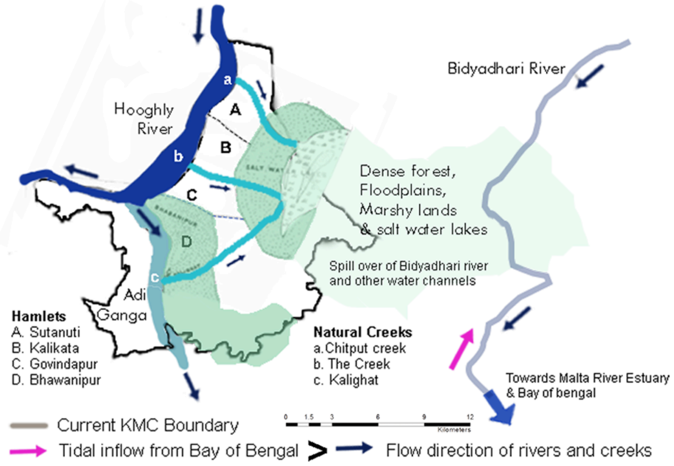


Figure 12- Kolkata Before 1690 pre-colonised , Source - Edited from Conjectural map of Calcutta, in the period of tradition

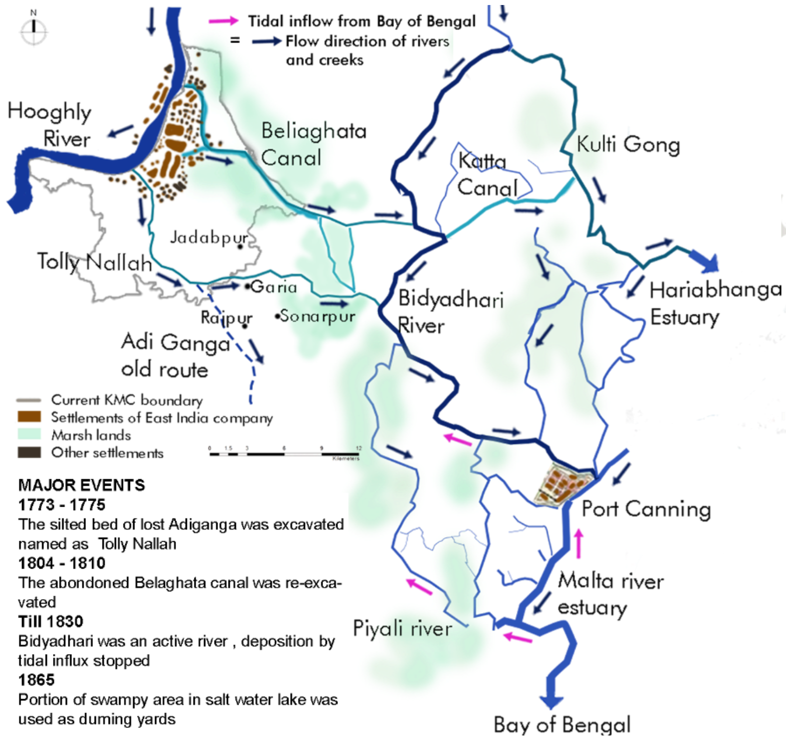
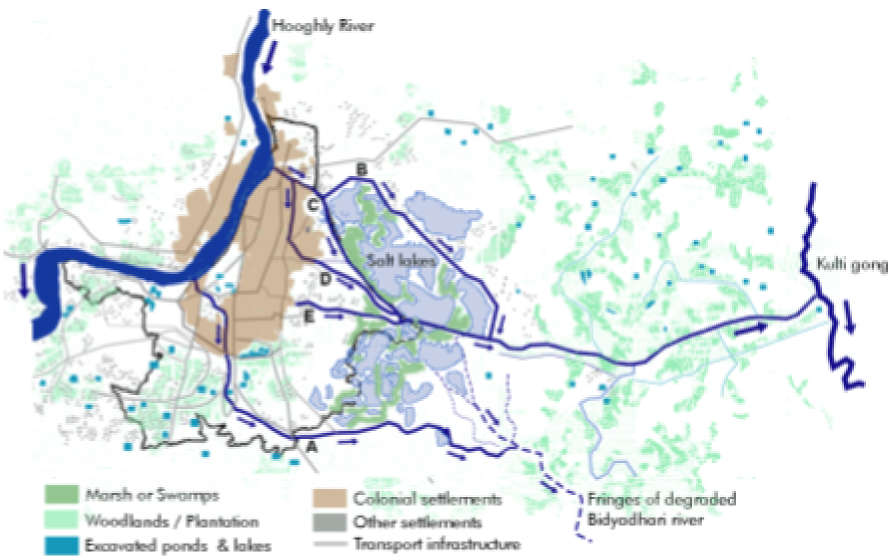


Figure 13 - Calcutta in 1893 Colonised, Source - Edited from Calcutta and environs 1893 map, Constable hand atlas of India The Edinburg Geographical Institute



MAJOR EVENTS TILL 1951

- Canals helped in navigation as well as drainage

- The sewarge system relying on the eastwards slope got established by excavation of various canals and laying of underground sewarge system

- Bidhyadhari river eventually got choked with sewage

- The waste water continuosly flows to the eastern fringes , converting the salt waters to brackish water, led to the formation of East Kolkata Wetlands

Figure 14 - Calcutta in 1951 After Colonisation , Source - Edited from Toposheet of India , NF 45 7 & NF 45 8

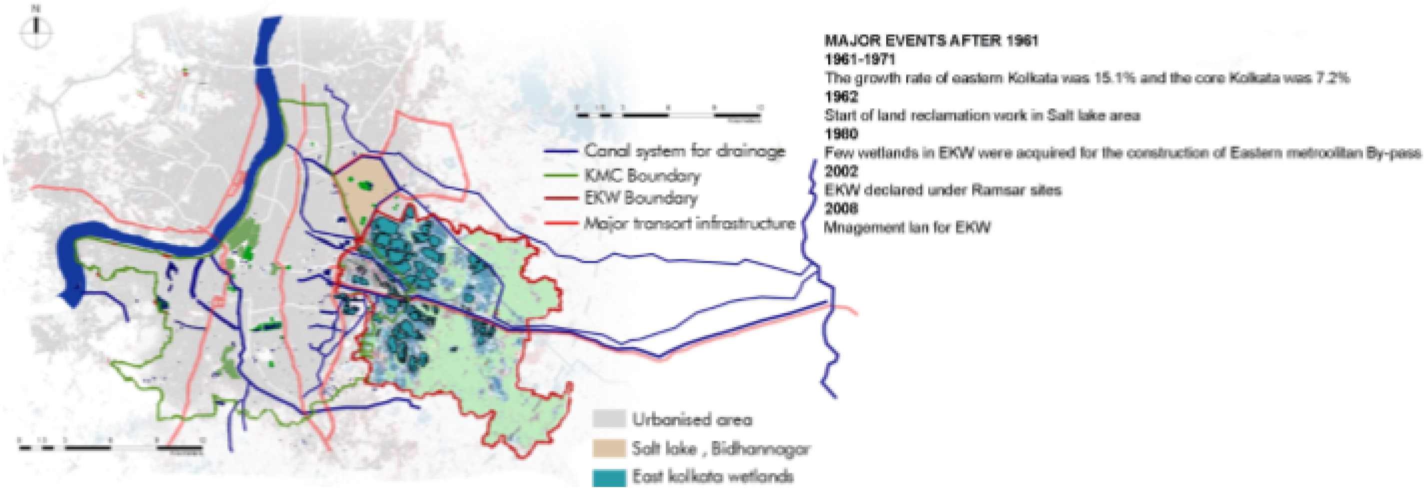


Figure 15 – Kolkata 2024

Figure 16 – Unique self- sufficient ecosystem of the city

Inference – Kolkata A typical riverine city, as it origin was surrounded by marshes, tidal creeks, mangroves, swamps and wetlands. These would act as natural sponge landscapes for the city. Over the years, city lost it natural sponge landscapes. The eastern fringes of the city has lost most of its natural wetlands & currently part of peripheral borough VII comes between the boundary of EKW as well one of the major KMC'S urban & transit development.

C. Change in Land use Land cover

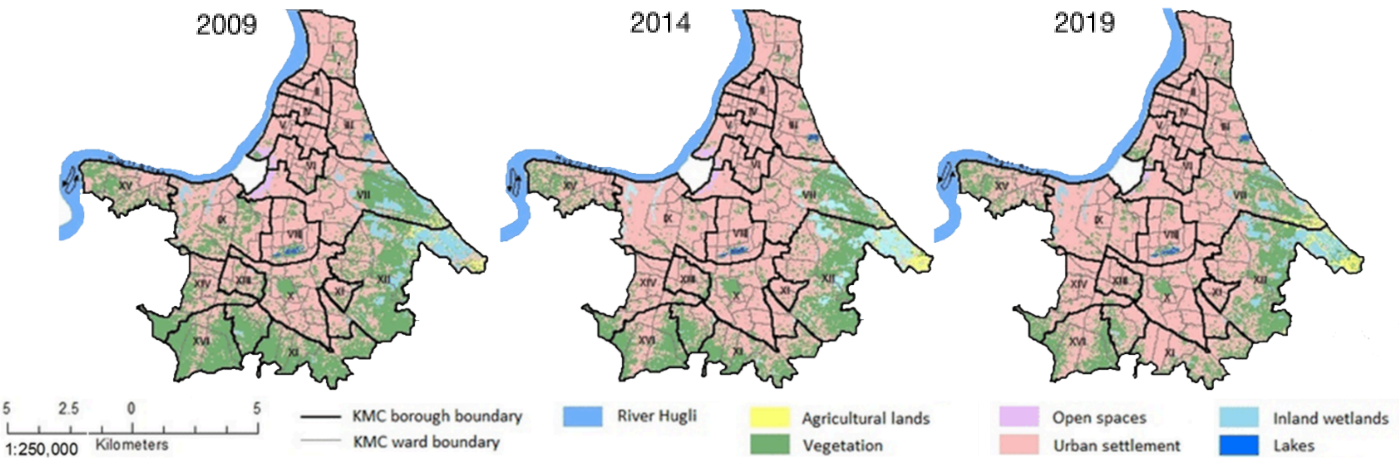
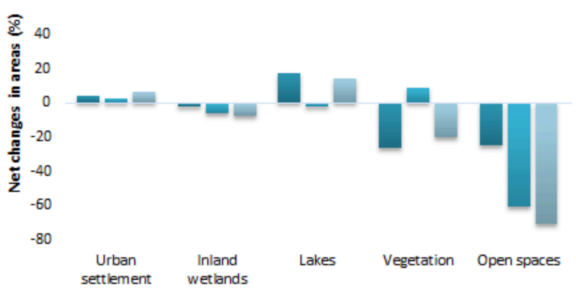


