

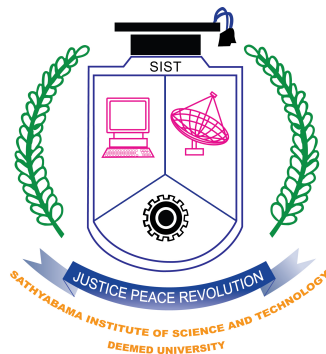
Evaluating The Impact of Urban Morphology along the Buckingham canal River

A Thesis

Submitted in partial fulfillment of the requirements for the award of
Master of Architecture degree in Sustainable Architecture

by

SUHAIL A S (39890019)



**DEPARTMENT OF ARCHITECTURE
SCHOOL OF BUILDING AND ENVIRONMENT**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

Accredited with Grade "A" by NAAC

JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600 119

MAY 2021



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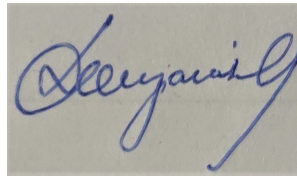
BONAFIDE CERTIFICATE

This is to certify that this Report is the bonafide work of **SUHAIL A S (39890019)** who carried out the Thesis entitled "**Evaluating The Impact of Urban Morphology along the Buckingham canal River**" under our supervision from January 2021 to May 2021.

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I **SUHAIL A S** hereby declare that the Thesis Report entitled “**Evaluating The Impact of Urban Morphology along the Buckingham canal River**” done by me under the guidance of **Ar.VIJENDRANATH** (Internal) and **Ar. BALAMURUGAN RAJKUMAR, Principal Architect -Proton Ateliers** (External) at Sathyabama Institute of Science and Technology is submitted in partial fulfillment of the requirements for the award of Master of Architecture degree in Sustainable Architecture.

DATE: 28 – 05 - 2021

PLACE: CHENNAI

SIGNATURE OF THE CANDIDATE

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ABSTRACT

At this rate of development of the urban sprawl, the flood exposure is increasing in coastal cities resulting in growing populations. Yearly global flood losses are approximately 600 crores per year all over the world. In this case the magnitude of losses when floods do occur would increase often by more than 50 % making it unable to prepare for large disasters, Sustainable development goal also talks about reducing exposure and vulnerability to disasters. India witnessed increased flooding in recent decades especially in urban areas. Cities are prone to flood risk due to uncontrolled population growth, built-ups, paved areas, waste disposal, vehicles, water use etc. Chennai, a coastal city is the fourth largest metropolis in india. This research study mainly focusses on understanding the impact of urbanization on flooding in the Buckingham Canal and to assess the possible damage due to urban planning and to provide suitable ideas for a sustained future.

TABLE OF CONTENTS

CHAPTER No.	TITLE	PAGE No.
	ABSTRACT	v
	LIST OF TABLES	ix
	LIST OF FIGURES	x
	LIST OF SYMBOLS AND ABBREVIATIONS	xi
1	INTRODUCTION	10
1.1	INTRODUCTION	10
1.2	AIM	12
1.3	METHODOLOGY	12
1.4	LIMITATIONS	12
1.5	SCOPE OF THE STUDY	12
1.6	RESEARCH QUESTIONS	12
2	SITE ANALYSIS	13
2.1	SITE STUDY	13
2.2	SITE CONTEXT	15
3	STUDY OVERVIEW	16
3.1	LAND USE MAP	16
3.2	SWOT ANALYSIS	16

3.3	CLIMATE ANALYSIS	18
3.4	RADIATION ANALYSIS	20
3.5	SUNLIGHT ANALYSIS	21
3.6	SHADOW ANALYSIS	22
3.7	TRAFFIC ANALYSIS	23
3.8	PEDESTRIAN ANALYSIS	23
4	GUIDELINE ANALYSIS	24
4.1	URDPFI GUIDELINES	24
4.2	CRZ GUIDELINES	25
4.3	STRATEGIES	26
4.4	QUALITATIVE ANALYSIS	28
4.4	QUANTITATIVE ANALYSIS	32
5	PROPOSAL	35
5.1	ENVIRONMENTAL SUSTAINABILITY (Bioswale, Tree Trenches)	36
5.2	ECONOMIC (Correction of River Bank)	44
5.3	SOCIAL	49
	REFERENCES	52

LIST OF FIGURES

- 1.1 Site location
- 1.2 Site understanding
- 1.3 Deposits in each part of river
- 2.1 Site visit
- 2.2 Zones around site
- 2.3 Site Context
- 3.1 Analysis of current state on site
- 3.2 SWOT Analysis
- 3.3 Precipitation & annual average rainfall graph
- 3.4.1 Wind Analysis
- 3.4.2 Wind Analysis
- 3.5.1 Radiation Analysis
- 3.5.2 Radiation with trees
- 3.6.1 Sunlight Analysis
- 3.6.2 Sunlight hours with vegetation
- 3.7 Shadow analysis
- 3.8 Road Network
- 3.9.1 Traffic Analysis during different times in a day
- 3.9.2 Pedestrian Analysis during different times in a day
- 4.1 Disaster Management
- 4.2 Transformation of Ghats
- 4.3 CRZ Notification 2011
- 4.4 CRZ Notification 2018
- 4.5 River section
- 4.6 Public Use of river
- 4.7.1 Bridge over river
- 4.7.2 Recreational space around river
- 4.8 River flowing illustration
- 4.9 Light Analysis
- 5.1 Site Map
- 5.2 Current situation of site
- 5.3 Canal Restoration plan
- 5.4 Restoration techniques
- 5.5 Helophytes
- 5.6 Bioswale
- 5.7 Restoration projects in other places.
- 5.8 Community Gardens
- 5.9 Public Plaza
- 5.10 Pedestrian Pathways
- 5.11 Flood Areas
- 5.12 Public Amenities, Seating and Social Spaces
- 5.13 Site map divided into sections
- 5.14 Buckingham Canal
- 5.15 Bioswales Benefits
- 5.16 Tree Trenches
- 5.17 Curb Bulbouts
- 5.18 Present Canal Conditions
- 5.19 Canal Bank Correction
- 5.20 Present Existing Problems and Solutions
- 5.21. Possible developments
- 5.22 Sectional View
- 5.23 Pavers section
- 5.24 Recreated area mapping
- 5.25 Canal Restoration Proposal
- 5.26 Market place view
- 5.27 Recreational Space view
- 5.28 Resilient feature of Canal view
- 5.29 Community Gathering Space View
- 5.30 Cycle Track View
- 5.31 Resilient Feature Canal view

LIST OF TABLES

1.1	Capacity of Zones in Chennai
3.1.	Space standards
4.1	Natural Hazards
4.2	Strategies
4.3	River Front Development
5.1	Analysis
5.2.1	Flowers and Shrubs
5.2.2	Flowers and Shrubs

1. INTRODUCTION

1.1 INTRODUCTION

Lack of efficient water sanitation to polluted rivers

Sewerage and sanitation is relatively poor in Chennai. Sanitation and safe disposal of human waste is a critical element of public health, directly impacting the well being of people. The absence of adequate number of toilets linked underground sewerage scheme, absence of sufficient and well maintained public/community toilets and the age old practice of open defecation are posing serious sanitation problems and health hazards.

For improving the water sanitation and supply Exnora, one of the main NGO in Chennai, has both an action in the field as well as some credibility with the Metro Water Board since "it helps in forming committees among the dwellers to organise the water distribution through tankers; it carries a strong lobbying action with the Metro Water Board to build toilets and rehabilitate storm water drains; and it is also part of the consumer committee of the Metro Water Board, as well as the vigilance committee. Up to now, treatment is of 60 % of the Board-water (thus a substantially lesser percentage if one takes into account the non-board supplies), divided in 5 % re-used by the industry, 10 % re-used by the electrical industry, and 45 % put back to rivers as interviews in the sewerage wing of the Board show. At present the sewage generated in Chennai city is being treated in the following nine number of treatment plants:

Sl. No	Location	Capacity (Million Litres per Day)
1	Kodungaiyur STP Zone - I	80
2	Kodungaiyur STP Zone - II	80
3	Kodungaiyur (New) STP Zone I & II	110
4	Villivakkam STP Zone - II	5
5	Koyambedu STP Zone - III	34
6	Koyambedu (New) STP Zone - III	60
7	Nesapakkam STP Zone - IV	23
8	Nesapakkam (New) STP Zone - IV	40
9	Perungudi STP Zone - V	54
Total Capacity		486 MLD

Point sources of contamination to surface water bodies are an expected side effect of urban development. Examples of point sources include direct discharges from sewage-treatment plants, industrial facilities, storm water drains and direct discharge from household and other activities. Despite improvements of the treatment of wastewater, still high quantities of untreated sewage are led into rivers, lakes, sea and marshlands in Chennai Metropolitan Area. Today the three major waterways of Chennai are still polluted due to outfalls from industries, commercial institutions, sewage treatment plants, pumping stations, sewers, and storm water drains. This wastewater discharge contributes to contaminated or polluted water of the waterways and leads to unsanitary condition.

It has been estimated that nearly 60 million litres of untreated sewage are released into the Buckingham Canal, Cooum and Adyar rivers The Buckingham Canal is the most polluted of the three major waterways in the city with nearly 60 % of untreated sewage being let into it daily (CMWSSB, in K. Lakshmi, The Hindu 2014) About 30 % of the untreated sewage gets into the Cooum river and the Adyar river receives the rest (Lakshmi, The Hindu 2014).

Tab 1.1 Capacity of Zones in Chennai

Flooding, a permanent risk during monsoon seasons

Other problems that Chennai experience are the rainfalls. Most of its rainfall happens during October to December associated with depressions and frequent cyclones during this period. Average annual rainfall is about 1200 mm – 1300 mm being situated on the coastal side.

Of these rainfalls some causes catastrophic events, such as the floods in the years 1976, 1985, 1996, 1998, 2005, 2008 and 2010 caused heavy damages. Nowadays, unexpected holidays due to heavy downpour are quite common especially from October to December. In short, Chennai is not starving for rain; it is starving for water which is due to mismanagement of water storage. In 2010 Chennai received about 760 mm rainfall only during the October – December period (Lavanya, 2012). Recent highest rainfall in a day was 423 mm on the 27th of October 2005.

The Corporation of Chennai (COC)

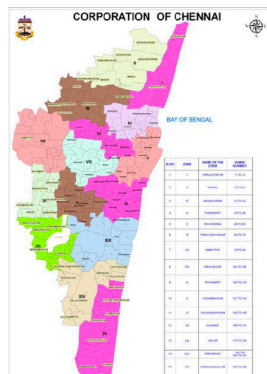


Fig 1.1 Site location

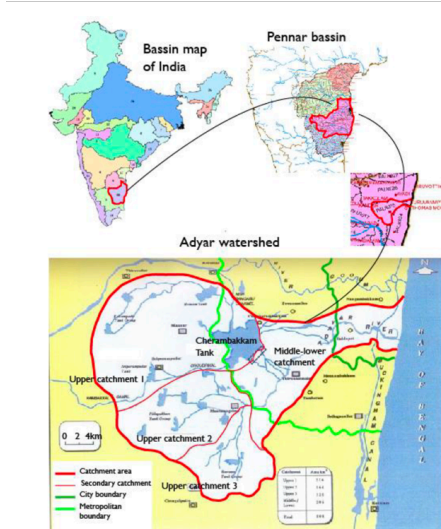
The Corporation of Chennai represent the first inner boundary of the city. The boundaries have extended since 2011: the area is 140 % more than what it was before, 426 km² from 176 km² earlier. Now it is merging 42 local bodies, including 9 municipalities, 8 town panchayats and 25 village panchayats. The city is divided into 15 zones, consisting of 200 wards.

The Corporation is composed of 14 departments, which are Parks, Roads, Health, Bridges, Building, Revenue, Electrical, Education, Town Planning, Land & Estates, Small Savings, Storm Water Drain, Mechanical Engineering and Solid Waste Management. In other words the Corporation is responsible for the maintenance of infrastructure such as roads, streetlights, and flyovers, the maintains of the city's cleanliness and hygiene levels, the removal of solid waste within city limits, the maintenance of parks, the building of health and education centres.

The Adyar river catchment

Hydrology: the Adyar plays a major role by collecting surplus water

The Adyar river has its catchment area in the Kancheepura District and originating from the Pillapakkam Tank Group and Kavanur Tank Group. The Adyar river has two arms. The northern arm comes from Chembarambakkam basin, the southern arm comes from Guduvancheri at an elevation of about 40 m above the sea level, and they join at Tiruneermalai. The Adyar river collect a surplus from about 450 tanks in its catchment, apart from overflows from the large Chembarambakkam tank. The Mambalam drain is also a flood accommodator which originates from Mambalam area, passes through T. Nagar, Nandanam and joins Adyar river.



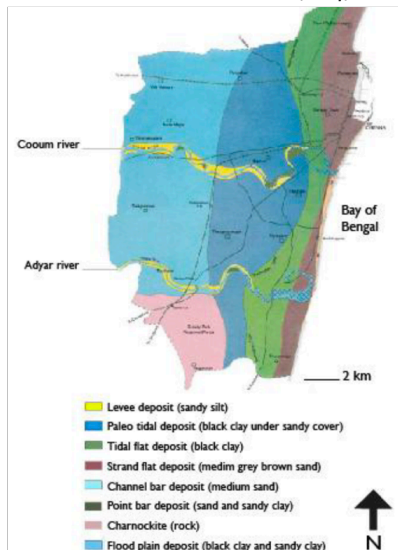
The flood plain of Adyar River is stressed due to unplanned development and encroachment. The change in the land use and land cover pattern due to rapid urbanization adversely affects the hydrological processes in the catchment, leading to a deteriorating water environment. Several Government agencies like Tamil Nadu Public Works Department (PWD), Corporation of Chennai, Tamil Nadu Slum Clearance Board (TNSCB), Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB), Tamil Nadu Pollution Control Board (TNPCB) and Chennai Metropolitan Development Authority (CMDA) have attempted in the rehabilitation and management of river. These agencies have focused mainly on the technical/ structural interventions in the system such as clearing of sand bar, dredging the sludge, constructing check dams and lining the river banks to improve the flow in the river.

Sources: Regional Study, Adyar River Revitalization, 2007 <http://cgwb.gov.in/watershed/about-ws.html> <http://slusi.dacnet.nic.in/watershedatlas/indexnew.html>

Fig 1.2 Site understanding

Geology: the alluvium character of the Adyar river

The Chennai district fall into an alluvial plain of the Cooum and Adyar river, coastal plains, and pediplains in south-west corner of the area, south of the Adyar river. The altitude of the landforms varies from 10 m above the sea level in the west to nearly sea level in the east. The Adyar river is of 42 km length and has a catchment area of 80 km². It drains the southern part of the district and remains flooded during monsoon. At high tides the backwaters of Bay of Bengal reaches up to 4 km along the bed towards west. The alluvium consists of sand, clay, sandy clay, silt and occasional gravels and is under crystalline rocks mostly of charnockite suits.



Source: Regional Study, Adyar River Revitalization, 2007

Pollution: a high level of contamination in the river

Rapid urbanization and industrial development during last decade have provoked some serious concerns in environment and especially in the heavy metal contamination in river, which is one of the major quality issues in many fast developing cities. In Chennai particularly the maintenance of water quality and sanitation infrastructure did not increase along with population: every year the demand of consumption of water increases and subsequently lead to the generation of enormous quality of waste water. Moreover it is common to see that the establishments led their sewage into the water system without proper prior treatments. Thus, the waste water is discharged directly into the rivers of Chennai city Adyar and Cooum rivers.

A study from CMDA on the Cooum and Adyar river looked at the BOD and COD3, that are most widely used as parameters for calculating pollution load applied to both wastewater and surface water. The biodegradability of the organic compound depends on the BOD: COD ratio in the wastewater. For typical untreated domestic wastewater with high organic content has the BOD5 /COD ratio above 0.7.

Fig 1.3 Deposits in each part of river

AIM : Evaluating the Impact of creating an urban morphology along the areas of Adayar river without creating a hindrance for the for the water movement.

Objectives of the study

- 1.To understand what is currently happening along the Adayar river : the origins, the purposes, objectives and implementation of projects
2. Re-imagining the Public Realm
3. To put into perspective the different points of view and assess the environmental awareness
4. To analyse the parameters of the river morphology development with respect to codes and conducts of the riverfront development of Tamil Nadu.
5. Analysis the various settlement patterns along the river stretch with respect to the guidelines
6. Restoring Ecology
7. Prioritizing Environmental Sustainability
8. Fostering Community Participation all directed towards building a resilient city.

LIMITATIONS

- The study will include the process and methods of rejuvenation of the river front
- Limited to create an urban morphology for the settlements around the chosen site.
- Proposal of recreational and sustainable spaces

SCOPE

Create a new identity for the canal banks as public spaces.

- Encourage a diverse set of activities that involve all strata of the society.
- Revitalize existing unused urban spaces.
- Develop a bio-diverse and native ecosystem to make the canal more resilient and sustainable.
- Enhance comfort and safety of the users through appropriate amenities, lighting and security.
- Increase the community interaction with the site.

Research questions?

1. What are the environmental awareness circumstances on the Adyar river in Chennai?
2. Analysing the sustainable techniques for restoring the river?
3. What are the sources of pollution in the Adayar river?
4. To evaluate the various proposals by the government along the Adayar river?
5. Finding the assessment criteria for a sustainable riverfront development.

2. SITE ANALYSIS

BUCKINGHAM CANAL : IN CHRONOLOGY

Construction	Renovation	Restoration	Flood Protection	Current Situation	Project Goals
The Buckingham Canal is the first man made saltwater canal. • 1802 - 1806 Construction • The Canal is constructed as a navigation channel connecting Madras with Ennore. • In 1855 the canal is further extended to the south. • During this period the width of canal is 100m and several boats can sail at a time. • The Canal manages flood waters and ensures tidal balance.	• In 1987 the entire MRTS line from Chennai Beach to Velachery begins construction parallel to Buckingham canal. • In 1992 Chennai Government constructs flood defenses such as a retaining wall and changes are implemented in the channels for the canal.	• Between 2000 - 2005 encroachment On Buckingham canal begins. • On January 20 , 2010 The Government of Chennai sets up a restoration trust to revamp the canal. • In 2009 various projects are taken up to improve the canal including dredging and measures for flood protection • In 2014, the Government of Chennai floats a tender for a detailed project plan to restore the Buckingham canal.	• During the December 2004 tsunami the canal acts as a buffer and pulls in seawater into the canal . • During the 2015 floods the canal acts as a buffer zone and prevents adjacent areas of the city of Chennai from getting flooded.	Currently the width of the canal has been reduced to a mere 12-15 mtrs. in most parts. Untreated sewage is dumped daily into the canal making the water body a city nallah.	The main aim of the project is to rejuvenate the canal and deal with current issues of sewage dumping, flooding and also addressing the settlement issues. This can be achieved by revitalizing the canal, increasing green spaces, methodological waste segregation and treating the polluted canal water and by creating an urban morphology.

<http://www.rejuvenation.com/>
<https://www.downtoearth.org.in/news/climate-change/revival-2018>
 How much has changed with climate change
 02/05

BUCKINGHAM CANAL : CURRENT STATE

Buckingham canal is in a current state of neglect and deterioration. The canal was created as an inland transportation solution for the Coromandel coastal cities and also acted as a source of great relief during the droughts and floods faced by Chennai. The canal was created over a series of periodic excavations however design, maintenance and regulations works took a back seat during the planning for the canal.



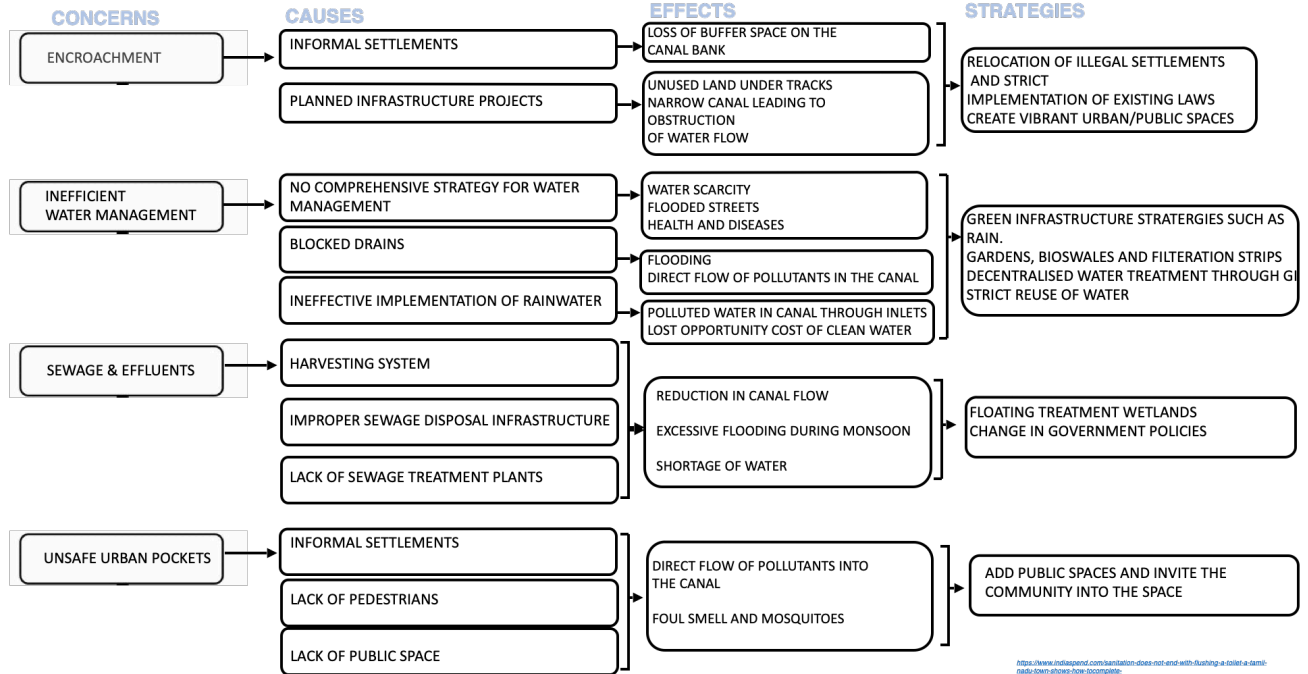
sewage into the canal. The wellbeing of the canal faces natural and man made challenges including weeding, silting, flow speed, sewage disposal, turbidity and encroachment.

The state of the canal has deteriorated over time and remains completely ignored by citizenry and authorities alike. This state of detriment began by heavy silting due to serious cyclones that struck the coast. The problem of silting was further intensified by tidal flow from shallow beds of rivers and back waters. The canal travels through different types of soil, most of which are loose in character. Since the canal is unlined the sides began to slip further reducing the depth of the canal. Further factors such as lack of funds and shift of focus to road and rail transport added to the decline of the canal. The ignorance of the authorities to reevaluate and allocate sufficient funds for the maintenance of the canal created a scarcity of resources required for repair and rejuvenation.



Fig 2.1 Site surroundings

KEY CHALLENGES



Site Selection

The site selection for the demonstration of the proposal has been done keeping in mind the maximum impact and highest footfall.

The goal of the design process is not only qualitative in nature but also technically grounded. Considering the above the site criteria parameters have been divided into two major categories – qualitative and technical, which are further divided into secondary criteria.

QUALITATIVE CRITERIA

Accessibility:

The site must be easily accessible to pedestrian as well as vehicular access owing to the presence of the OMR along the length of the site. The future developments on the site must also work in a view with the bigger idea of accessibility. The chosen site must have a good consistent and flat topography that allows for easy wheel chair access along with good walkability for pedestrian access. This will make the site easily accessible for all the nature and class of people.

Proximity to amenities:

The site must be in tandem and in close proximity with MRTS stations. Public amenities see a large number of the population in a periodic fashion. Hence choosing a site adjacent to the same would subsequently mean high footfall in the public spaces designed around them. These spaces would not only satisfy the need of the encompassing areas but also create a prolific environment.

High footfall region:

As per a report created by the Times of India published in 2009, the daily footfall experienced by the Thiruvanniyur MRTS station is a startling 7596 people ranking as the third busiest station on the MRTS. The proximity of the site to the station or one of a similar stature guarantees a good footfall on the site.

Safety Barriers

The presence of the canal behaves like a natural barrier through landscape. This feature behaves like a safety feature and allows one to control the penetration into the site.

Sewage Outfalls:

The sewage outfalls along the Canal require immediate attention. The selected stretch must take action against the sewage effluents in the river.

Sense of belonging and commitment to the site:

The site but be surrounded by residential areas that could add to the demographic expected on the site. The site would hence have the potential and the location to serve the citizens residing around it by adding to the public amenities available to them within a given radius. Surrounding residential areas would create a set of population with a strong sense of belonging and a strong commitment to the utilization and revitalization of the site. This would be ideal for environmental initiatives such as the building and maintaining of Floating treatment wetlands and Bioswales.

TECHNICAL CRITERIA

Convenience:

The site must be located close to the MRTS stations since it is very convenient for the people to access and participate. Convenience of the people becomes vital to the success of any intervention

Development Plans :

Site must not interfere with any existing or future development. Also it shouldn't have any detrimental impacts on neighboring land uses. The design for the site should in no way interrupt with the development of the new MRTS station proposed along it. On the contrary the two would function in tandem with each other.

Sizing and accommodation of functions

Site must be large enough to accommodate the following:

A minimum number of garden plots to be viable in the long term

A composting system

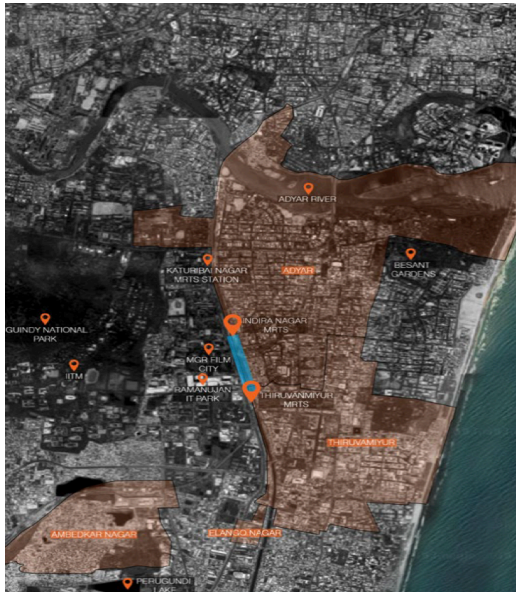
Rainwater tanks

Seating areas and shelter for gardens

Garden beds including raised garden beds for people with mobility issues

Land Ownership and acquirement

The land owners for the plot must be government bodies or alike so that the process of acquirement for dedicated public spaces should be a smooth process. This further reflects as no costs in legal and compensation battles which could be utilized for the betterment of the design.



HIGH FOOTFALL ZONES AROUND

The site is surrounded by prestigious and crowd pulling institutional buildings on the western side. Buildings in the Ramanujan IT park have a daily footfall of approximately 58,000 people. This only accounts for regular footfall and does not include additional diurnal migrating footfall. Institutions like NIFT or Anna University add to the variety and bring in a different set of demographic expected on site. The varying age group add to the safety and energy of the space and ensure use of the space at varying times of the day.



Fig 2.2 Zones around site

SITE CONTEXT



Fig 2.3 Site Context

3. STUDY OVERVIEW

CURRENT STATE OF CANAL BETWEEN INDIRA NAGAR AND THIRUVAMIYUR

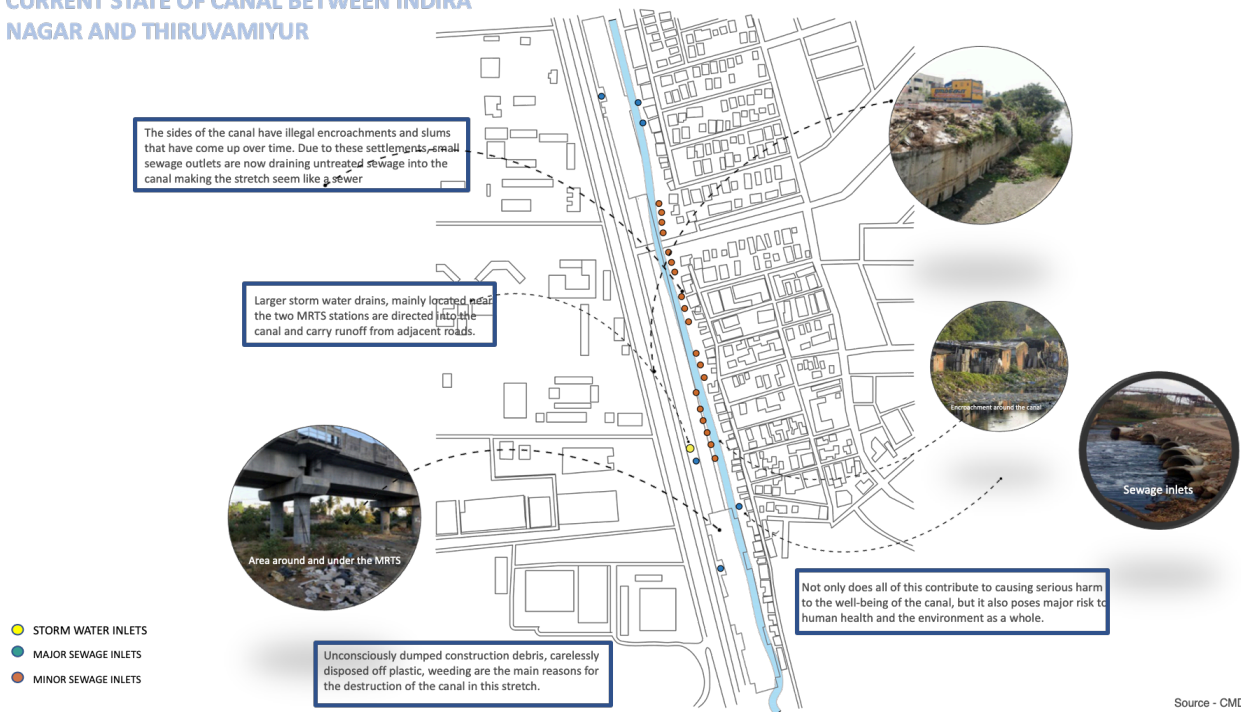


Fig 3.1 Analysis of current state on site.

Buckingham Canal : SWOT Analysis

Strengths

Continuous Waterfront

The Buckingham Canal runs across the Chennai city for a length of nearly 48 km. The edge character and nature of the canal differs in different parts of the city but essentially forms a continuous corridor. This corridor is a major asset and can become a green public corridor which can function as an open space for the entire city. It will provide the people and city 48km of accessible waterfront and recreational space. Various activities can be planned along the canal across the city based on the context and needs of the residents.



Historical Significance

The Canal was constructed in early 19th century for the purpose of a navigating channel parallel to the sea. The canal formed a major transportation channel. Through the retrieved photos, the canal can be seen as a green corridor with wooden boats cruising through the waters. Celebrating the history, the canal can become a place to showcase the history.



Habitats and Ecology

The canal helps manages the flood water and regulates the ecosystems of the city. The canal forms an integral part of the network of water bodies essential to maintain resiliency of the city. The canal forms a rich ecosystem which can enrich the biodiversity of the region. This forms a great asset for bio-parks, open spaces and urban greens. The rich ecology corridor can also form asset for development adjacent to the canal.



Development along the canal / Community

Over the period of time, developments have come up along the canal. Though the adjacent development is not ideal for the health of the canal, the community living along the canal edges have a strong sense of ownership and responsibility towards the canal. These communities are a big strength and can help regenerate the canal through different means. Various departments of the government have proposed schemes for the canal.



Weakness

Water Quality

Due to various reasons such as industrial waste, domestic waste water directly discharged into the canal, the canal water is heavily polluted leading to a bad environment. The pollution also invites unwanted plant species in the water causing harm to the ecology of the canal. Due to the pollution, the canal is considered as a sewage drain instead of a green vibrant open space corridor.



Solid Waste Management

The city and the canal face a huge problem of solid waste management. Open garbage disposal and dumping of waste in the canal are major sources of pollution in the canal. The dumping of waste obstructs the flow of water and can cause major disaster like flooding during extreme event of rainfall or other such natural disaster. The waste also causes major deterioration to the quality of water and the ecological value of the canal.