Figure 17 – Distribution of land use and land cover (LULC) classes in 2009, 2014, and 2019 featuring the wards and boroughs of the (KMC) post monsoon, Source - (Mukherjee, Sikdar, Pal, & Schutt, 2021)



LULC Classes	Urban Settlement	Inland Wetlands	Lakes	Vegetation	Open Spaces	Agricultural Lands
2009, post-monsoon	139.23	49.69	0.36	86.75	1.54	34.21
%	44.66	15.94	0.11	27.82	0.49	10.97
2014, post-monsoon	144.50	48.82	0.42	63.83	1.16	53.05
%	46.35	15.66	0.13	20.47	0.37	17.02
2019, post-monsoon	148.04	45.89	0.41	69.31	0.46	47.67
%	47.48	14.72	0.13	22.23	0.15	15.29

Figure 18 – Distribution of LULC by class area extent (km2) and percentage (%). Source - (Mukherjee, Sikdar, Pal, & Schutt, 2021)

Inference - The area under urban settlement increased by 6.38% in the post-monsoon period. Areas of open spaces overall declined in distribution during both types of seasons of the total observation period (2009–2019). The peripheral boroughs VII, XII, XI, and XIV lost most of their blues and greens.75% of the city is impervious surface, and 80% of the water transforms into runoff after 32mm / 2h of rainfall. (Mukherjee, Sikdar, Pal, & Schutt, 2021)

TABLE III

EFFECT OF URBANIZATION ON SURFACE RUNOFF AND INFILTRATION, Source – (WMO 2008)

Types of Surfaces	Evaporation	Shallow Infiltration	Deep Infiltration	Surface Run-off
Natural Ground Cover	40%	25%	21%	10%
10%-20% Impervious Surface	38%	21%	21%	20%
35%-50% Impervious Surface	35%	20%	15%	30%
75%-100% Impervious Surface	30%	10%	5%	55%

E. Lost water bodies

Detailed map book of the city containing 284 plates by the National Atlas & Thematic Mapping Organisation showed it to be 8,731 around 15-20 years ago. Google's satellite imagery of Kolkata showed it was 4,889 in 2006. That number has further whittled down to around 3,500 now (Ray, 2015). Study (2005-2015) shows 53% loss of wetland in peri-urban areas of the city

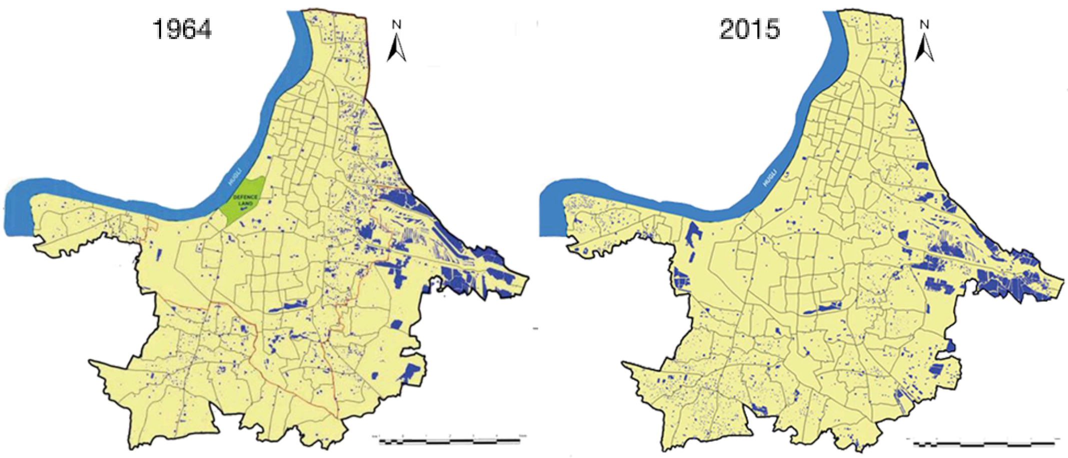


Figure 19 – Distribution of water bodies in KMC (1964 – 2015)

Inference - In the metropolitan part of the city, the demise of small water bodies, has created problems in holding capacity of surface runoff and groundwater recharge. The filling up of ponds and marshlands to obtain real estate is linked to increased problems of drainage and flooding. These pukurs or tanks are overflowing during rain resulting in flood, as their link to one another and the rivers that carry their excess water to the sea has been cut off by the unplanned urbanization. The efficacy of wetlands towards flood resiliency has decreased by 65%

F. Hydrology – Watershed and drainage basins

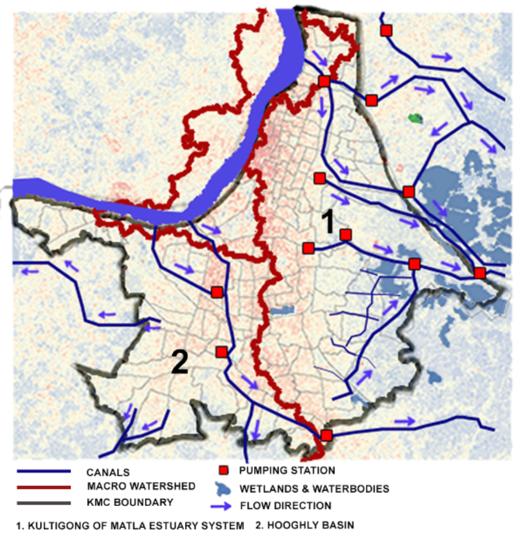


Figure 20 – Natural macro water shed overlapped with current canal network

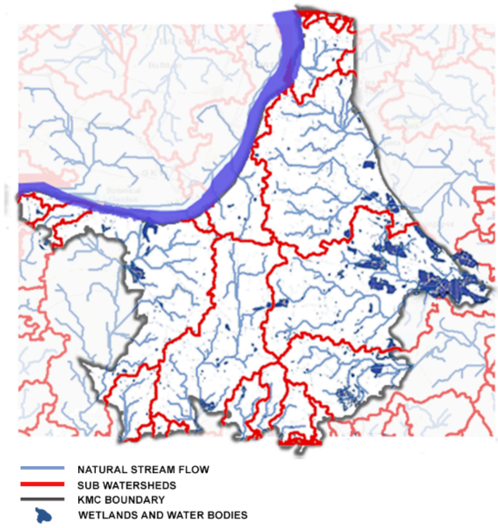
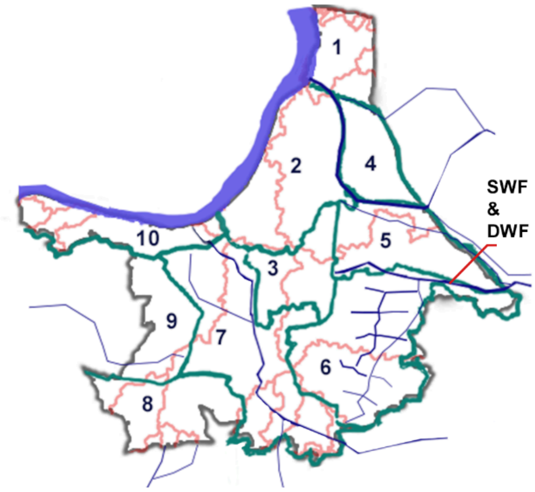


Figure 21 – Natural micro water shed



Drain into Kultigong of Matla estuary system which lies on the eastern side of the city.

1. Bagjola Basin
2. Town System
3. Suburban system
4. Maniktala Basin ,
5. Tangra Topsia Basin ,
6. T.P Basin -

Major outfall of Town system Suburban system

Tangra Topsia Basin and TP Basin - Storm water channel and Dry weather flow channel

Drains into the hooghly river in the west.

7. Tolly Nallah Basin
8. Churial Basin
9. Manikhali Basin

Figure 22 – Overlay of modified drainage basins and natural watersheds

Inference – The unplanned and organic growth didn't respect the natural watershed and water flow of the city. The original design of Kolkata's drainage system was based on the drainage capacity of the sub-basins. However the unplanned diversion of surface runoff from one sub-basin to another is one of the reasons for overloading of the existing drains, resulting in flash floods.