Lack of Public Awareness

A large number of people are unaware of the potential of the canal and the effects of its severely bad condition. Also due to lack of awareness, people continue to dump waste in the canal causing pollution. Part of the population is also unaware of the historical significance of the canal and its present condition.



Lack of Accessibility

Parts of the canal are encroached by development while some stretches of the canal are inaccessible due to the transportation corridor of MRTS. The canal has become a backyard for the development on the banks and thus neglected. Lack to visual and movement accessibility near the canal, prevents people from accessing the canal and thus leading to further neglect.



Opportunities

Accessibility and Continuous Public Open Space

As mentioned earlier the 48km of canal front can be made available to the public as a open space for recreation. The canal has a potential to boost open space index in the city. Corridors, walkways, parks and gardens can be designed along the canal which can connect to the other parts of the city and form a network of cycle tracks and walkways. In this way the canal can gain back its importance.



Historic interpretation

The historical significance and heritage of the canal present an opportunity to create programs and functions bringing people closer to the canal. Museums, photographic exhibitions can be displayed along the water front. This shall also attract people and tourists. Along with providing information the history can also form a theme for way finding and signage along the canal and the city.



Economic Opportunity

The canal provides an excellent opportunity and opportunities to create market spaces, food kiosks, urban farming, urban settlements etc. which can give platform for local citizens to generate income.

Environmental Remedy

The canal can play a huge role in mitigating floods, regulate water help build a resilient city. The canal connects all the three rivers of the city along with other water bodies like wetlands is a unique feature which allows the regulation of water. The ecology of the canal has a potential to create bio-diversity parks, botanical gardens which can also educate the people. Clean water in the canal will ensure people to interact with water, bring them closer to the water network and also the canal to function as local transportation corridor.



Threats

Flooding

Without proper solid waste management, pollution control, the water flow through the canal will be blocked. This will block the discharge of water from the canal into the rivers followed by sea and cause flooding in the nearby areas. In case of extreme high rainfall or tsunami, where the canal has to function as a water regulating agent and save the inland from flooding, the canal will not be able to function as one.



Health Hazards

With the increasing levels of pollution, the canal will become the backyard of the city and will function as a dumping place and sewage channel. Not only will this severely affect the quality of water and the ecology of the canal, it will also affect the health of local residents as it can be a medium through which diseases can spread. The deteriorating health of the canal shall also affect the health of the canal and increase the possibilities of flood and tsunami.



Negligence

With high embankment walls, solid waste dumping, polluted water, the canal will become a neglected place and a backyard of the city. Rather than celebrating the canal as a green space of the city it will become neglected making it open for landfill and building purposes.



Poor Development controls

With the canal being neglected it can be encroached with development for infrastructure or residential purposes.

https://www.researchgate.net/publication/263579726_Rapid_Assessment_and_SWOT_Analysis_of_Non-technical_Adaptability_of_Natural_Wastewater_Treatment_Systems/figure/fig1



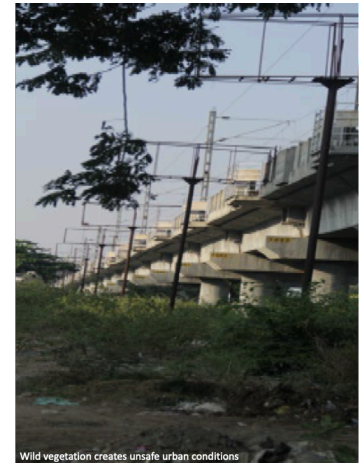
Bridge provides easy access to communities of east bank



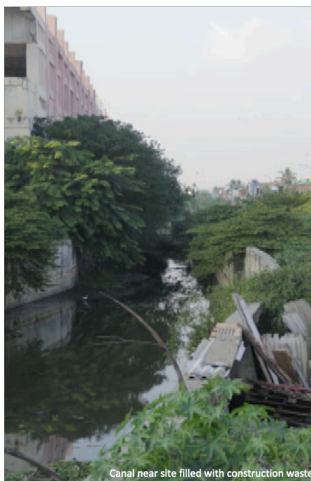
Inactive urban edge



Vast unused space near Thiruvannmiyur station



Wild vegetation creates unsafe urban conditions

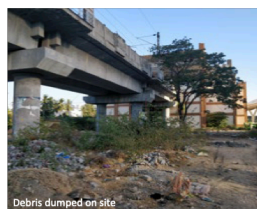


Canal near site filled with construction waste

- Located exactly adjacent to the Thiruvannmiyur MRTS station, this stretch of unused land has a great potential of becoming a community asset. Though easily connected and accessible near a foot over bridge, the current overgrown area is an urban void and becomes a unsafe zone in the night.
- Due to the stretch being neglected, the adjoining Buckingham canal stretch is also neglected and dumped with construction debris.
- The strip, shaded by the elevated tracks can become a new public space and add to the public realm of the adjoining area.



Vacant land leading to a unsafe urban edge in late hours



Debris dumped on site



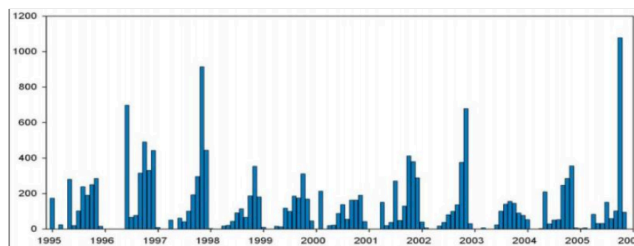
Site can become a community asset with easy connectivity

Fig 3.2 SWOT Analysis

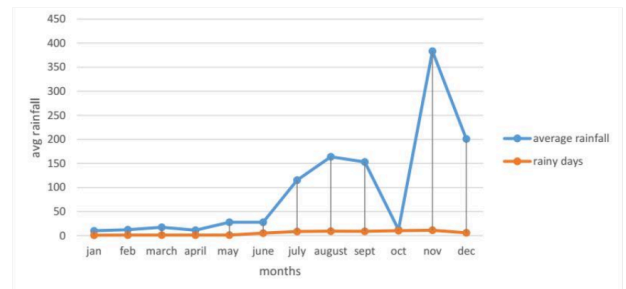
CLIMATE AND PRECIPITATION

The main seasons are listed down below,
-Summer Monsoon (June - September)
-Winter Monsoon (December – February)
-Early Monsoon (March – May)
-Late Monsoon (October – November)

During the late monsoon, Chennai gets no precipitation, and the summer monsoon is also slightly light in other parts. The Eastern Ghats and the coast are more affected in the late monsoon due to cyclones from the bay of Bengal. The months with the highest precipitation are from October until December.



Precipitation monthly



Annual average rainfall

The monthly precipitation over the district of Kanchipuram (Chennai) for the years 1995 – 2006, the deviation of the precipitation shows the characteristic rainfall. The dry periods are always in the beginning of the year, the rainfalls mainly in the late monsoon period between October until December. So far the annual precipitation is characterized by a mean amount of rainfall of 1270mm. Years of an annual rainfall of more than 1640 mm can be called years of high precipitation. Extreme precipitation appears statically 2-3 times in 100 years and shows precipitation higher than nearly 2000 mm.

Fig 3.3 Precipitation & annual average rainfall graph

WIND ANALYSIS

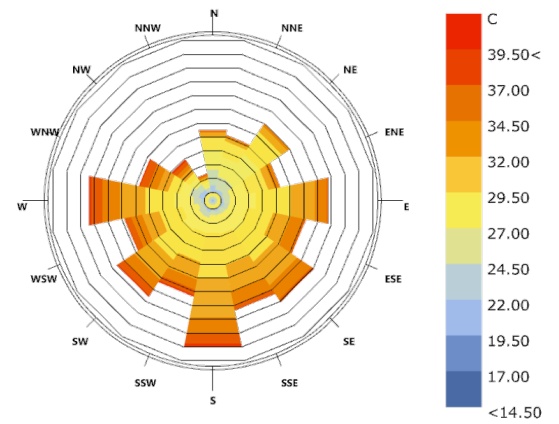
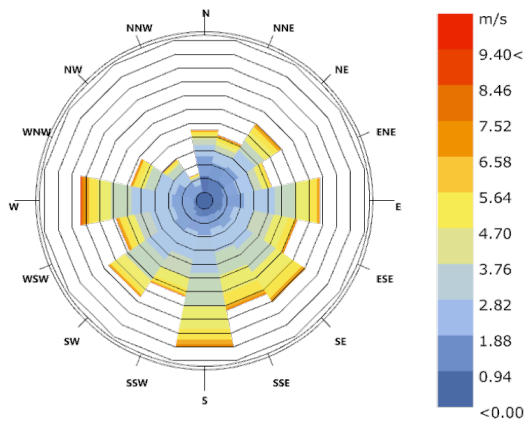


Fig 3.4.1 Wind Analysis

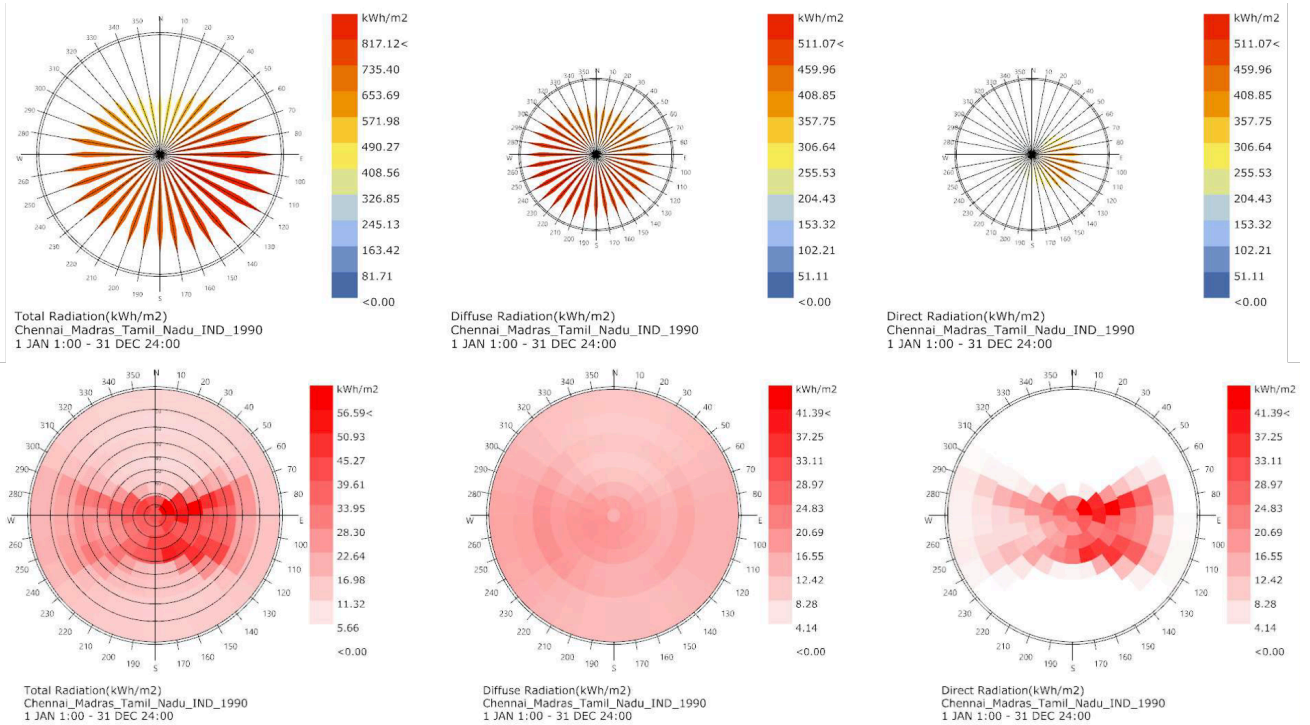
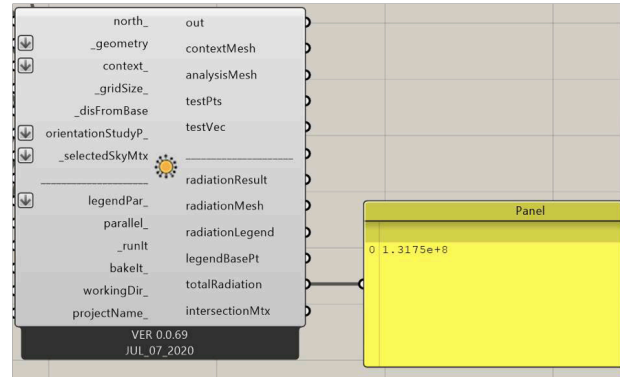
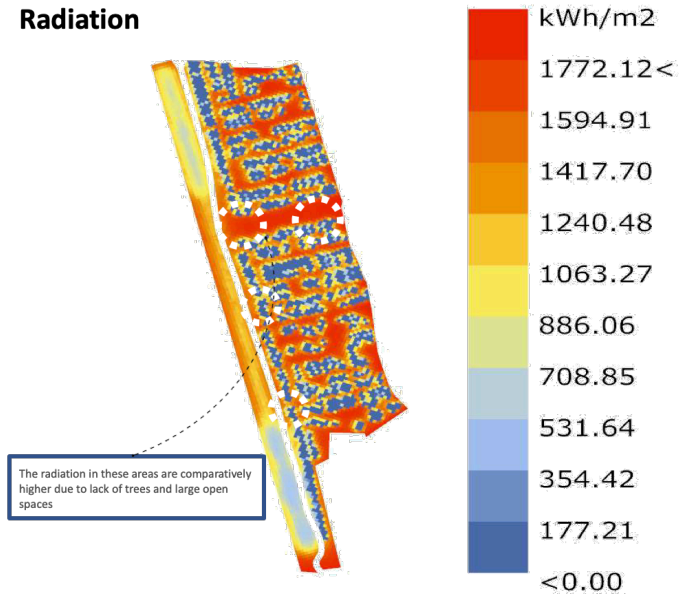


Fig 3.4.2 Wind Analysis

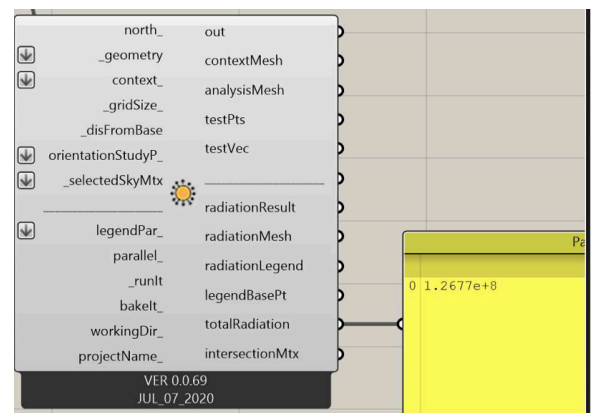
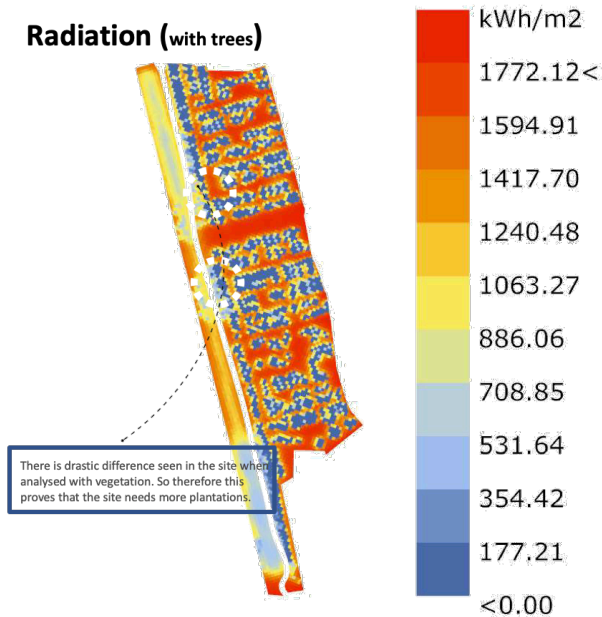
Radiation



Radiation Analysis
Chennai_Madras_Tamil_Nadu_IND_1990
1 JAN 1:00 - 31 DEC 24:00

Fig 3.5.1 Radiation Analysis

Radiation (with trees)