G. *Failing of canal system*

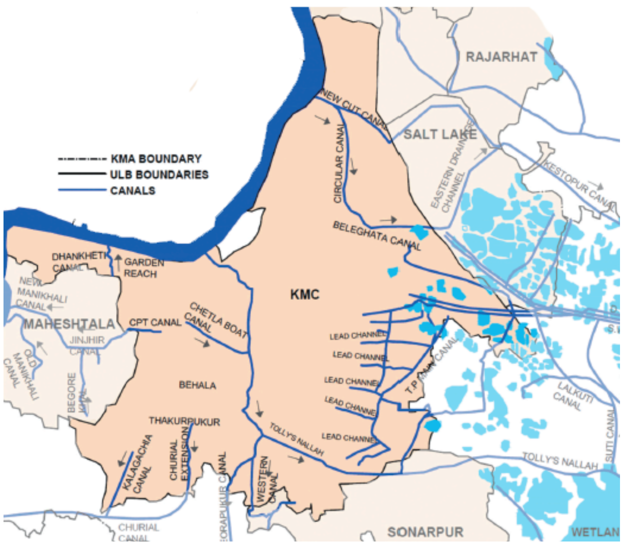


Figure 23 – Existing canal network. Source - (Mukherjee & Bardhan, Flood vulnerability and slum concentration mapping in the Indian city of Kolkata-A post Amphan analysis, 2021)

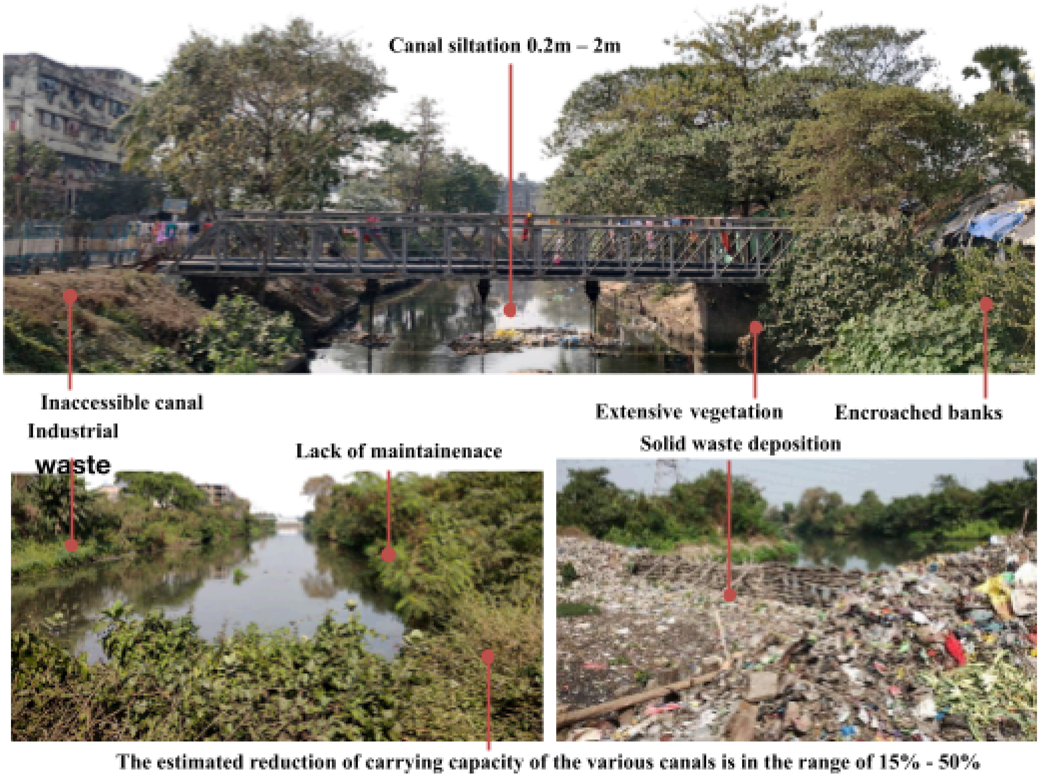


Figure 24 – Existing conditions of the canals

H. Topography

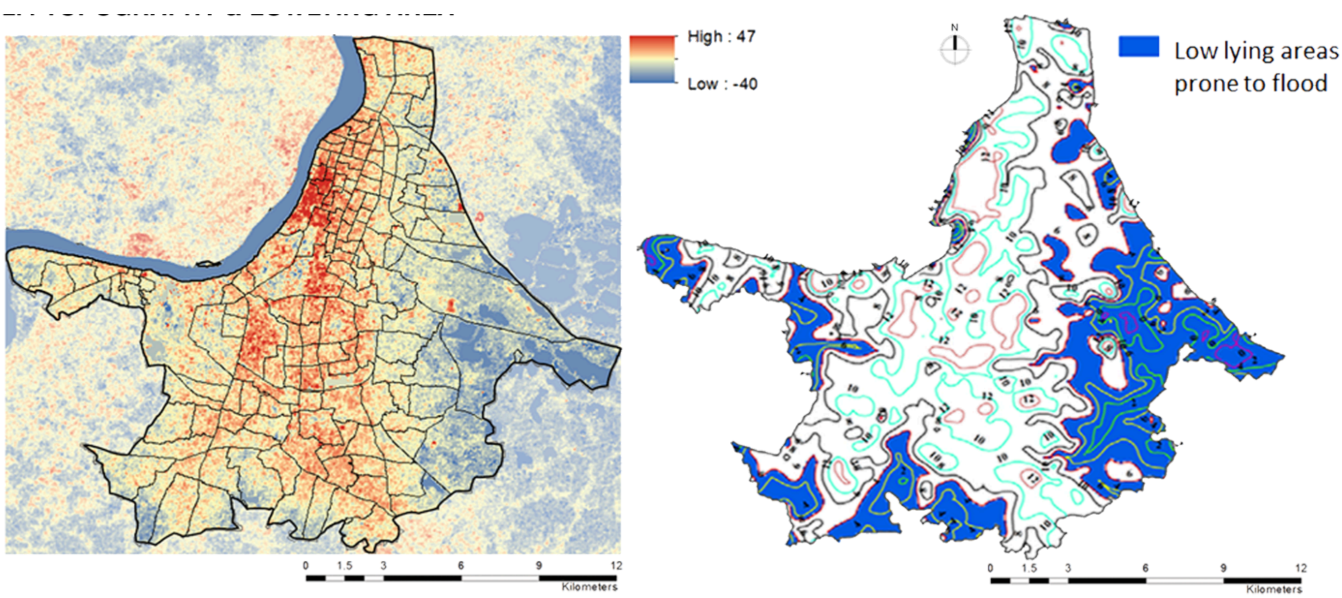


Figure 25 – Topography and contours

Inference - The topography of the city played a vital role in shaping the form of the metropolitan area. The land slopes down from the West (the River Hooghly) towards east and south east. The topography of the city reveals some saucer like low-lying places that can be easily inundated but require a lot of time to drain the excess water after rainfall. Kolkata is situated on the plain land so there is minimum slope (2 to 0°) from west to east in the land and with anthropogenic interference local slopes of land have been modified accordingly which makes an impact on drainage. The south eastern fringes of the city are low lying areas. The elevation of the KMC area ranges from 1.5 to 9.0 m above MSL with an average elevation of 6 m above MSL.

I. Geology

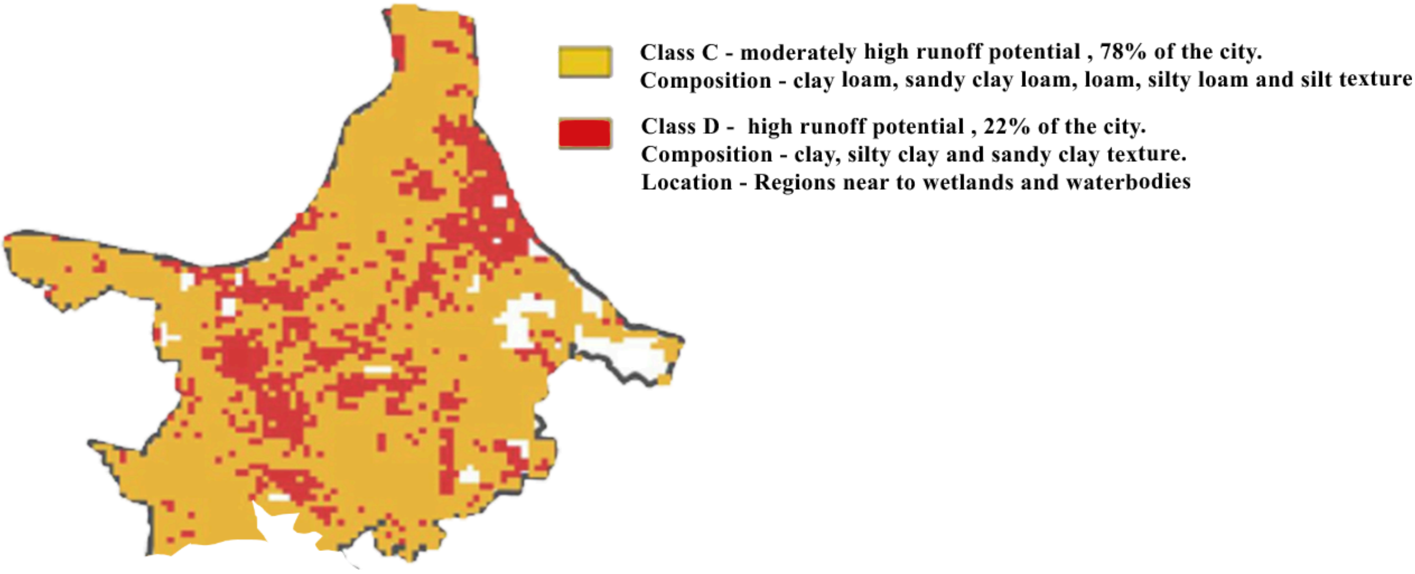


Figure 26 – Hydrological soil group. Source - (Bose & Mazumdar, 2023)

J. Flood Vulnerability Index

According to the research done by (Mukherjee & Bardhan, Flood vulnerability and slum concentration mapping in the Indian city of Kolkata-A post Amphan analysis, 2021) the flood Vulnerability index is calculated based on two variables - the depth and duration of flooding. The vulnerability index for each variable **(IN)** is defined as the ratio of the value of that variable in each borough **(V n)** to the maximum value **(V max)** for the variable in the city $FV_{IN} = V_N / V_{MAX}$. Water depth during the water logging period **(FV_{ID})** is calculated based on KMC borough-wise data (KMC report, 2013) where the maximum depth **(D max)** recorded is 42 cm. The water logging period (in hours) **(FVI_T)** is calculated based on KMC ward-wise data (KMDA, 2010) where the maximum and minimum periods of water logging due to heavy rainfall in KMC wards, are 101 h and 0 h, respectively.

Borough	Water depth during water logging period (in cm) (D)	FVI_D (D/D_{max})	Water Logging period (in hours) (T)	FVI_T (T/T_{max})	FVI ($FVI_D + FVI_T$)
I	36	0.86	8	0.08	0.9
II	8	0.19	14	0.14	0.3
III	8	0.19	12	0.12	0.3
IV	8	0.19	30	0.30	0.5
V	42	1.00	26	0.26	1.3
VI	42	1.00	4	0.04	1.0
VII	42	1.00	72	0.71	1.7
VIII	36	0.86	8	0.08	0.9
IX	36	0.86	8	0.08	0.9
X	42	1.00	0	0.00	1.0
XI	36	0.86	8	0.08	0.9
XII	42	1.00	2	0.02	1.0
XIII	42	1.00	2	0.02	1.0
XIV	36	0.86	101	1.00	1.9
XV	36	0.86	72	0.71	1.6

FVI	Borough nos.	Relative Ranks/ Degree Of Flood Vulnerability
.3-.8	III, II, IV	Low
.8–1.4	I, V, VI, VIII, IX, X, XI, XII, XIII	Medium
1.4–1.9	XV, VII, XIV	High

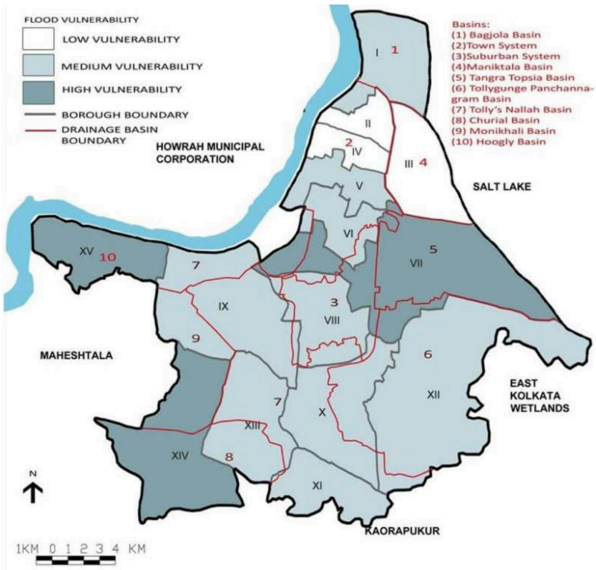


Figure 27 – Borough-wise flood vulnerability assessment. Source – (Mukherjee & Bardhan, 2021)

Inference - As a result, the most flood-prone boroughs are concentrated in the Monikhali Basin, Hooghly Basin, Churial Basin, and Topsia-Tangra Basin. Boroughs XV, VII and XIV are in a high degree of flood vulnerability. Overlaying studies on LULC, Loss of water bodies, and topography it is found that the eastern fringes are the low-lying areas of the city as well as have lost most of its blue greens thus becoming the catalyst for urban flooding.

K. Social vulnerability study

Borough VII and XV locations invariably feature a large proportion of slums due to poor infrastructure, low in habitability and poor socio economic background.

Borough	Population, 2011	Slum population, 2009	Slum population in percentages
I	310,059	78,860	25.4
II	202,195	57,212	28.3
III	365,618	156,247	42.7
IV	235,399	82,039	34.9
V	226,274	44,869	19.8
VI	252,287	108,204	42.9
VII	**534,606**	**286,473**	**53.6**
VIII	255,577	70,948	27.8
IX	392,692	131,777	33.6
X	347,960	72,414	20.8
XI	146,439	60,417	41.3
XII	393,283	110,162	28.0
XIII	244,597	49,342	20.2
XIV	311,687	68,982	22.1
XV	**278,021**	**192,369**	**69.2**

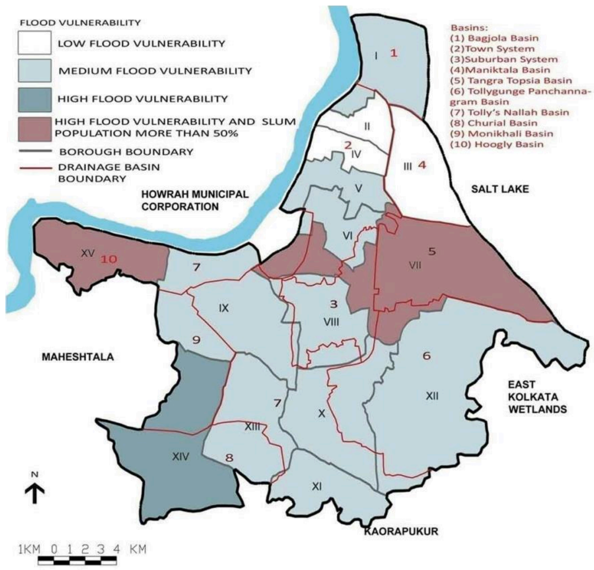
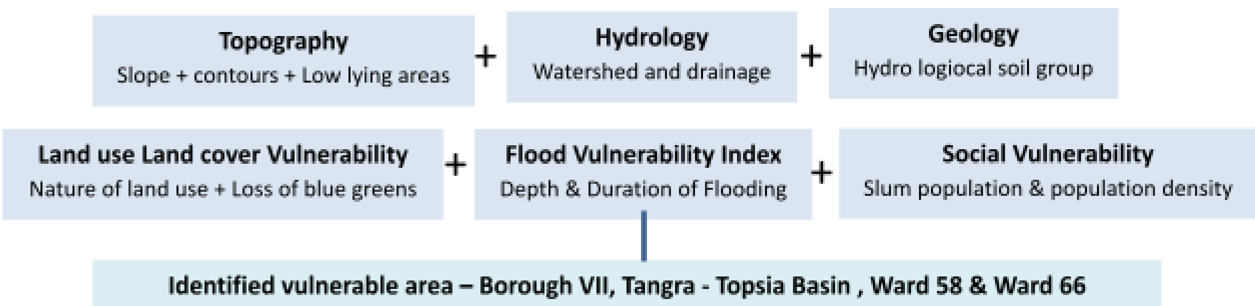


Figure 28 – Borough-wise flood vulnerability map of KMC and overlay with concentration of slum population. Source – (Mukherjee & Bardhan, 2021)

Inference - Borough VII and XV are most vulnerable and needs priority settings in terms of flood management initiatives and habitat up-gradation.

III. STUDY AREA DELINEATION



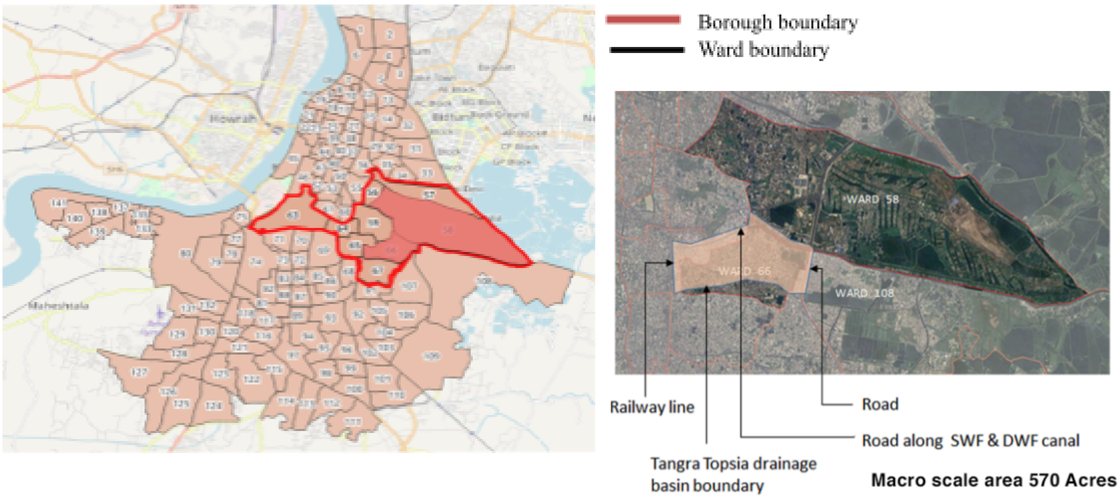


Figure 29 – Identified Vulnerable Borough, wards and delineation of master plan boundary