Radiation Analysis
Chennai_Madras_Tamil_Nadu_IND_1990
1 JAN 1:00 - 31 DEC 24:00

Fig 3.5.2 Radiation with trees

SUNLIGHT HOURS

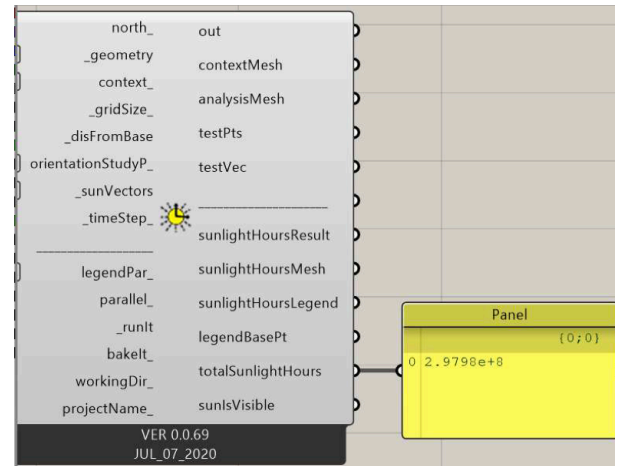
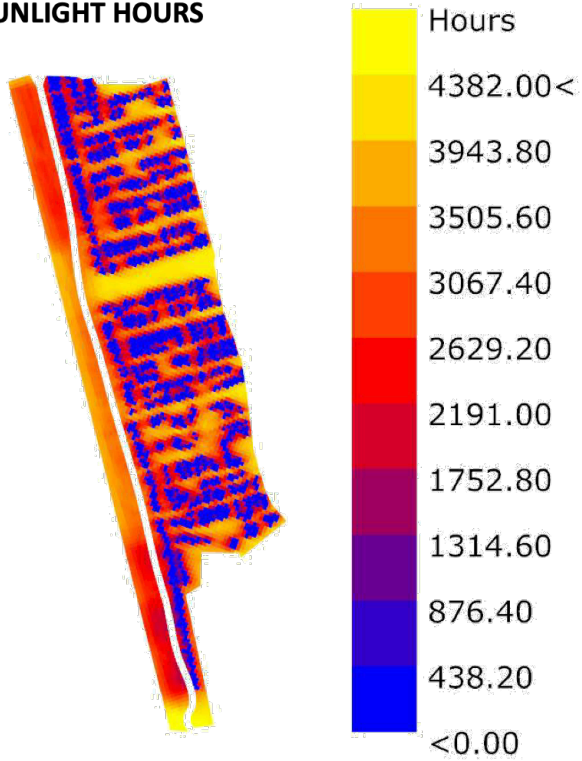


Fig 3.6.1 Sunlight Analysis

SUNLIGHT HOURS (with vegetation)

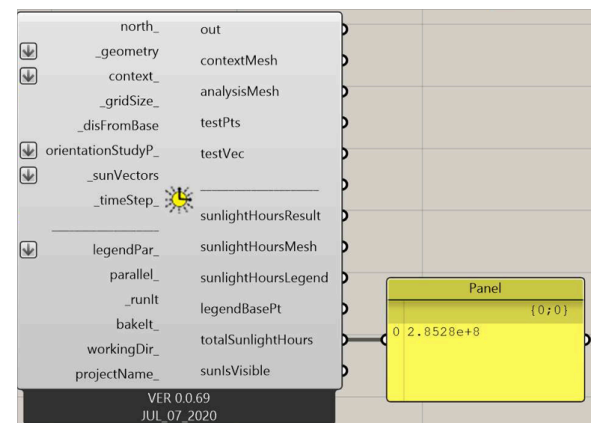
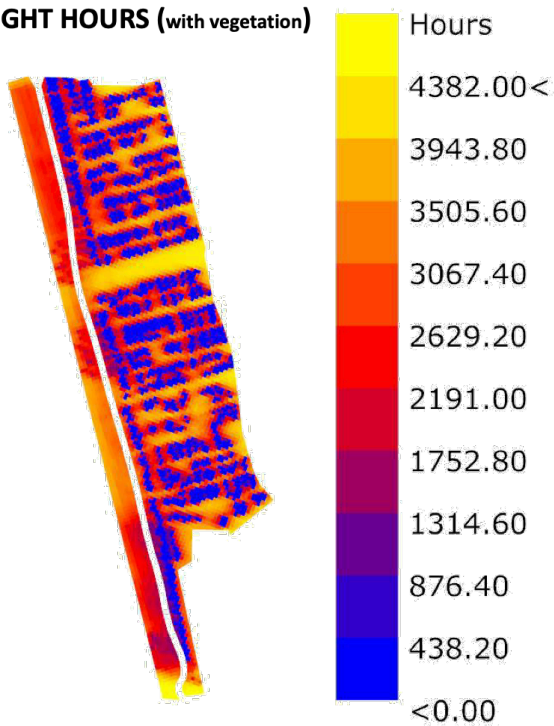


Fig 3.6.2 Sunlight hours with vegetation

SHADOW ANALYSIS

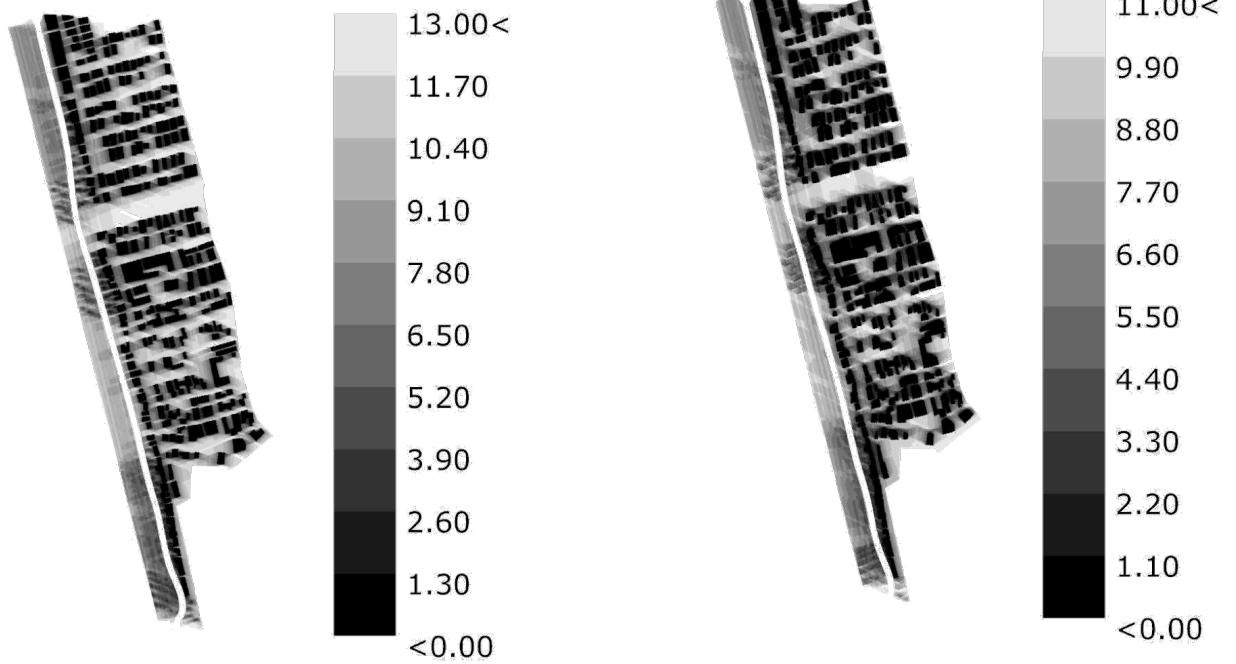


Fig 3.7 Shadow analysis

The Rajiv Gandhi Road which is the major road in the study area has a road width of 38m which comes under sub-Arterial road. The other roads were identified as collector, local and cul-de-sac which had 10m to 12m, 7.5m and 3m widths respectively.

Space standards for road types are

1.Urban Expressway	50-60 m
2.Arterial Road	50-80 m
3.Sub Arterial Road	30-50 m
4.Distributor/Collector Roads	12-30 m
5.Local Street	12-20 m
6.Access Street	6-15m

Tab 3.1 Space standards

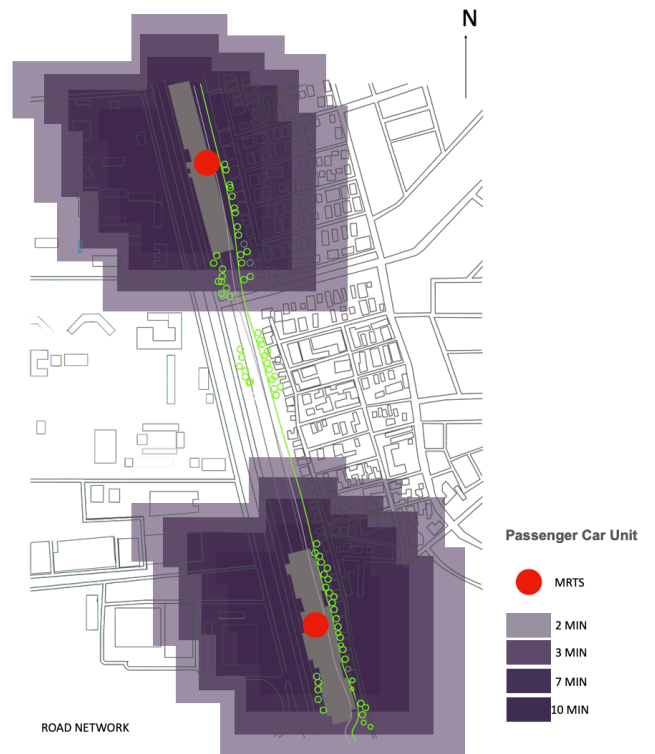


Fig 3.8 Road Network

VEHICULAR TRAFFIC ANALYSIS

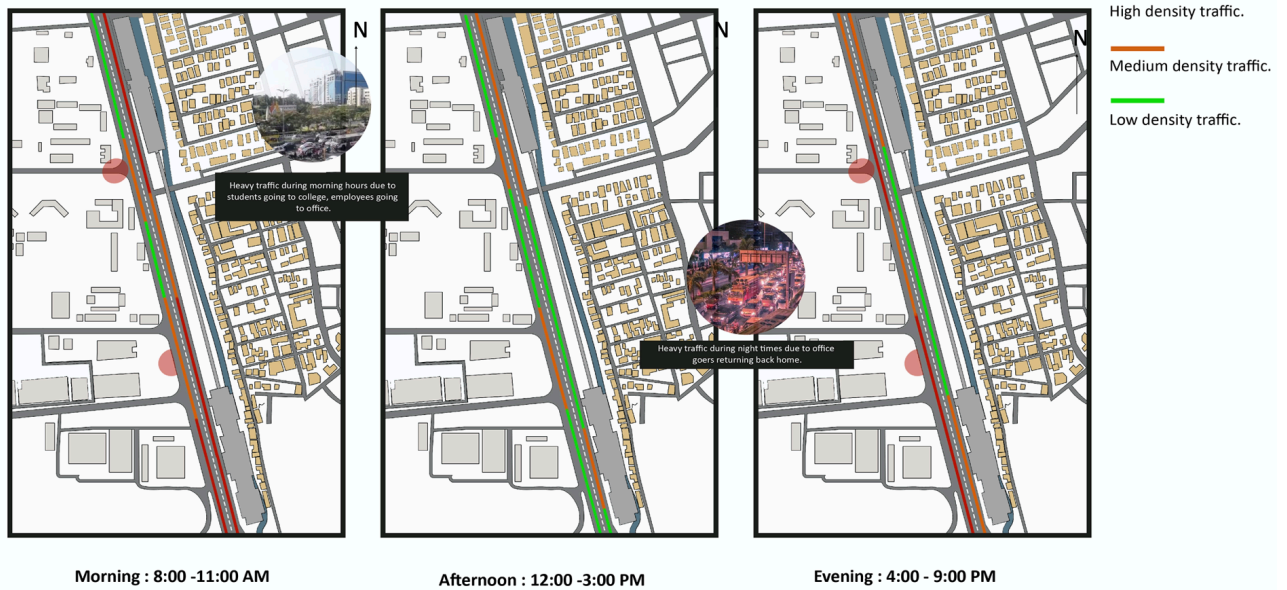


Fig 3.9.1 Traffic Analysis during different times in a day

PEDESTRIAN TRAFFIC ANALYSIS

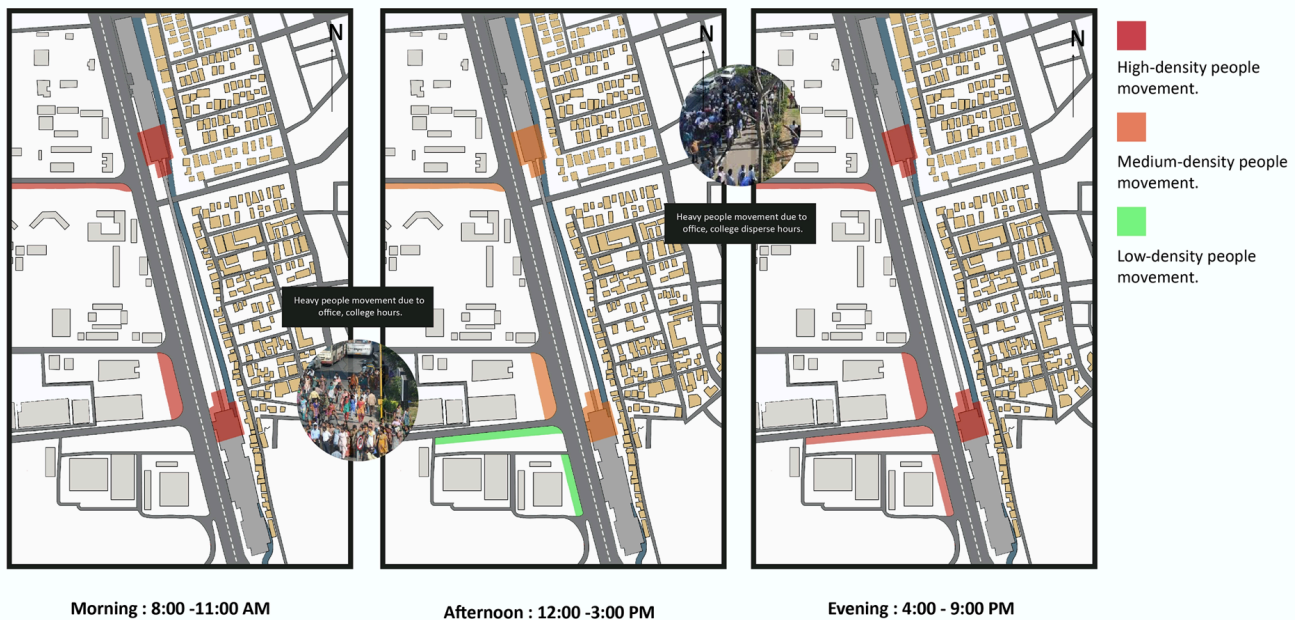


Fig 3.9.2 Pedestrian Analysis during different times in a day



FLY ASH DUMPING

Industrial dumping in the river and canal has resulted in silting and formation of sand bars, obstructing the water movement into the sea.



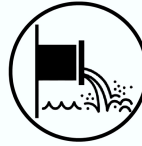
COASTAL POLLUTION

Chennai's water bodies and channels suffer from water pollution eventually resulting into coastal pollution.



COASTAL EROSION

A relatively new threat to the city as a result of the construction of sea harbors. The harbor docks block the sediment flow running northwards along the coast causing sedimentation south of the harbors and erosion north to the harbors.



UNTREATED SEWAGE

Adyar and Kosasthalaiyar river suffer from chemical pollution due to industrial effluents discharged into the rivers. Buckingham Canal receives 60% of untreated sewerage surplus.



REAL ESTATE PRESSURES

The rising Real Estate demands has resulted in shrinkage of some of the important water bodies and marshes in the city eventually reducing the holding capacities of the water bodies.



DIMINISHING WETLANDS

Urban Development, poor management of wetland systems, legal and illegal dumping of solid waste and construction wetlands have collectively resulted in diminishing wetlands which were vital part of the hydro-ecosystem of the city.