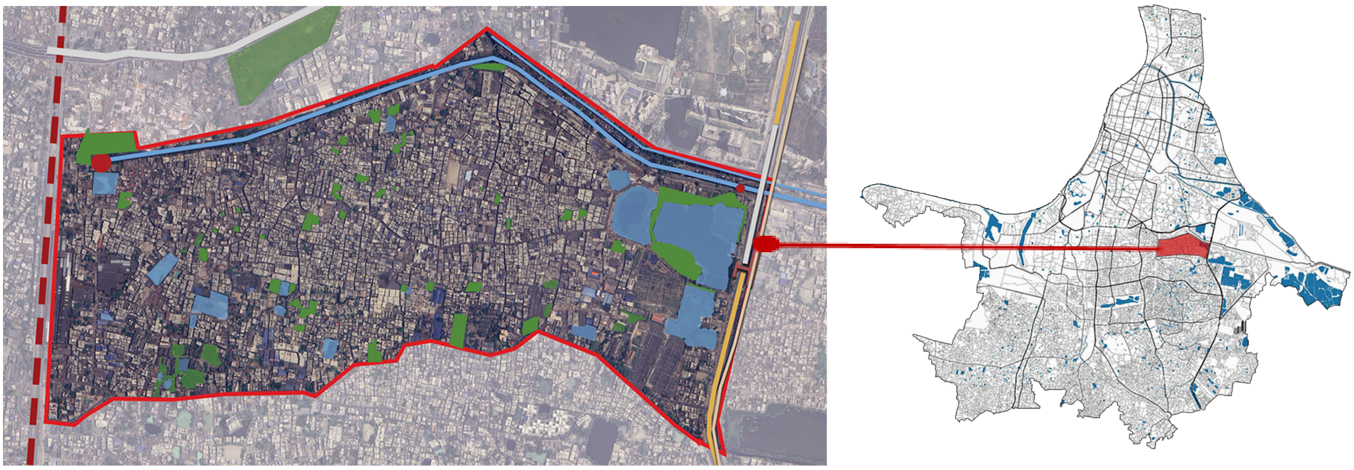


Figure 30 – Master plan & study area boundary

A. Description and Image of the study area

The selected master plan boundary is having an area 570 Acres. The areas is located strategically and is bordered by storm water canal and dry weather flow canal on the north and railway line in the west, Rashbehari connector in the south and E.M. By Pass on the east. A number of small scale industry and leather tanneries are spread along the canal. Although lacking an identity, the area is surrounded by notable infrastructure and urban development projects. Over the years major migration led to the dense population. The area selected was a part of agricultural and wetlands with a number of water bodies. The diminishing of the water bodies and the lost connection between the water bodies due to anthropogenic activities has led to a major issue of urban flooding effecting the livelihood of a large number of population. Many people depend on the ponds for their daily needs. The storm water canal now carry sewage water pumped from two pumping stations namely Ballygaunge pumping station and BR Ambedkar pumping station are heavily polluted and silted, making them inefficient to carry storm water.

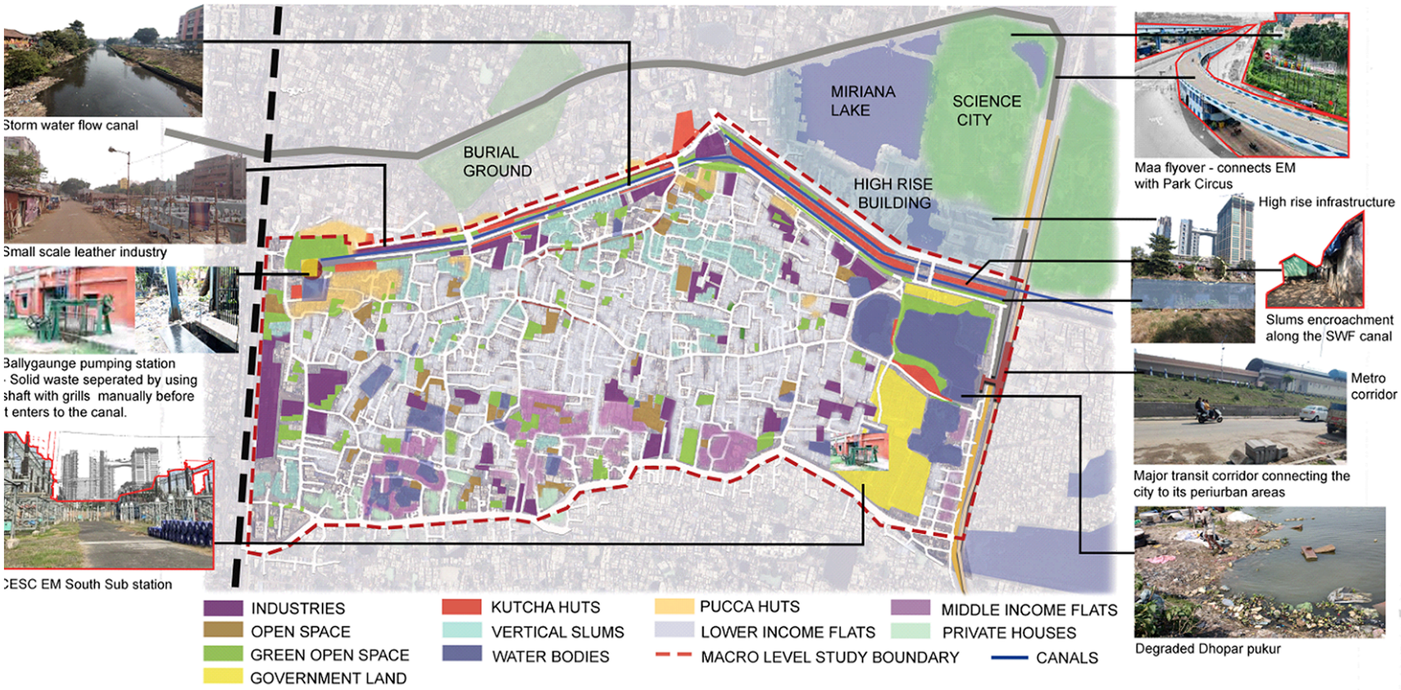


Figure 31– Image of the study area

B. Scenarios of floods in the study area

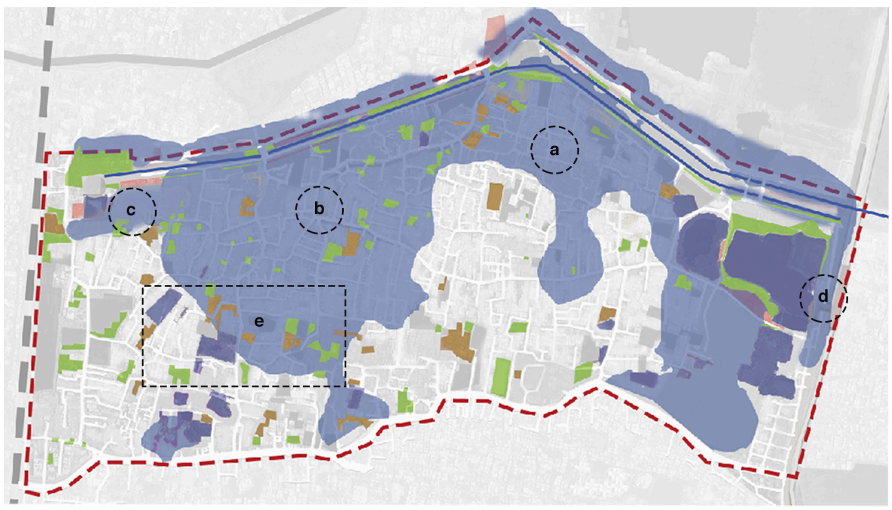


Figure 32 – Effects of urban flooding. Source – TOI, 2019

Figure 33 – Water logged area. Source – Edited from disaster atlas map of WB

Identified reasons for flooding –

1) The dense urban fabric keeping no room for water to reach catchment areas. Due to lack of proper storm water drainage network and sewage network the roads gets logged with rain water mixed with grey water. The accessible roads gets

blocked during monsoon making it difficult for the habitants to move and access their work places and other basic needs.

Figure 34 – Dense urban fabric

2) The construction of EM Bypass and the metro corridor at a higher level than the study area, results in all the extra water to flow down to road and get water logged. The corridor built disconnected the linkages between the water bodies. The commercial built ups between the road and the water bodies, doesn't allow the water to flow naturally to the catchment ponds.

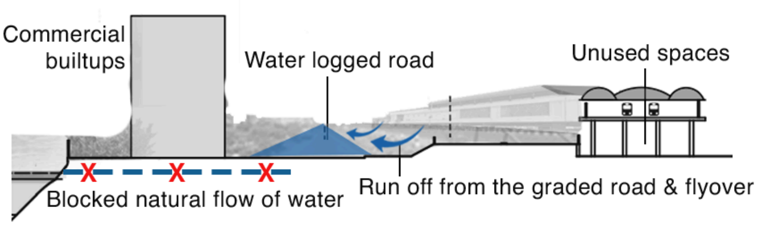


Figure 35 – (d) Typical scenario along the EM Bypass and Metro corridor

3) The filling up of blue and green areas , decreases the efficiency to hold and slow down the runoff

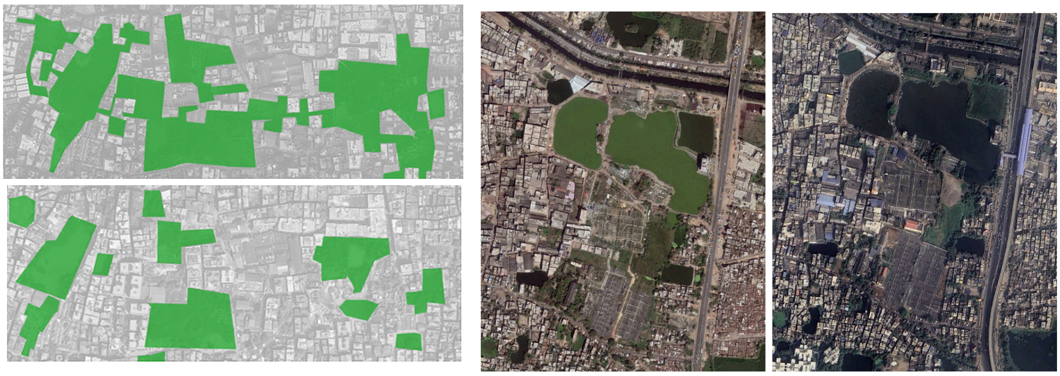


Figure 36 – (e & f) Decreased in blue and green areas with loss of connection between them

4) The degraded storm water and dry weather flow canal. Majorly these canals are encroached by slums resulting in direct sewage dumping into the canal. The edges of the canals are impermeable and are used for solid waste dumping. The open spaces along canal are not accessible and in many places encroached by parking for industrial vehicles. Although KMC has taken some initiatives along the canals to enhance the aesthetics such as installation of grill fencing and creating high walls. This discourages a connection between human and canal thus making the canal more ignorant and prone to degradation.