Annual Average Rainfall
1400mm



Total Catchment of Reservoirs
11057mcft



River Discharge Capacity- Adyar
72000c/s



Flood Discharge- Adyar 2015
>80000c/s



Water Demand
1200MLD



Water Supply
985 MLD



Water Deficit
215 MLD



Projected Water
400 MLD

4. GUIDELINE ANALYSIS

GUIDELINES : URDPFI Guidelines

Sr. No.	Types of Natural Hazards	Salient Features on Prevention, Preparedness and Mitigation of respective Disasters		
1	Flood Management	Prevention and Preparedness - Set up River Basin Organisations to deal with the management of water resources at river basin level. - Preparation of Flood Management Plan by joint effort of States and concerned department of Central. This plan should be integrated with plans at city region or district level. Mitigation - Identification and marking of flood prone areas on maps, preparation of close contour and flood vulnerability maps, formulating plans for expansion and modernisation of flood can also be included in Development Plans. - Implementation of the schemes for expansion and modernisation of the flood forecasting and warning network, execution of flood protection and drainage improvement scheme and identification of reservoirs. - Implementation of activities, which include construction of dams and catchment area treatment (CAT) works in India as well as neighbouring countries for flood mitigation.	3	Drought Management Prevention and Preparedness - Preparation of Drought Management Plan at district and State level in integration with Disaster management Plan and development plans. Plan to be prepared in advance based on the long season forecast issued by India Meteorological Department (IMD) in April and also the previous season rainfall. Mitigation - Measures for integration of soil, water and forest management and form part of soil conservation, watershed development and forestry programmes. - Drought proofing measures are taken before the crop is planted and drought management measures are taken during the crop-growing period.
7	Urban Flooding Management			Prevention and Preparedness - Contour Mapping will be prepared at 0.2 - 0.5 m contour interval. - Inventory of the existing storm water drainage system will be prepared on a GIS platform. - Catchment will be the basis for planning and designing the storm water drainage systems in all ULBs. - Storm water drainage systems for coastal cities have to be designed taking into account the tidal variations. - Risk assessment will be carried out with a multi-hazard concept leading to fool proof land use planning. - Involvement of the Residents' Welfare Associations & Community Based Organisations in monitoring this and in all Urban Flood Disaster Management actions. Mitigation - Future Storm water drainage systems will be designed with a

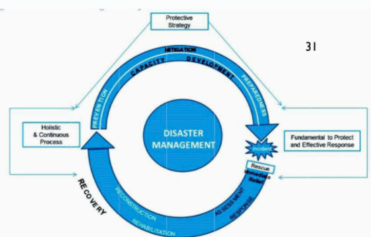


Fig 4.1 Disaster Management

SOURCE30 : <http://mohua.gov.in/upload/uploadfiles/files/URDPFI%20Guidelines%20Vol%20I.pdf>

Tab 4.1 Natural Hazards

		Runoff Coefficient of up to 0.95 in using Rational Method taking into account the approved Land-use Plan.
		■ Rainwater Harvesting as an integral component of the building. ■ Encroachments on Drains and in Floodplains will be removed by providing alternative accommodation to the poor people. ■ Low-lying areas should be reserved for parks and other low-impact human activities. ■ Storm water drainage concerns will be made a part of all Environmental Impact Assessment norms.

S.No.	Activities	Recommended Buffer
		population in the annulus between 1.5 and 5 kms. Administrative actions ensure that there is no influx of large population in this area
		• Population Restriction: – Population density within 10 km radius: Less than two-third of state average; – Population within sterilised zone (5Km radius) Less than 20,000; – Population centres with more than 10,000 persons more than 10 km away; – Population centres with more than 100,000 person) more than 30 km away;
12	High density/ high activity zones	Areas around high density, mixed land use or residential areas along dense commuter's zones/ arterial and sub-arterial roads to be buffered with trees and plantations, flexible building material for attenuation/reflection.

Guidelines for Rain Water Harvesting

Rainwater harvesting is the technique of collection and storage of rainwater at surface or in sub-surface aquifers, before it is lost as surface run-off. The augmented resource can be harvested in the time of need. Artificial recharge to ground water is a process by which the ground water reservoir is augmented at rate exceeding that under natural conditions of replenishment.

The functioning of ground water recharge units, various methods and techniques have already been elaborated in Infrastructure Planning section. Ministry of Water Resources, Central Ground Water Board (CGWB) has issued the 'Manual on Artificial Recharge of Ground Water'⁸⁷, which can be referred for development of such projects.

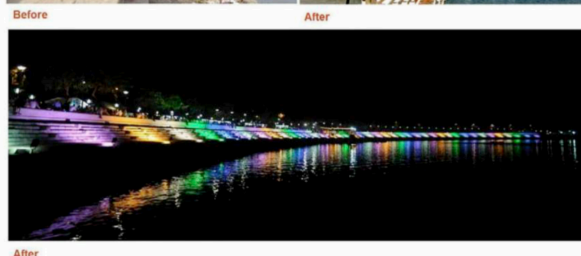
Case Study: Kankaria Lake, Ahmedabad

Restoration of lake in a fast growing urban environment - Kankaria Lake in Ahmedabad

Key Highlights:

1. Source of water: Surface and recharge of groundwater, for drinking and irrigation
2. Supports livelihoods
3. Food and nutrition
4. Act as flood control measures
5. Recreation Spot
6. Lake as a 'natural infrastructure' for climate change adaptation

Transformations of Ghats: Kankaria Lake, Ahmadabad



31 Source: MoUD presentation.

Fig 4.2 Transformation of Ghats

CRZ GUIDELINES

Coastal Regulation Zone Notification, 2011

Index

- CRZ I: Eco-sensitive and intertidal areas
- CRZ II: Areas which have been developed up to or close to the shore
- CRZ III: Areas that are relatively undisturbed and do not fall under CRZ-I or CRZ-II
- CRZ IV: Area between Low Tide Line and 12 nautical miles into the sea/ tidal influenced waterbodies
- NDZ: No development zone that extends up to 200 m from High Tide Line towards land in CRZ-III area

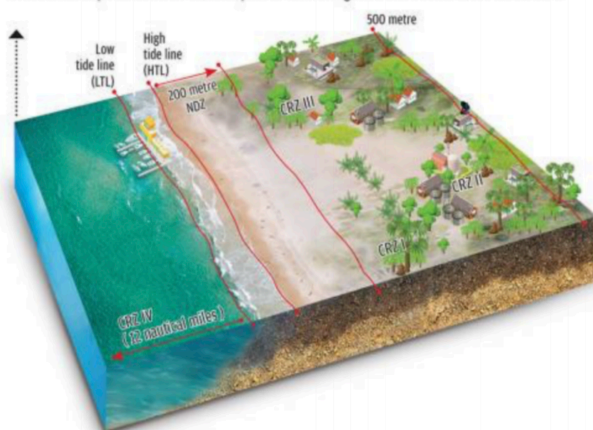


Fig 4.3 CRZ Notification 2011

Coastal Regulation Zone Notification, 2018



Index

- CRZ I A: Eco-sensitive areas
- CRZ I B: Inter-tidal areas
- CRZ II: Areas which have been developed up to or close to the shore
- CRZ III A: CRZ-III areas, where the population density is more than 2,161 sq km as per 2011 Census
- CRZ III B: Areas with population density of less than 2,161 per sq km, as per 2011 Census
- CRZ IV A: 12 nautical miles from the Low Tide Line towards the sea
- CRZ IV B: Tidal influenced waterbodies
- NDZ: 50 metres from High Tide Line in CRZ III A areas, 200 m from HTL in CRZ-III B areas

Fig 4.4 CRZ Notification 2018

HOME WASTE

Improper disposal of waste . Dumping of waste in the river by the homes located along the river

TRANSPORT

Vehicle emission contribute to poor air quality. Wearing of road surfaces, tyres and break pads release small particles including heavy metals into the environment

WASTE WATER AND STORM WATER

It enters urban streams through leaky pipes, illegal connections and consented over flows during storms, Rainwater carries pollutants through the storm water system into the water waste

STRATEGIES

Restoration category	Restoration type	Example of intervention
Reestablish morphological river type	Initiate a river-type-specific morphology Set initial measures for type-specific self-development of the river/the river floodplain system (e.g., braiding, meandering) and instream structures	- Remove bed and bank stabilization - Reconnect or create side arms - Restructure riparian zone (wood structure, bays) - Initiate dynamic aquatic/terrestrial transition zone - Small-scale river widening
Reestablish lateral connectivity/floodplain habitat restoration	- Increase/reconnect floodplain/natural retention areas - Initiate/create floodplain habitats	- Remove/replace/lower dams - Lower the floodplain area - Initiate/plant floodplain vegetation - Initiate/create aquatic floodplain habitats - Initiate/plant floodplain vegetation

Flow management	Increase residual flow Increase dynamic flow	Increase and adapt residual (environmental) flow Increase and adapt dynamic (environmental) flow
Mitigate hydropеaking	Modify power plants Alter the mode of hydropower production Create compensating reservoirs Divert hydropеak flow Coordinate hydropеaks	- Produce hydropower without hydropеaking - Mitigate hydropеaks - Mitigate hydropеaks through compensatory reservoirs - Divert hydropеak flow to a larger receiving river or to a dammed river section - Avoid overlapping hydropеaks
Temperature management	Modify turbine intakes	Create multiple entry devices and operate water release according to environmental criteria
Sediment management	Reopen sediment sources Active sediment input	Remove, lower, reconstruct torrent controls, weirs, ramps, Open riparian zones and floodplain areas Donate sediment to the river
Land use	Modify land use	Encourage extensive sustainable , Create buffer zones agriculture.

SOURCES:

<https://www.sciencedirect.com/journal/journal-of-hydro-environment-research>

<http://www.springer.com/series/5637>

The 4th International Conference on Water Resource and Environment (WRE 2018)

IOP Conf. Series: Earth and Environmental Science 191 (2018) 012099, IOP Publishing

doi:10.1088/1755-1315/191/1/012099

Tab 4.2 Strategies

STAGES INVOLVED IN STRATEGIES

River Accessibility : This strategy will help to make river front accessible easily. By analyzing hierarchy of the roads and there use, the accessibility plan and ways can be sorted out. Accessibility some areas of river front is very important because of the use and activity variations in those areas. the connection between two river front areas will be the main aspect in this strategy not only physical but also visual connection will help the river fronts to engage in these character and to involve people throughout the stretch.

Transportation : The riverside road and subordinate roads connecting the main roads are usually loaded with traffic the improvisation on those roads and some of the laws can make it more suitable and more resilient in the way of access and ease. By existing road widening and making some of the roads, streets uni-directional the problems can be minimized and the situation can be more practical.

Drainage system Management : The strategy to manage these drainages and promoting less connection on labor and achieving more through existing can help the current scenario of riverfront. Making sewage and treated water to be carried away from the river and not letting the water to be merged in the river water, improving the hygiene of the river. Desilting the river is one of the main aspect in this strategy. By desilting the river depth can be maintained and there will be no flooding issues.

Public Space Enhancement : By the strategy of enhancing public areas and promoting new activities near riverfront, the public involvement can be achieved. By creating smoothing space and promoting riverside lands for various activities, the character of the river-side area can be changed and it will be more active than the current situation.

Heritage Promotion : This strategy will help the riverside area to enhance the historical character and to promote the heritage value if any.

Land Use Management : As mentioned earlier desilting will help the river to maintain the depth and avoid flooding issues. This will cater to solve the problems regarding lands restrictions and the land can be used in many creative ways. By demolishing urban sprawl and unauthorized commercial area and relocating them in a nearby allocated land will serve the purpose and will activate the riverside area in different parts of the city. By restricting some areas for riverside wetlands the ecological value can also be

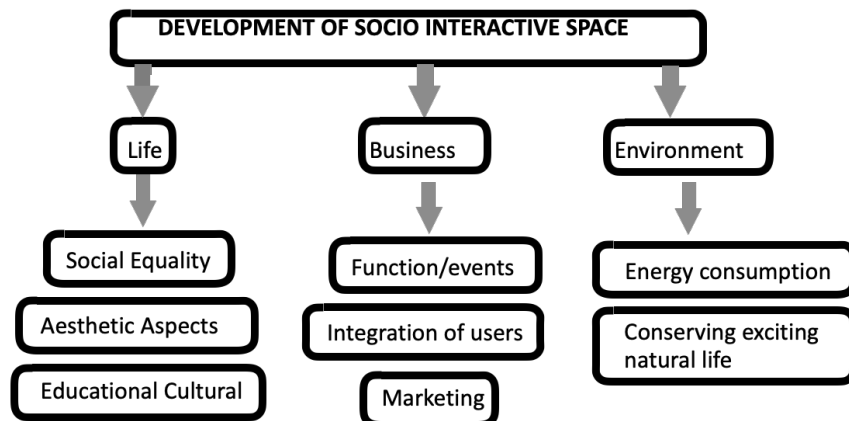
maintained.

HIGHLIGHTS OF RIVER FRONT DEVELOPMENT

Public space - Riverfronts are public spaces. The city people can use them for a variety of activities, like a festive gathering place, a variety of recreation resources (active as well as passive) or for some mixed use, be it residential, retail, a city landmark etc.

Recreation/Fitness - They could be used as space for cycling, jogging or other activities that require open areas. It can also be utilized for some passive activities or fishing and boating are. These activities will serve a threefold purpose – provide recreation, create a healthier environment and thus keep people fit and healthy.

Tourism - Tourism improves the economic wealth of the city. The rejuvenated and re-energized riverfronts will attract more visitors. Cities developed them as destinations to expand their tourism industry.



Tab 4.3 River Front Development

QUALITATIVE ANALYSIS

Recommended for Open-Space

Buffer Typologies

- The wider the river zone buffer, the more benefits it provides in terms of wildlife habitat, water temperature modulation, protection from non-point sources of pollution, flood mitigation, sediment removal, and bank stabilization.
- The riparian buffer should be no less than 75 feet at its narrowest, with three zones of buffer from the stream edge inland.
- The first zone should be undistributed forest to provide food, shade for the water body, and slope stability.
- The second zone should consist of managed woodland that allows for infiltration, filtration of sediment and nutrients and nutrient uptake by plants.
- The buffer area on the upland side should include a sheet flow of rainwater runoff to maximize vegetative and soil contact with the runoff.
- The riparian corridor should be uninterrupted, helping to reduce the concentrated flows to the water body and providing continuous habitat for birds and other wildlife species that require undisturbed access to food, shelter and water.
- Trees are the most important element in a riparian corridor for removing nutrients, stabilizing the soil, modifying water temperature and providing food for aquatic organisms.
- Recreation in the buffer should be balanced with the effects this will have on existing features, especially in terms of excess nutrients, contaminants and chemicals, including pesticides, fertilizers, and herbicides.

Source :riverlifepgh.org/resources

Ecological Conservation and Open-Space Buffer Zone

For open spaces along the river, a buffer zone should include design and development techniques that will provide and enhance the following: provision of ecosystem services, ecological restoration, conservation and improvement of biodiversity, increased habitat corridor potential, improved public trail access, open-space amenities, and environmental education.

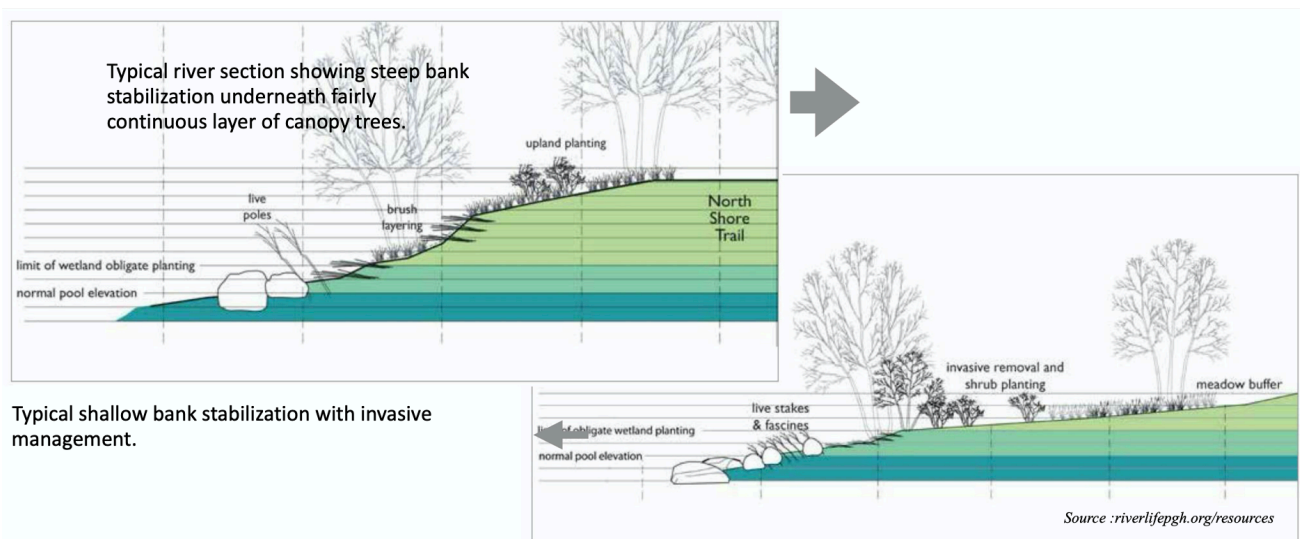


Fig 4.5 River section

CONNECTION TO THE RIVER

- Streets should be designed with all transportation modes fully accommodated instead of being designed primarily for automobiles. In addition to being multi-modal, complete street design considers urban.
- Maintain established build-to lines along major perpendicular connections. Where retail and restaurant uses will be located, provide for sidewalk café seating and arcaded ground floors where appropriate.
- Street trees, lighting, sidewalks, and curbs should comply with all municipal standards and guidelines.

Perpendicular Connections along Private Uses

- Provide a minimum walkway width of 12 feet for perpendicular connections to be maintained as an easement or public right-of-way. Provide a minimum setback for all structures, including fences, of 10 feet on either side of the connection.

If possible, locate public amenities, such as seating, maps, etc., at the ends of the connection to serve as a focal point, drawing attention to the riverfront and encouraging movement along the trail connection.

Perpendicular Connections along Public Uses

- Provide storefront glazing, extending from the ground to a minimum height of 12 feet. Wrap the storefront glazing around the corners of the buildings, to provide visual connections to the publicly oriented uses from all approaches.



Source : riverlifepgh.org/resources

Fig 4.6 Public Use of river

Riverfront Trails

- In general, contain the trail within a canopy of deciduous trees, providing shade in the summers and allowing sunlight to penetrate in cooler months. The trail should move in and out of the tree canopy, opening to provide views to the river and closing again to provide a sense of intimacy and enclosure.
- Avoid planting trees in even rhythms such as those typically used in street tree plantings, unless it is desired to emphasize a specific architectural character. Instead, plant them in groups with varying densities.
- On the river side of the trail, design the tree canopy to open and close, creating new views both to and from the trail. This will create views of the surrounding riverfront.



Riverfront Promenades

- Use higher-quality materials, such as stone paving, for promenades.
- Promenades along a riverfront park should be considered part of the park.
- Plant trees within 15 feet of the river edge of the promenade.
- Plant dense landscaping below the front edge of promenades in order to frame views and give the user the sense of vantage point that comes from sitting above the trees.
- For buildings located along promenades, provide ground floor uses that are public in nature, including civic, cultural, retail, entertainment, restaurants, and public lobbies.

Source : riverlifepgh.org/resources

Riverfront Streets

- Locate primary addresses and entrances to buildings on the riverfront street.
- Provide a 7- to 8-foot sidewalk and 4- to 5-foot tree range. Where space is limited, the trail may substitute for the riverside sidewalk.
- Plant riverfront streets with dense tree canopies, allowing views to the river below the canopies.
- Streets should be designed with all transportation modes fully accommodated instead of being designed primarily for automobiles. In addition to being multimodal, complete street design considers—along with the urban design and environmental goals—thoughtful design and integration of materials, landscaping and stormwater management.

Scenic Drives

- Views should be maintained from scenic drives into the river valleys through the careful selection of structural elements, including barriers.
- Provide landscaping and street trees for scenic drives in order to enhance the roads as green boulevards through the community.
- Utilize high-quality materials for the reconstruction of scenic drives, including concrete sidewalks.



Source :riverlifepgh.org/resources

Fig 4.7.1 Bridge over river

Fig 4.7.2 Recreational space around river

Landings

- Landings should be transitional and connective points between the river's edge, the riverfront park and the community, with access to the trails, esplanades, promenades and transit connections.
- Landings should comprise a series of spaces that vary in size and purpose, and serve those who use the riverfront park daily or for an occasional or one- time visit

Transportation Planning

- Consider future plans for water transportation as opportunities to make connections to water landings.
- Provide secure bicycle storage, personal lockers, changing rooms, and showers to accommodate a minimum of 5 percent of the building's occupants.



Site Planning

- Locate public entrances to retail and commercial uses along the riverfront facade of the building. Create riverfront addresses, particularly with regard to publicly oriented uses.
- Utilize landscaping, rather than walls and fences, to create semipublic/ private buffers .
- Maximize the use of pervious materials and green infrastructure .
- Reduce on-site heat gains by minimizing dark-coloured surface areas, such as black asphalt. Acceptable alternatives include concrete paving, unit paving

Source :riverlifepgh.org/resources

Open-Space Planning and Design

- When designing new open spaces, check plans for the surrounding community. Public open-space requirements should be met through the creation of riverfront promenades, additional perpendicular connections to the park and other spaces that complement the river park.
- Design new open spaces to occur mid-block, not at corners, and in locations that are adjacent to the riverfront or perpendicular connections to the park.

URBAN MORPHOLOGY

Building Contextual Scale and Massing

- In new districts, a master plan should outline the minimum and maximum requirements for building height and massing.
- In dense urban areas, construct buildings to a minimum of four stories and 60 feet high in districts adjacent to a river, with six to eight stories preferred.
- Design building massing with consideration of maintaining views of rivers, key landmarks and architecture, and the vistas and spaces around them. Maximize light and air to open spaces and minimize shadows on adjacent properties and open spaces.

Source :riverlifepgh.org/resources

21

- For individual building projects, identify the height patterns that are present in the district in which they are located. Relate the height of the new development to the height of the surrounding district, and reduce negative impacts on adjacent properties, such as blocking views, casting open spaces into shadow for a significant period of the day

Setbacks and Build-to Lines

In general, build to the property line or an established build-to line of an existing district for all properties located along both perpendicular and parallel connections, with the intention to develop a consistent and continuous urban fabric within districts.

- “Hold the corner” of buildings at intersections, except where open spaces are strategically located.

In new districts, an individual district master plan should outline the minimum and maximum requirements for building setbacks and build-to lines

Ground-Floor Design

- Activate the ground floor with different uses and make them adaptable over time.
- Maximize glazing at least 60 percent.
- While publicly oriented uses are generally encouraged along all district edges, there are also many opportunities to create residential communities adjacent to the park.

Building Materials

- Compose buildings of materials with a “Pittsburgh palette” to enhance the quality of the riverfront.
- These materials can include stone, metal, brick, terra cotta, aluminum, glass, and steel, and can be locally sourced in order to meet green building targets.
- Other materials may be used for trim and detail, but are not encouraged as a primary building material.



Source :riverlifepgh.org/resources

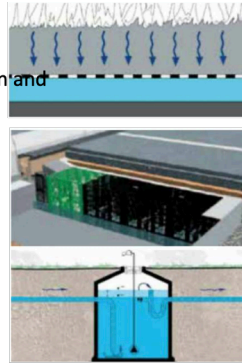
Fig 4.8 River flowing illustration

Green Roof:

These can be planted partially or completely with vegetation and soil over a waterproofing membrane.

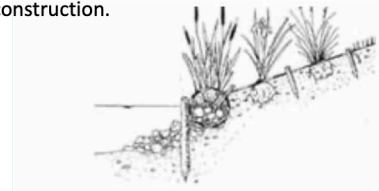
Underground Substrate Filter: These are box structures, built underground, containing compression-free material that helps to treat organic pollution.

Cistern: These function mainly as rainwater storage and secondly for stormwater detention.



Bioengineering:

Bioengineering seeks to harness the inherent qualities and capabilities of organic matter to replicate natural systems as closely as possible, not only in the use of materials, but also in the methods of construction.



Landscape

Lighting

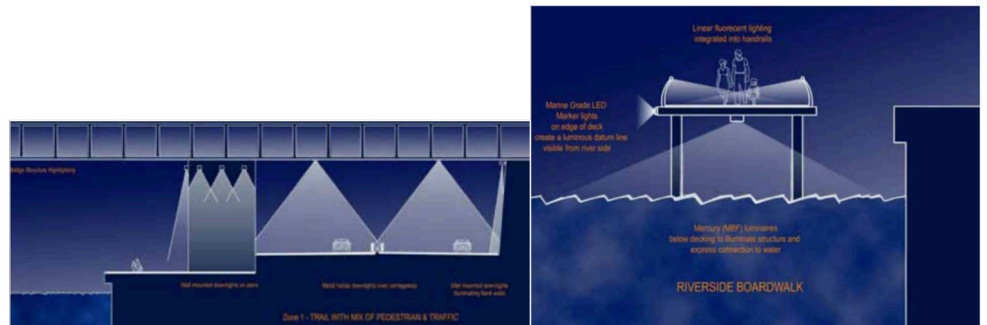
Lighting has the power to ensure that the public realm remains safe, comfortable and engaging after dark.



Fig 4.9 Light Analysis

Source: <http://www.iaeme.com/IJCIET/index.asp>

- Lighting Landscapes
- Lighting Fountains
- Water Features
- Lighting Art Installations
- Build Quality



QUANTITATIVE ANALYSIS

River Restoration

SMALL RESTORATION

MEDIUM RESTORATION

LARGE RESTORATION

1. Small Restoration, that is restoration that was done in a segment with the length of 0 meter to 100 meters.
2. Medium Restoration, that is restoration that was done in a segment with the length of 100 meters to 500 meters
3. Large Restoration, that is restoration that was done in a segment with the length of larger than 500 meters.

Source: <http://www.iaeme.com/IJCIET/index.asp>

In this research, issues in hydrological model is that transformation of morphology and water quality therefore causing transformation

1. Development that not environmentally friendly.
2. There are no healthy lifestyles in the community
3. there are no good drainage planning and maintenance system in the city
4. there are no consistency of the authority in enforcing the regional spatial planning.
5. There are no effort in conservation of balancing factor of water environment.
6. Subsidence
7. Very high rainfall

Design Flood Volume

Design flood volume is the magnitude of the flood volume that used in understanding if the capacity of the river are able to stored the flood volume. The formula to calculate the design flood volume is by using rational formula. Below here is the formula of the design flood using rational method:

where: $Q = 0,00278 C \times I \times A$

Q : maximum flood volume (m³/second) C : coefficient of surface flow ($0 \leq C \leq 1$) I : rainfall intensity (mm/hour)

A : area of watershed (Ha)

Hydraulics

Hydraulic is a study of water flow through an open channel. Open channel flow experience retardation in the flow process from upstream to the downstream

Open Channel Flow

River is one of the example of open channel flow of the water flow from the upstream to the downstream that experience

retardation both by the channel wall roughness and the roughness of the channel's bottom.

Flow Volume

Volume is a velocity of water flow through a cross-section of a channel per time unit. In International system unit, volume stated in

meter cubic per second (m³/second). Below is the formula of the volume:

Restoration Model of River Morphology and Water Quality in Urban Area

$$Q = A \times V$$

where:

Q : volume (m³/second)

A : area of river cross-section (m²)

V : velocity of water flow (m/second)

Velocity of the flow can be obtain by using this formula:

$$V = \frac{1}{N} \times R^{2/3} \times S^{1/2}$$

Where:

$$V = \frac{1}{N} R^{2/3} S^{1/2}$$

: velocity of the water flow in the channel (m/s) : coefficient of channel wall roughness

: hydraulic Radius

: channel slope

5. PROPOSAL

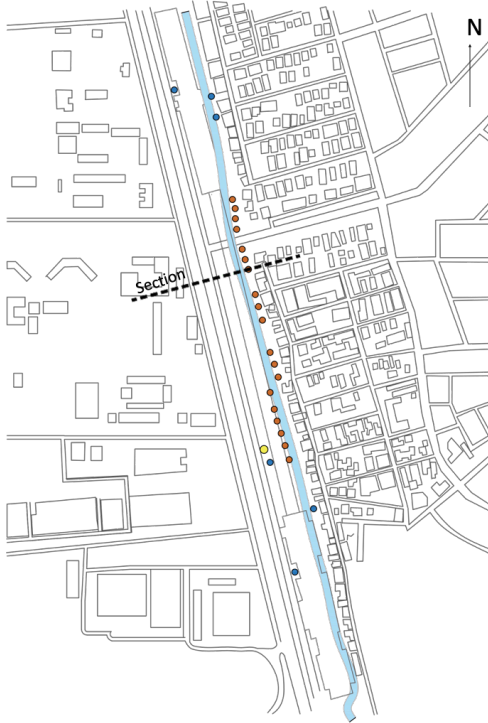
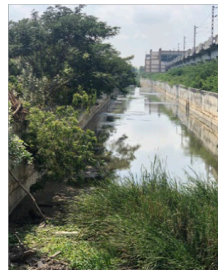


Fig 5.1 Site Map

Analyzing Sewage and Storm Water Outfalls

Different elements of Green infrastructure have been recommended after careful site analysis as the condition of the site and its context have heavily affected the state of the canal water. Identifying the Sewage outlets and Storm Water drains has helped place and propose the variety of GI elements that will ensure that the water entering the canal from the vicinity is clean as well as the current situation of the water is also taken care of.



Due to these settlements, small sewage outlets are now draining untreated sewage into the canal making the stretch seem like a sewer. Larger storm water drains, mainly located near the two MRTS stations are directed into the canal and carry runoff from adjacent roads. Unconsciously dumped construction debris, carelessly disposed off plastic, unruly weeding are evident reasons for the deterioration of the canal in this stretch.



Fig 5.2 Current situation of site

WATER MANAGEMENT: CANAL RESTORATION

Aerators

Three types of aerators must be employed on the canal surface namely jet aerators, manifold aerators and nano aerators. Phosphates compounds present in domestic sewage can be changed to alternate phosphate compounds using nano aerators



Micro plastics

Micro-plastics don't dissolve in the water and the particles are very small. The nitrate oxide content is converted to aluminum nitrate by plants which further fosters the aquatic life of the canal.



Vertical green wall

The retention wall for the canal can be planted with specific plants to purify the water of the canal.



Use of check dams

Check dams must be used through the length of the canal. Check dams can be employed in order to create divisions in the canal to counter solid waste and sedimentation. The check dams also aid in control and maintenance of the canal. The check dams also help in damage control by controlling the flow of the water flowing through the canal. Check dams also reduce the water flow speed and reduce the particle content of the canal water.



Changing the flow of the canal

The first step is to change the flow of the canal from upstream to downstream. If the flow is altered the water will flow into the canal from Adyar river which would lead to an increase in 1' to 2' water level rise.



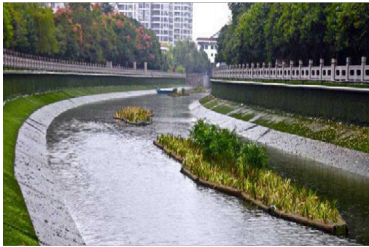
Floating treatment island

Floating treatment islands not only add to the beautification of the site but also clean the water up to 80%. Plant roots used in the floating treatment islands introduce bacteria into the water that change the chemical composition of the water. The ammonia and the sulphate content of the water, which is the major cause for the smelling of the canal, are broken down and the smell is reduced.



Fig 5.3 Canal Restoration plan

WATER MANAGEMENT & RESTORATION TECHNIQUES



Floating treatment islands are artificially created islands that employ natural processes to purify and treat water bodies. Major pollutant reduction mechanisms have been spotted in FTWs. Floating treatment islands have been demonstrated to be successful in effectively removing waterborne pollutants. Many floating treatment islands can also be used as storm water catchments. The following examples are a few demonstrations about how floating treatment islands have been designed and executed in our country.