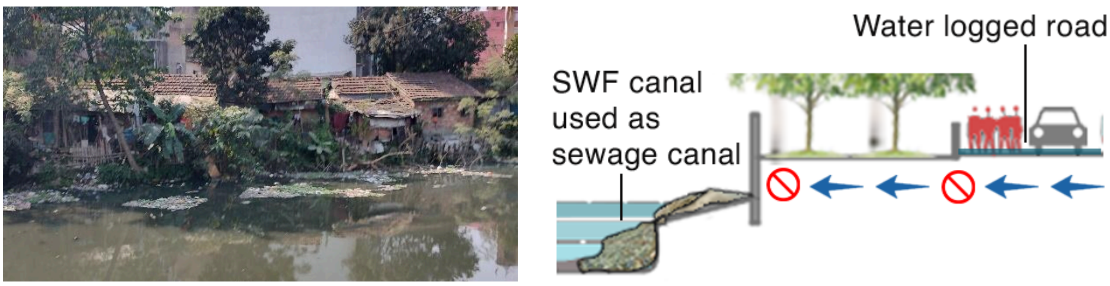


Figure 37 – Condition of canal and canal edges

C. Analysis of the population affected

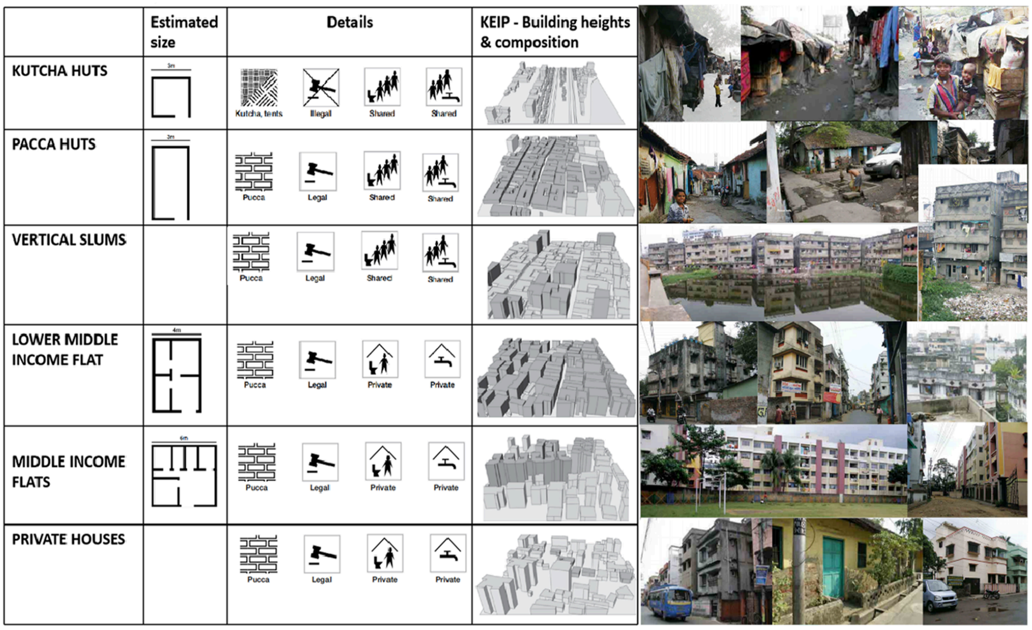


Figure 38 – Living conditions of the population

TABLE IV
ANALYSIS TO IDENTIFY THE INTENSITY OF VULNERABILITY AND SCOPE OF INTERVENTIONS

Housing typology	Access to open space for recreation	Proximity to water bodies	Dependency on water bodies	Effects during monsoons
Kutcha huts	Roads, Canal and pond edges	50m – 100m	Economy, Sanitation, Waste disposal, Daily Chores	Water inside homes, less access to clean water, Low economy generation, prone to water borne diseases
Pacca huts	In between spaces of houses, Roads , Canal and pond edges	100m - 300m	Economy, Sanitation, Waste disposal, Daily Chores	Water inside homes, less access to clean water, Low economy generation, prone to water borne diseases
Vertical slums	Terraces, Roads, Canal and pond edges	50m – 600m	Waste disposal	Water in ground floors, water logged roads, inaccessibility to reach workplaces and water pipelines to fetch water
Lower middle income flats	Terraces, Play grounds	500m – 1.5km	Waste disposal	Waterlogging in access roads and water in ground floors
Middle income flats	Terraces, Balconies, Parks within housing complex and neighborhoods	1km – 1.5km	NIL	May face waterlogging in access roads
Private houses	Private garden and public parks	>1.5km	NIL	Not much effected due to better infrastructure and drainage around

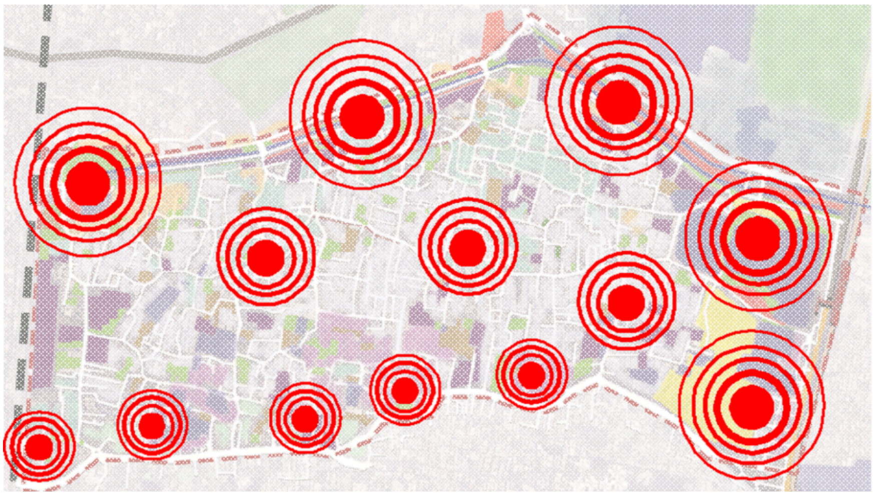


Figure 39– Intensity of vulnerability according to the analysis in Table IV

Inference – The major intensity of flood vulnerability is found to be along the canal and the dhopar pukur along the EM Bypass. The population living around these areas doesn't have proper access to infrastructure. They don't have much of an open space around thus the proposal to enhance the road, canal, and edges would create opportunities for place-making and play areas as well as conveying and storing the rainwater in monsoon seasons. There is a need for intervention of the canal and the water bodies since most of the people are dependent on the water bodies.

IV. UNDERSTANDING NATURE-BASED SOLUTIONS

A. Need for a landscape approach

A landscape approach is essential for urban flood mitigation because it integrates natural systems and human infrastructure to manage water flow more effectively. Considering the entire watershed and incorporating green infrastructure such as wetlands, parks, and porous surfaces reduces runoff, enhances water absorption, and mitigates flood risks. It balances ecological health with urban development, promotes sustainable land use, and fosters resilience against extreme weather events. This holistic perspective addresses immediate flood risks and supports long-term urban sustainability and environmental quality.

B. Understanding Nature Based solutions and its elements

1) Definition **-** 'Nature-based Solutions are actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits" (IUCN, 2016)

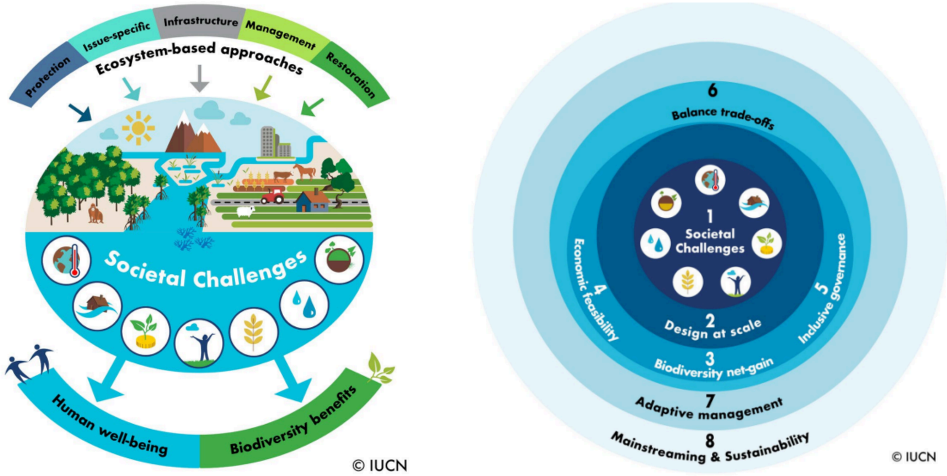


Figure 40 – Introduction to NBS. Source – IUCN, 2016

2) Water-sensitive urban design principles

Water-sensitive urban design and planning (WSUDP) integrate the urban water cycle, water supply, wastewater, stormwater, and groundwater management with spatial and urban design. This approach contributes to sustainability and livability, particularly when considered part of an overall urban strategy. (CSE 2016)

TABLE V

BROADER CONCEPTS OF WATER SENISTIVE URBAN DESIGN, Source – CSE 2016

Water- sensitive concept	Water-sensitive planning principle	Water-sensitive planning approach
Minimizing runoff volume	Protecting existing natural features and ecological processes	• Disturbance to soil and landscape minimized by maintenance of natural landforms. Waterways protected by provision of a buffer of natural vegetation to urban development • Natural channel design and landscaping used so that the drainage network mimics natural ecosystem
	Maintaining natural hydrologic behaviour of catchments	• Limiting increase in storm-water runoff volume by using natural drainage paths and infiltration basins • Reducing impervious areas and increasing pervious areas
Minimizing runoff discharge	Integrating water into the landscape to enhance visual, social, cultural and ecological value	• Minimizing use of hard engineered structures • Using native vegetation in storm-water management and all landscaping to maximize habitat values • Passing runoff through vegetated patches and/or through the ground, to cleanse the water from pollutants, especially from suspended sediments
	Minimizing sewage discharge into natural environment	• Wastewater treatment on-site or contribution to municipal wastewater treatment and reuse scheme • Reducing flooding at the downstream end of catchment
Minimizing the pollutant load	Protecting water quality of surface- and groundwater	• Control runoff from disturbed areas during the construction phase of the development • All storm-water runoff from hard surfaces is treated through infiltration, sedimentation, storage or biological treatment before leaving the site
	Minimizing demand on the reticulated water supply system	• Rainwater tanks collect roof runoff to supply toilet, laundry and outdoor uses. Houses connected to (or utilize) a grey-water or sewage recycling system to provide an alternative source of water for toilet flushing and outdoor use. • Houses incorporate water-efficient appliances and plants that need little water (preferably of local provenance) grown extensively in gardens

3) Elements of NBS for sustainable urban drainage system

Filter strips - are grassy or other densely vegetated strips of land that collect surface water runoff as sheet flow from impermeable surfaces.

Swales - Swales are linear vegetated channels with a flat base that encourage sheet flow of water through grass or other robust vegetation. They collect, convey and sometimes store surface water runoff allowing water to soak into the ground where soil conditions are suitable.

Bio-retention areas and rain gardens: Bio-retention areas and rain gardens are planted areas designed to provide a drainage function as well as contribute to the soft landscape.

Filter drains and trenches: Filter drains and trenches are linear excavations filled with stone that ideally collect surface water runoff laterally as sheet flow from impermeable surfaces. They filter surface water runoff as it passes through the stone allowing water to infiltrate into soil or flow.

Permeable pavements: Permeable pavements provide a surface that is suitable for pedestrian or vehicle traffic while allowing surface water runoff to percolate directly through the surface into underlying open stone construction.

Detention basins: Detention basins are vegetated depressions in the ground designed to store surface-water runoff and either allow it to soak into the ground or flow out at a controlled rate. Within development, these basins are usually small grassed areas, sometimes with a micro-pool or planted area at a low point where some standing water can accumulate.

Infiltration basins: The basins collect surface-water runoff from small areas and are usually off-line to prevent siltation

Ponds: Ponds are depressions in the ground that contain a permanent or semi-permanent volume of water.

Wetlands: Wetlands are shallow ponds with marshy areas, covered in aquatic vegetation. They retain sediments for an extended time and remove contaminants by facilitating adhesion to aquatic vegetation and aerobic decomposition

Catchment treatment: Treatment of incoming contaminated water into a water body or treatment in stages in the catchment area using decentralized wastewater treatment.

Floating wetlands (in-situ treatment): Creation of floating islands with wetland plants (rooted emergent macrophytes) that are grown on floating rafts/mats. This facilitates root-zone treatment and maintains or improves the water quality in the water body. The plant roots hang beneath the floating mat and provide a large surface area for bio-film growth which forms an important part of the treatment reactor.

Creation of buffer/treatment zone using constructed wetlands (floating/subsurface flow) on the periphery of the water body (protection): A peripheral wetland can be designed either as a sub-surface flow type or a floating type. Depending on the design, the use of wetland plant species will vary

Bio-remediation (in-situ treatment): In-situ decomposition of organic matter in a water body using biological products. Depending on the type of product being used, the dosage, cost and frequency varies.

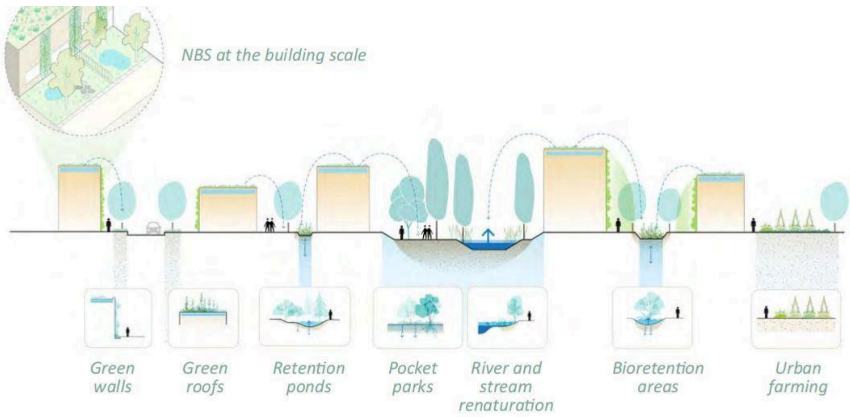


Figure 41 – Implementation of NBS elements at a neighbourhood scale

V. DESIGN PROPOSALS

A. Concept

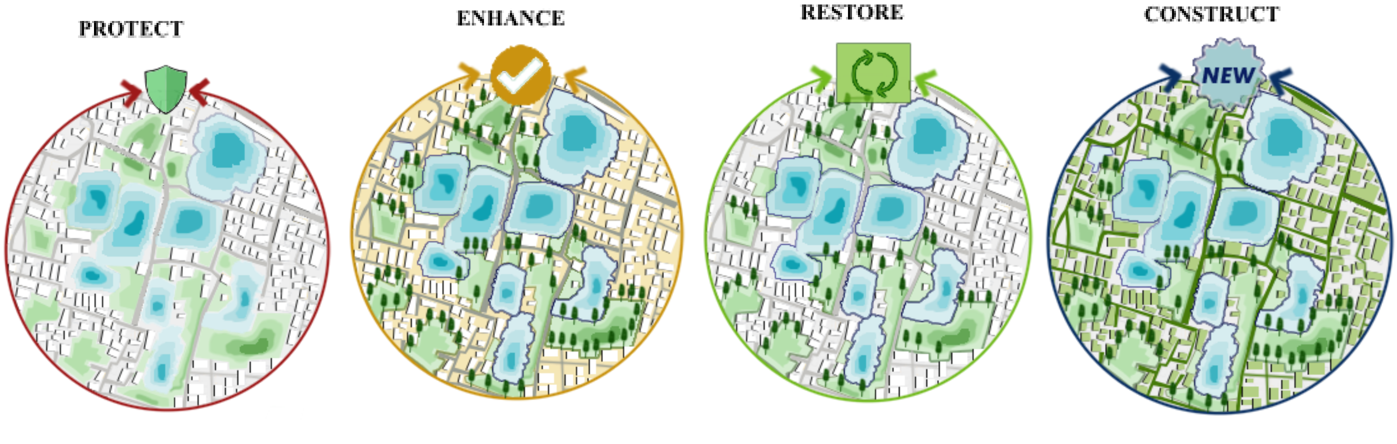


Figure 42 – Concept

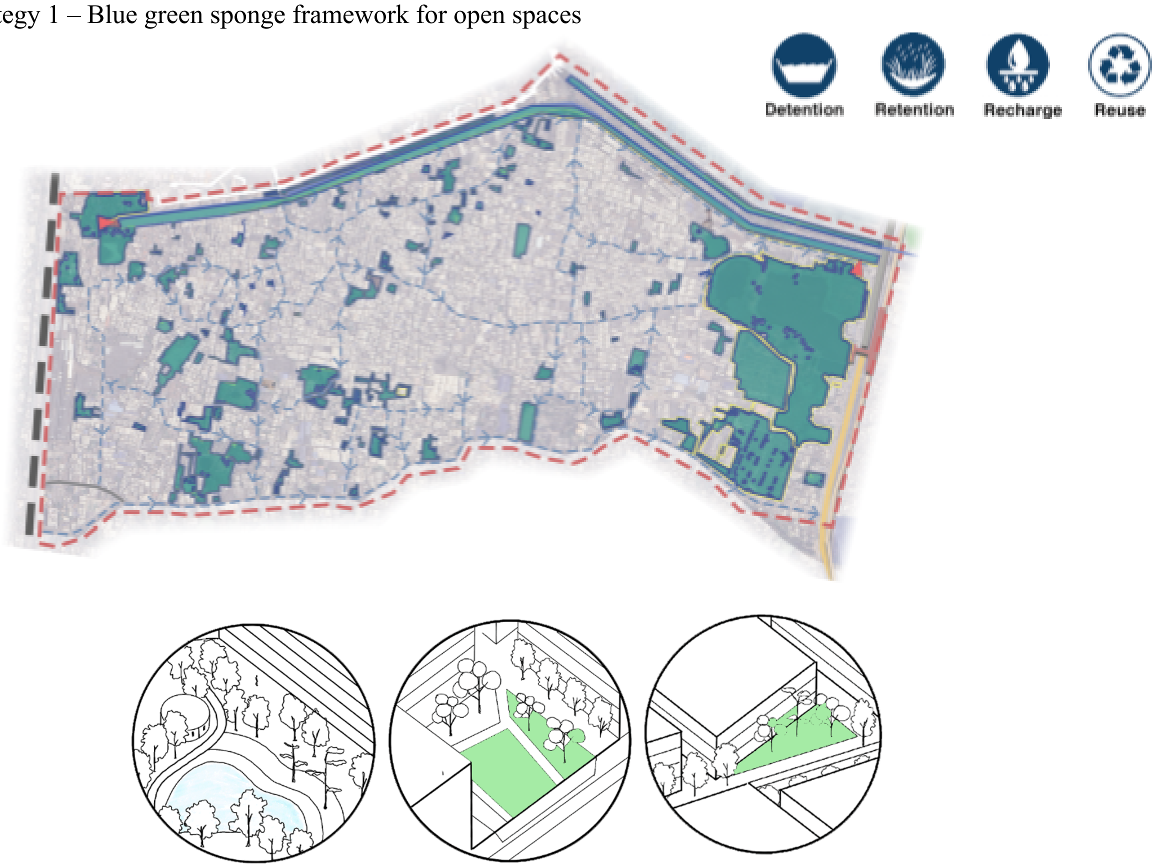
Protect - Focuses on safeguarding and enhancing natural and semi-natural features that absorb and manage water. These includes the ponds, wetlands, open spaces and the canal edges. By protecting these areas from development and degradation, the landscape maintains its ability to regulate water flow, mitigate floods, and improve water quality. This approach supports ecological balance, enhances resilience to climate change, and ensures sustainable urban environments by leveraging the natural landscape's capacity to manage water efficiently.