Nekhnampur Lake, Hyderabad



The 3,500 sq ft Floating Treatment wetland has been designed using styrofoam, bamboo, gunny bags, coir etc. This floating island is multi-layered and installed close to the inlet of the lake. When the water passes through all the layers, it gets filtered, eventually resulting in optimum fresh water. This combination used is Mosquito Repellent while also helping in the cleaning of water and increasing the biodiversity of the lake.

Hebbagodi Lake, Bangalore



The 12,000-sq ft island has strips of vegetation that crisscross the waterbody. Floating rafts are built with reused, PVC pipes making use of the Hydrophobical Plants. Silt-removing and dewatering operations were taken up on a war footing. Energy-efficient cascading aerators were installed to increase the level of dissolved oxygen in in water. Underground conduits were laid to address sewage spills and stench.

Kaikondrahalli Lake, Bangalore



The base of the Floating Treatment Wetland was created using Pvc Pipes and discarded plastic bottles, netting, nylon meshbags. The idea behind the construction of this FTW was to Reduce Eutrophication (the depletion of oxygen in a water body due to excessive nutrient accumulation, which kills aquatic animals), improve the landscape of urban lakes, and preserve their shores through wave absorption.

Poisar Lake, Mumbai



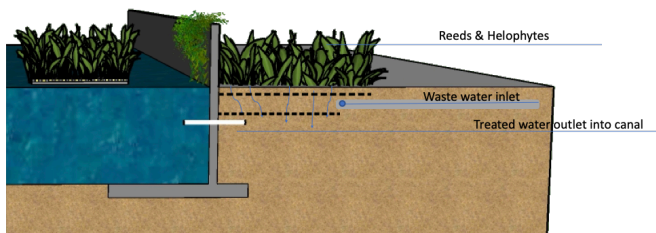
The base of the FTW is made using 500 discarded plastic bottles which were tied together to create a makeshift 'mop'. The plants in the wetland provide a peculiar habit. For beneficial micro-organisms in The root zone (which also pump oxygen from the atmosphere into the bed) and jointly purify the sewage while the plants are automatically nurtured by the nitrogen and phosphorous in the sewage.

Fig 5.4 Restoration techniques

CONSTRUCTED WETLANDS & FLOATING TREATMENT ISLANDS IN THE CANAL WATER

Artificial wetlands have become recognized world over as an effective, low-cost technology to improve the water quality of aquatic environments by absorbing harmful nutrients and chemicals from the municipal waste entering and polluting them. The Constructed Wetland span an average area 375 square meters . The width of the strip measures at 1.5 m respectively

Design Section



BENEFITS OF HELOPHYTES

1. Plants directly uptake pollutants, especially nutrients, from the water, using a process known as biological uptake.
2. Microorganisms growing on the floating rafts and plant root systems break down and consume organic matter in the water through microbial decomposition.
3. Root systems filter out sediment and associated pollutants.

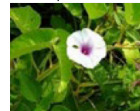
Vetiver Grass



Cattail



Water Spinach



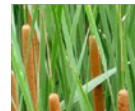
Colocasia



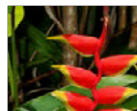
Dwarf Canna Indica



Common Cattail



Heliconia



Common Reed

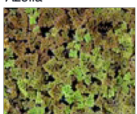
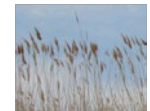


Fig 5.5 Helophytes

<https://www.urbangreenbluegrids.com/measures/bioswales/>

BIOSWALES BY THE ROAD SIDE

Bio-swales are vegetated, shallow, landscaped depressions designed to capture, treat, and infiltrate storm water runoff as it moves downstream. They are typically sized to treat the water quality event, also known as the “first flush” which is the first and often most polluted volume of water resulting from a storm event.

The water run off from the service road can be directed into the Bio-swale, post which the water will percolate through the layers and get purified. Some of which will be directed towards the canal by a pipe and the rest will enrich the ground water level. The proposed Bio-swales covered an area of 9 square meters. ie. 1.5m x 6.0m respectively.

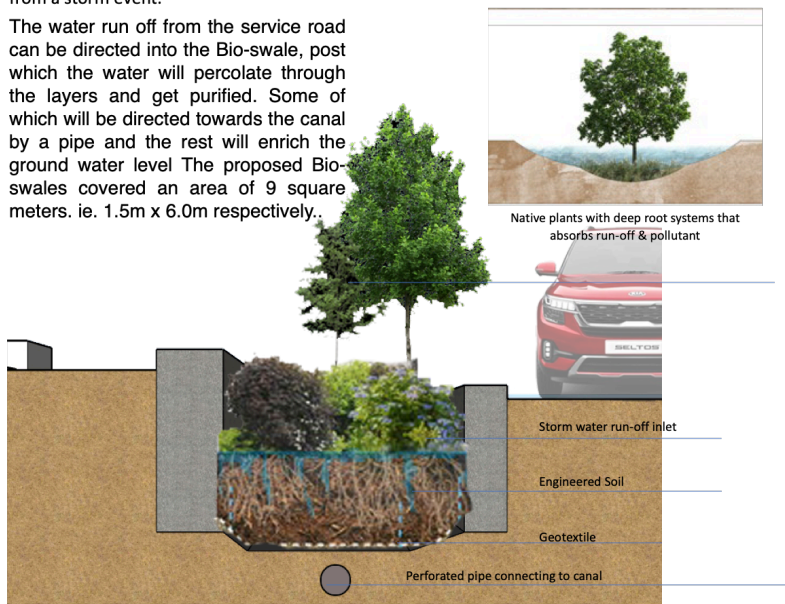


Fig 5.6 Bioswale

DESIGN CONSIDERATIONS

1. Bio-swales require appropriate composition for soil construction. The engineered soil mixture will consist 5% maximum clay content. The side slopes are 4:1, with a maximum slope of 3:1.
2. In order to protect adjacent subsurface infrastructure we have maintained minimum clearances. We can install waterproof liners as separation barriers.
3. The Bio-swales are designed to help us maintain a 5-foot minimum clearance from the bottom of the bio-swale to high groundwater table.
4. The overflow/bypass drain system has been raised approximately 6 inches above the soil surface to manage storms larger than the water quality event.
5. The overflow/bypass drain system has been raised approximately 6 inches above the soil surface to manage storms larger than the water quality event.
6. Runoff that enters the bio-swale in a sheet flow fashion requires that the edge of the bio-swale be flush with grade. Where curbs are necessary, intermittently space curb cuts to allow runoff to enter and be treated within the swale.

Source - <https://www.urbangreenbluegrids.com/measures/bioswales/>

Matunga Garden Under Flyover, Mumbai



AIM: CREATING A NEW PUBLIC SPACE UNDER FLYOVER
POINTS TO BE NOTED: MAKING USED OF UNDER USED LAND PARCELS FOR PUBLIC BENEFIT .

The Matunga Garden-under-Flyover Project was built with an idea of protecting the space from misuse and encroachment from hawkers, gamblers, drug addicts, etc and creating a public space for the nearby residents. This space has a walking path & green planter beds creating a safe pedestrian zone on a busy road and has attracted thousands to make this a walkers space.



The Underline, Miami USA



AIM: CREATING NEW PUBLIC SPACE UNDER A METRO LINE
POINTS TO BE NOTED : THE UNDERLINE PUBLIC SPACE GEARED TOWARDS PROMOTING AN ACTIVE LIFESTYLE



The Underline, currently under construction, is a new 10 Mile long public space in Miami. It will connect communities, improve pedestrian and bicyclist safety, create over 120 acres of open space with restored natural habitats, encourage a healthy lifestyle, provide an easily accessible place to exercise, create a mobility corridor that integrates transit, car, biking and walking, provide a 10-mile canvas for artistic expression and generate significant economic impact.

Fig 5.7 Restoration projects in other places.

COMMUNITY GARDENS

Creating Community gardens with children's play area

Provide people and the children of the neighborhoods with spaces for social gathering and recreational facilities

Objective

Design a community park for the people that is accessible to all strata of society.

The park must have ground markings to give designated spaces to children, senior citizens and differently-abled residents.

Designated spaces must be dedicated to weaker sections of the society in order to ensure smooth, safe and comfortable use of the space.

The community garden must be a combination of soft scape and hardscape to promote connection of the users to the natural terrain.

Exposure to natural terrain ensures better fitness and activity levels amongst children and adults alike.

In order to ensure activity in the space throughout the day, lights must be installed along various circulation spaces and activity zones so that spaces feel safer.



Fig 5.8 Community Gardens

PUBLIC PLAZA

Creating public spaces such as plazas and pavilions

Plazas and pavilions create very effective public spaces and also add to the accessibility for pedestrians and bicyclists. This space can be used as a multiuse area to house various events and activities. On not very busy days this space can also contribute to the public realm as breathing spaces and pause points.

Strategies

Create attractive plaza spaces that are well maintained. The Public space must feature landscape elements, amenities like drinking water and public toilets and fixed and movable seating.

The public plazas must be placed near pedestrian ways in order to increase footfall. Instead of have one large plazas the plaza could be broken into various smaller plazas and squares.

Placing public spaces near transit stops will also ensure greater footfall and add to the transit public infrastructure.

Plazas must be accessible to bicycles to encourage activities and accessibility

The plazas must include sidewalks and other existing pedestrian walkways. By creating a leveled area adjoining the sidewalks, plazas can ensure visibility and safely connect the plaza to the street. This also makes the plazas more accessible to the differently abled.

The plazas should house a diverse set of functions and be used for events and activities. The plaza must be designed to be weatherproof.

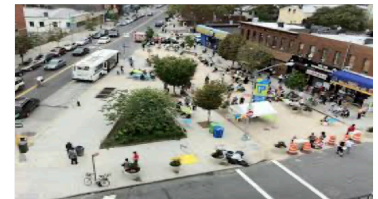


Fig 5.9 Public Plaza

PEDESTRIAN PATHWAYS

Designing pedestrian pathways

Creating pedestrian pathways and sidewalks will encourage people to adapt to a fitter lifestyle. An active lifestyle can be encouraged by creating pause spaces and enclosures to make physical active more convenient to the people.

Strategies

Create a buffer to separate vehicular traffic from pedestrian traffic. This can be done with the help of landscape elements such as urban furniture and other design elements. Provide infrastructure needed to encourage walking for longer distances such as drinking water public toilets.

Provide lighting and other safety measures like CCTVs to offer adequate levels of safety to encourage the use of the pedestrian walkways at all times of the day. Add elements for comfort shade and visual interest such as trees, small landscape patches etc.

The sidewalk must be designed for anticipated activity along it. The width of the sidewalk must correspond to anticipated usage volumes instead of having one consistent width.

Special attention must be paid to the designing of intersections and crossings. If necessary, more crossings must be added to the current pedestrian network to encourage pedestrian movement and convenience.

The on-site pathways created must be in accordance to existing sidewalks and pathways. The intersection between the on-site pathways and the existing pathways must be treated carefully.

Pathways must be designed and oriented in a manner to create intrigue and interest. There must be signages and markings on site to aid in way finding for pedestrians and cyclists.



Fig 5.10 Pedestrian Pathways

EDGE CONDITIONS

Design Strip - Sidewalk edge conditions

Create interesting and attention-grabbing edge conditions to invite people in and safer sidewalks.

Strategies

Incorporate art and food festivals along the street to create interest and incentive for pedestrian traffic.

Organizing pedestrian programs like garbage cleaning drives with Swachh Bharat Abhiyaan or initiatives like Happy Street.

Enhance street activity by introducing outdoor cafes and activities

EXPANSION OF FLOOD AREAS

Design the edge conditions to counter the overflow during the monsoons and flood conditions.

Creating an edge condition to control and mitigate flood conditions

A planted buffer zone of 5 mtrs. will be maintained on both sides of the canal

The banks of the canal must be re naturalized and hardscaping must be controlled and limited along the banks to ensure percolation of water into the ground table.

Native vegetative cover along with rain gardens must be employed at stipulated distances to ensure collection and percolation zones

Mandatory Constructed Wetlands must be maintained along the entire length to ensure polluted runoff is treated before entering the canal.



Fig 5.11 Flood Areas

PUBLIC AMENITIES LIKE DRINKING WATER AND TOILETS

The recreational space must be self sufficient in its functioning as a public space.

The Strip can function as a plug into the existing public amenities and make up for the missing amenities in the neighborhoods it passes through

Strategies

The Toilets must be strategically placed closer to high footfall regions in order to cater to high footfall zones.

Additional portable toilets and drinking water sources must be provided during events and festivals.

The maintenance of the toilets must be handed over to members of the community in order to generate job opportunities and sources of income.

Other public amenities missing in various zones must be identified with the help of the community and their placement must be mapped with the involvement of the community



SEATING AND SOCIAL SPACES

Foster community and interaction spaces.

Create a pause point for the otherwise busy station zones.

Strategies

Must be accessible to all sections of the society.

Must be comforting and in well-lit zones

The space must be designed with anthropometrics and social characteristics in mind.

The space must have temporary furniture as well to allow the people to shape the space as they please to use.

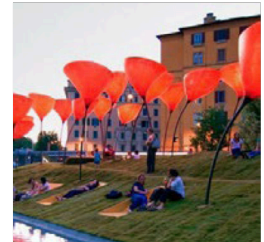


Fig 5.12 Public Amenities, Seating and Social Spaces

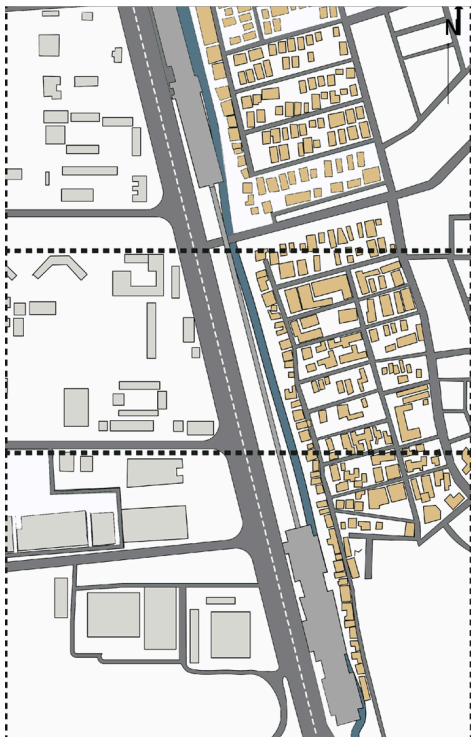
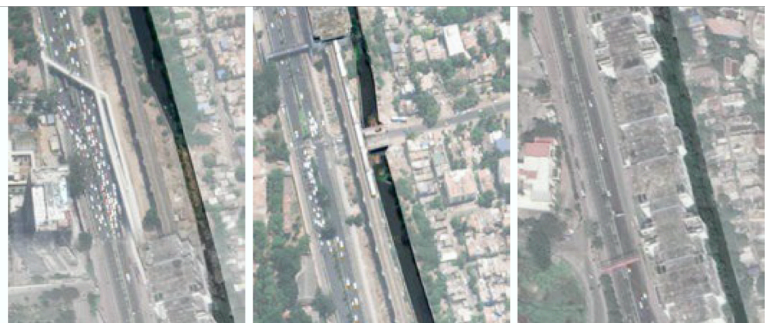


Fig 5.13 Site map divided into sections.



Analysing the canal and surrounding areas by dividing into sections.

The design is a stretch of 800m, where falls the major footfall regions which directly and indirectly affects the canal and its surroundings. The idea is to revive the canal and its surroundings and put it into its maximum usage for long term. The process involves in identifying the possible threats and the ways to mend the same.