Enhance - Enhancing existing blue-green spaces with additional features like permeable surfaces, rain gardens, green roofs, re-naturalised canal bed and edges to better capture and filter rainwater. Enhancing the degraded blue green infrastructure would support a diverse plant and animal life which ensure that these spaces are resilient, functional, and provide additional ecological and recreational benefits.

Restore - Restoring blue-green spaces in sponge landscapes can significantly boost economic up lift ment by enhancing property values, attracting investment, and stimulating local economies. Revitalized parks, wetlands, and greenways draw residents and tourists, supporting local businesses and creating job opportunities. Improved water management reduces the need for costly infrastructure and lowers long-term maintenance expenses. Additionally, healthier, resilient environments foster livability and appeal, attracting skilled workers and businesses. By integrating natural features into urban planning, communities benefit from both enhanced ecological functions and economic growth, making blue-green space restoration a smart investment for sustainable development and economic vitality.

Construct - Constructing blue-green spaces in sponge landscapes involves integrating water features and vegetation to enhance water management and ecological health. This includes creating interconnected systems of parks, green roofs, and wetlands to absorb and manage storm water, reduce runoff, and support biodiversity. By incorporating sustainable design practices and engaging communities, these spaces mitigate flood risks, improve environmental quality, and enhance urban and rural resilience.

B. Design strategy 1 – Blue green sponge framework for open spaces



- Figure 44 – Conceptualizing open areas within dense urban fabric as sponges also keeping in mind a community centric design

Figure 45 – Transformation for underdeveloped parks to sponge parks & making it more accessible to all age group

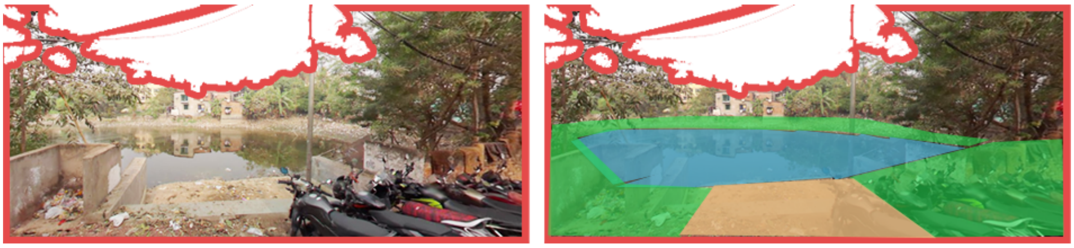


Figure 46 – Improvement of pukurs water quality , making it more useable & accessible for community , enhancement of biodiversity around.

C. Design strategy 2 – Place making

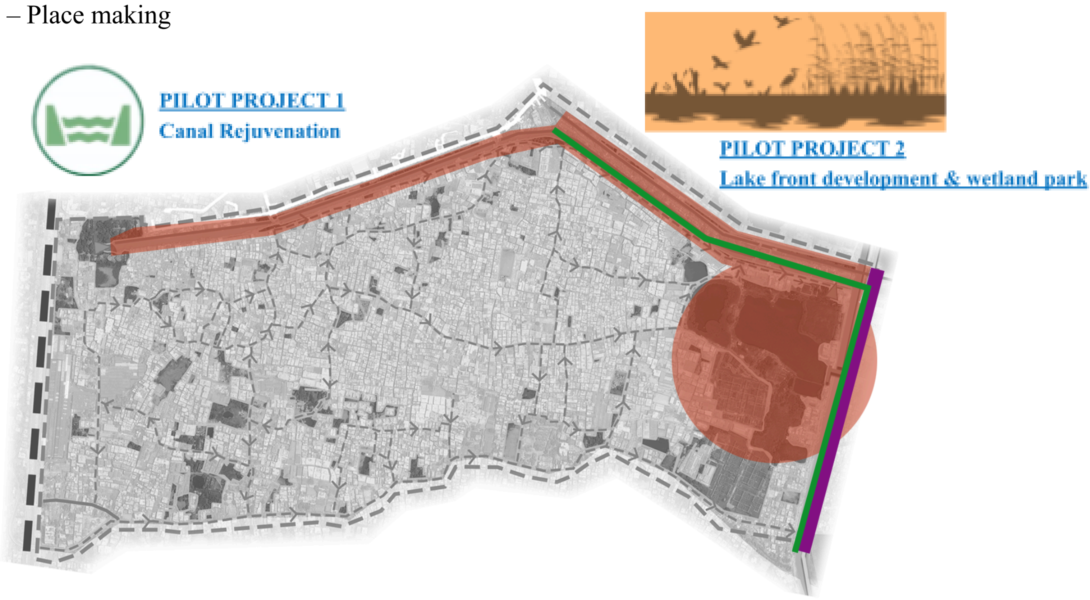


Figure 47 – Place making oppurtunities and identified pilot project site

Placemaking along canal edges and lakefront areas would create dynamic public spaces by incorporating waterfront parks, pedestrian promenades, and local businesses. Opportunities include developing vibrant community areas with seating and event spaces, enhancing connectivity with bike and walking paths, and integrating green infrastructure like rain gardens to manage storm water. This would add to an overall image to the study area, making it a landmark of the city.

D. Design strategy 3 – Community driven design

Figure 47 – Community focused design

Since the urban fabric is dense, setting individual rainwater harvesting will be challenging thus the common open spaces could help to store rainwater water for individual neighbourhood. In designing common open spaces, integrating rainwater harvesting involves installing systems like rain gardens, permeable pavements, and storage cisterns. These features capture and utilize rainwater for irrigation, reduce runoff, and recharge groundwater. This sustainable approach conserves water, mitigates flooding, and supports vibrant, eco-friendly landscapes, enhancing the functionality and environmental impact of public spaces.

Design strategy 5 – Reimagining transit corridor

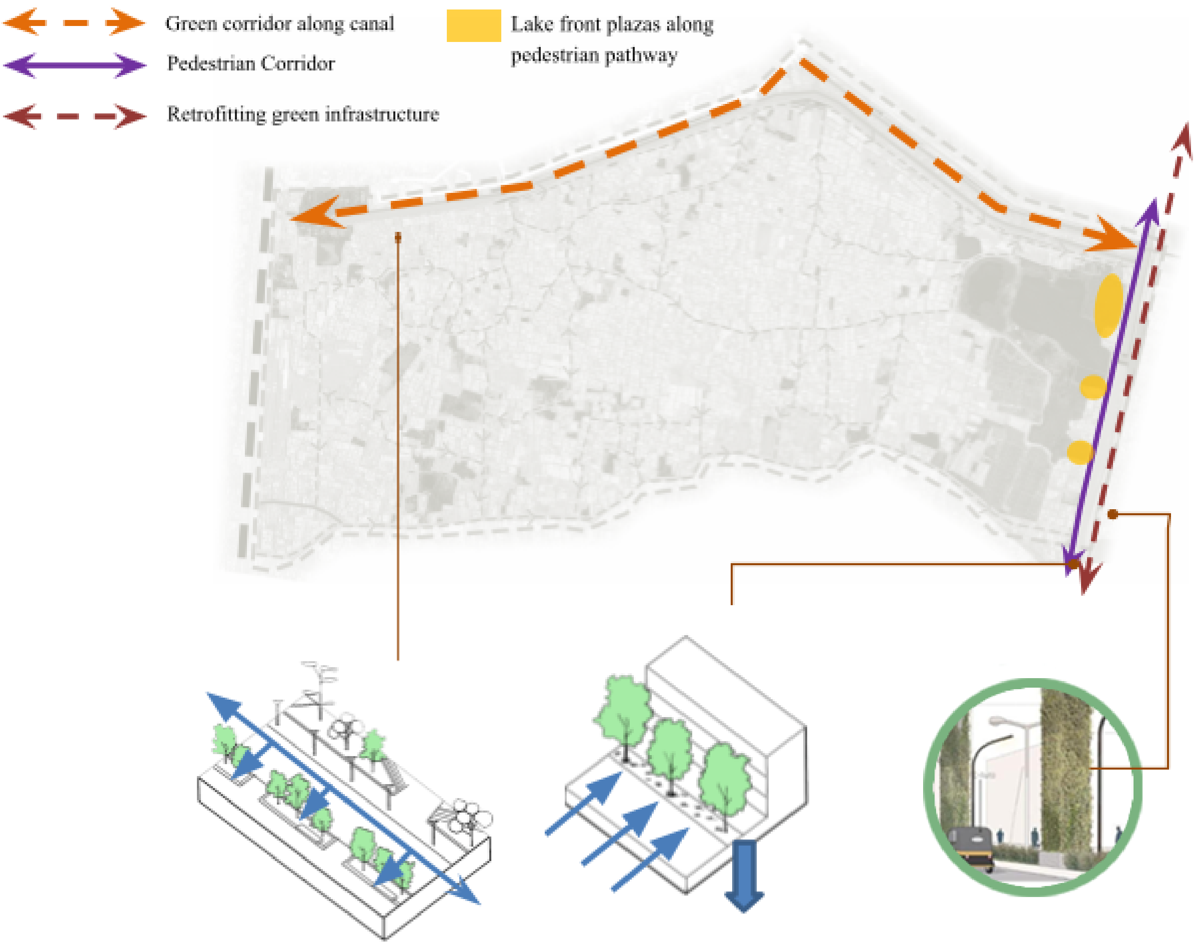


Figure 48 – Safe pedestrian side walks with Planting buffers, Street tree canopies & tree pits helps to slow down and convey rain water

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