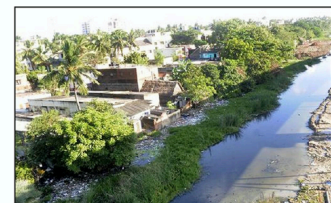


Fig 5.14 Buckingham Canal

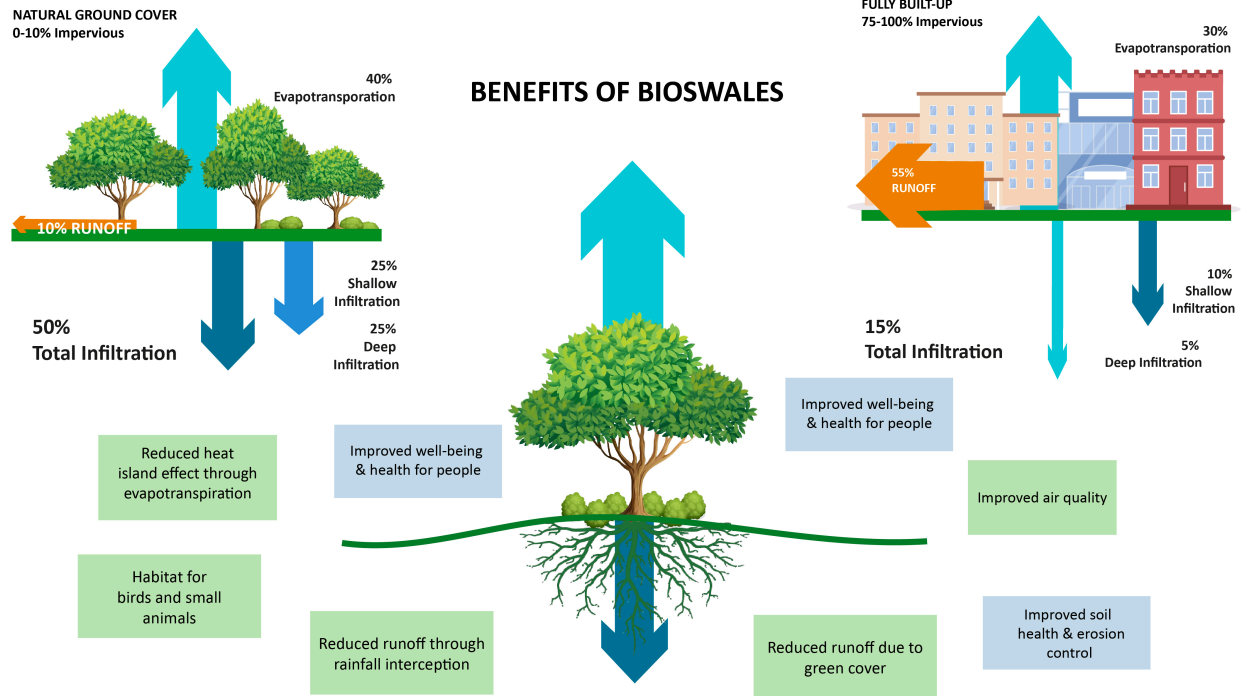


Fig 5.15 Bioswales Benefits

Tree Trenches

PERFORMATIVE ABILITY

Highly Effective in All Conditions
Moderately / Conditionally Effective
Not Effective / Not Applicable

Minimum Water Table Depth: 1.2m
Maximum Slope (in %): 15%
Suitable Soil Type: Engineered Soil

A tree trench, often known as a "vertical rain garden," is a system that consists of piping for water storage, structural soils and a tree. It manages stormwater runoff and promotes the use of trees in urban areas.

Planting a single tree creates multiple benefits for urban areas including purifying the air, reducing the heat island effect, creating wildlife habitat, buffering wind and noise, and increasing property values. In terms of stormwater management, trees reduce runoff through the interception of rainfall and evapotranspiration.

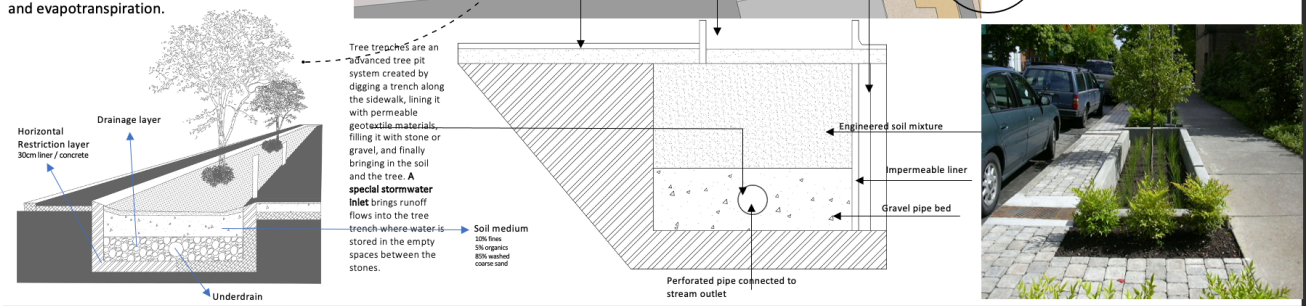


Fig 5.16 Tree Trenches

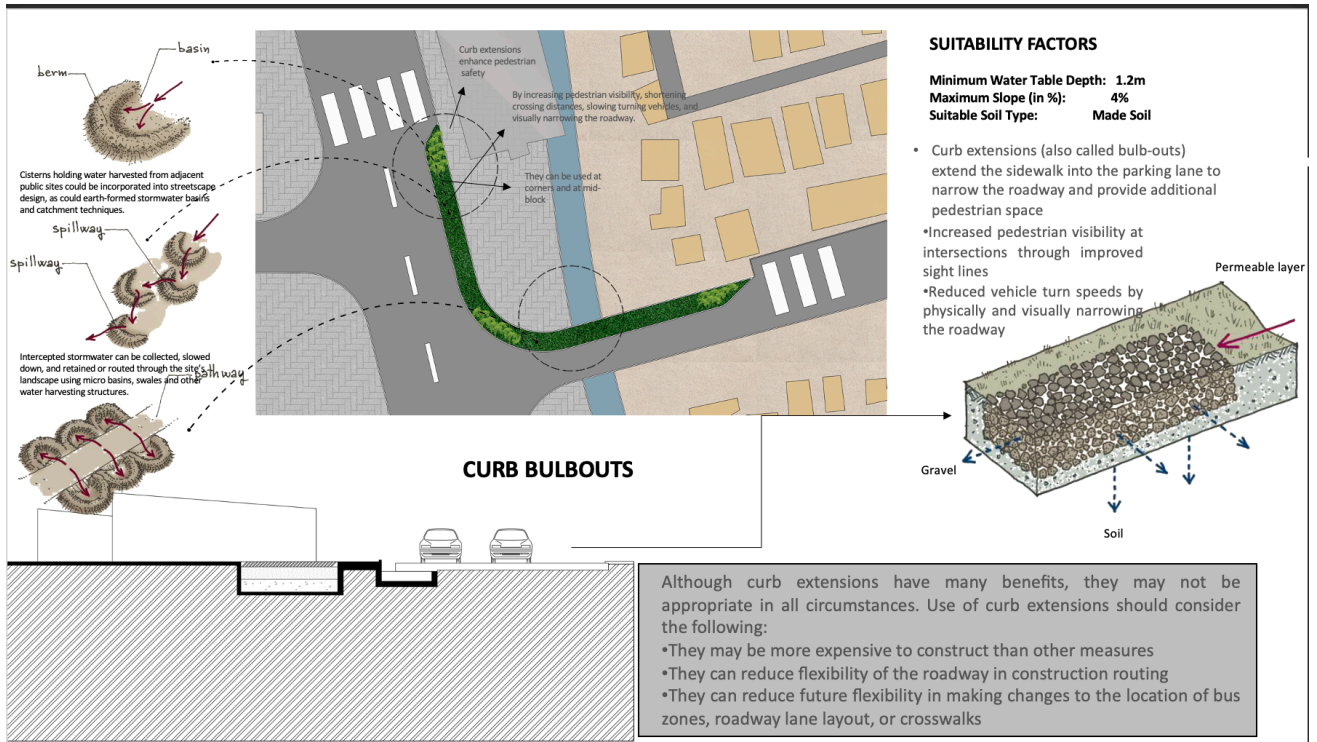


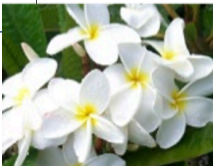
Fig 5.17 Curb Bulbouts

ANALYSIS

Locations	Limitations	Depending factors
1. On medians <2m and >2m	Water table depth: 0.6m Max. slope : 4% Soil type : Engineered	Low maintenance and medium cost related to drainage area.
2. On streets >5.5m and adjacent Street 5m+ road width	Water table depth: 0.6m Max. slope : 4% Soil type : Engineered	Low maintenance and medium cost related to drainage area.
3. On pedestrian >3.5m, 2.5m-3.5m and adjacent Street 5m+ road width	Water table depth: 1.2m Max. slope : 15% Soil type : Engineered	Medium maintenance and medium cost related to drainage area.
4. On medians >2m and pedestrian >3.5m	Water table depth: 1.2m Max. slope : 15% Soil type : Engineered	High maintenance and medium cost related to drainage area.
5. On streets >5.5m and adjacent streets 5m+ road width	Water table depth: 1.2m Max. slope : 4% Soil type : Engineered	Medium maintenance and medium cost related to drainage area.

Tab 5.1 Analysis

NAME	HEIGHT	SPREAD	COLOUR
1. Tulip Tree <i>Liriodendron tulipifera</i>	165 ft	40-50 feet.	Orange, Yellow
2. Nutmeg Tree <i>Myristica fragrans</i>	66 ft	30 feet	The flowers, borne in umbel-like cymes, are creamy yellow and fragrant.
3. Champa White <i>Plumeria obtuse</i>	5-25 ft	39 feet	White
4. Magnolia Tree <i>M. Macrophylla</i>	30 to 40 ft	50 feet	Fragrant White Blossoms
5. Prickly Paperbark Tree <i>Melaleuca Styphelioides</i>	32 ft	26 feet	White Blossoms

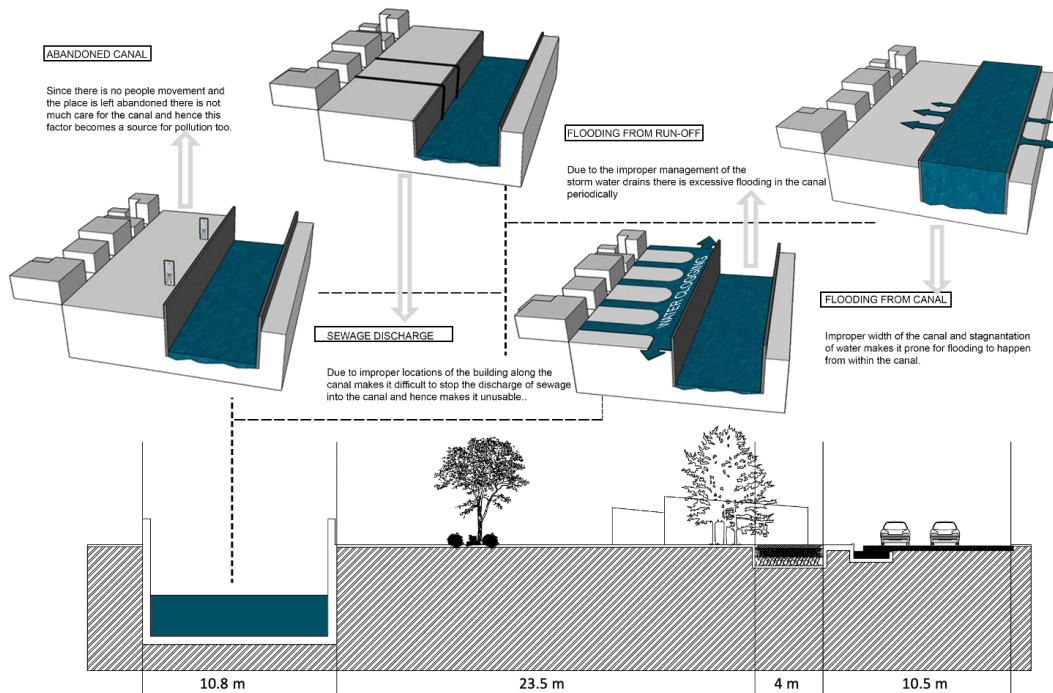



Tab 5.2.1 Flowers and Shrubs

NAME	HEIGHT	SPREAD	COLOUR
1. Rose periwinkle <i>Catharanthus roseus</i>	39 in	25 in	Periwinkle is a <u>color</u> in the blue and violet family.
2. Indian abutilon <i>Abutilon indicum</i>	4-6 ft	3-4 ft.	Bright yellow-orange blooms
3. Nerium <i>Nerium oleander</i>	15 ft.	10ft.	Pink is the most common <u>color</u> .
4. Shell ginger <i>Alpinia zerumbet</i>	6 ft	-	White and Pink.
5. Golden Dewdrop <i>Duranta erecta</i>	2 m.	1.3 cm	Shades of Blue and Purple.
6. Bougainvillea <i>Bougainvillea glabra</i>	20 feet	13-26 ft	Bougainvillea comes in a variety of <u>colors</u> – pink, purple, orange, yellow and white with magenta being the most common <u>color</u> .
			 

Tab 5.2.2 Flowers and Shrubs

PRESENT CANAL CONDITIONS



Issues:
Due to the improper management issues with the Canal, it faces a lot of problems that deteriorates the canal from its purpose of creating a vibrant space in the city. There are a lot of issues to be addressed like the informal settlements, flooding, sewage discharge, few storm water outlets, Flooding from the canal everything causes the canal to loose its charm. This canal has a huge potential to bring back the cities ecosystem.

Fig 5.18 Present Canal Conditions

Canal Bank Correction

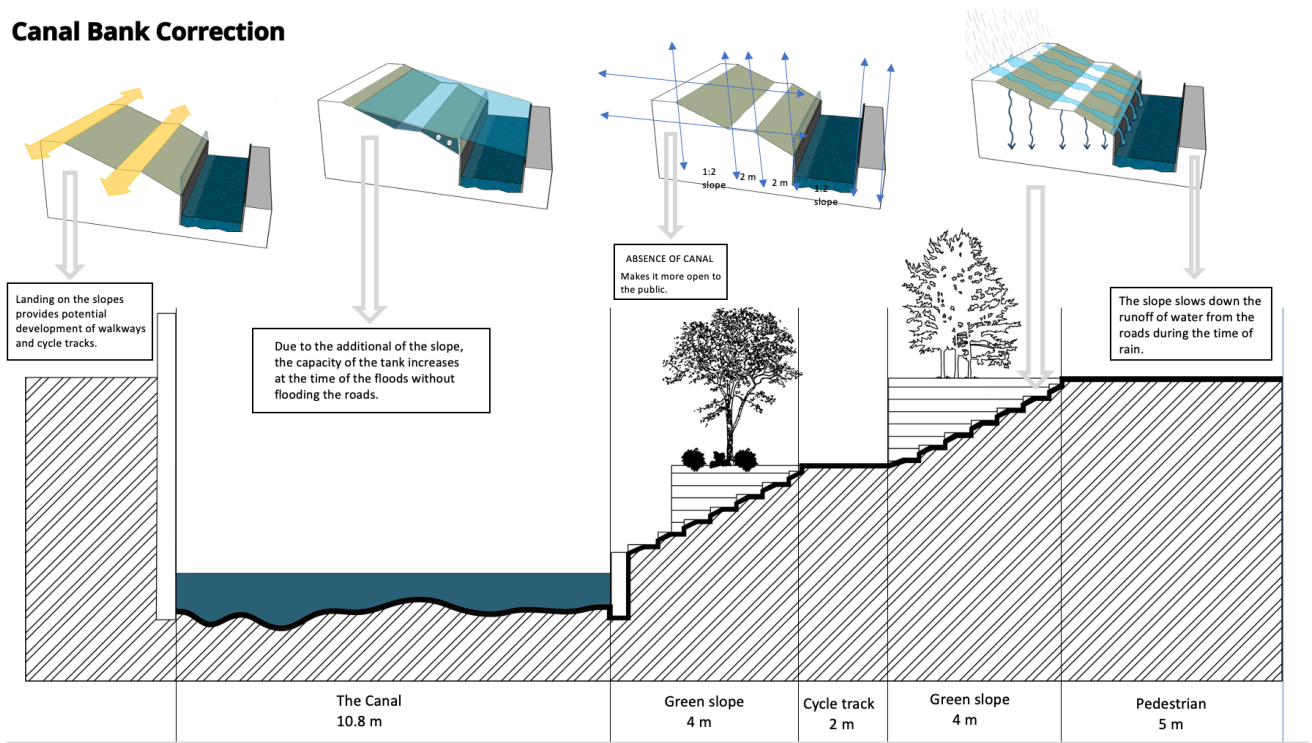


Fig 5.19 Canal Bank Correction

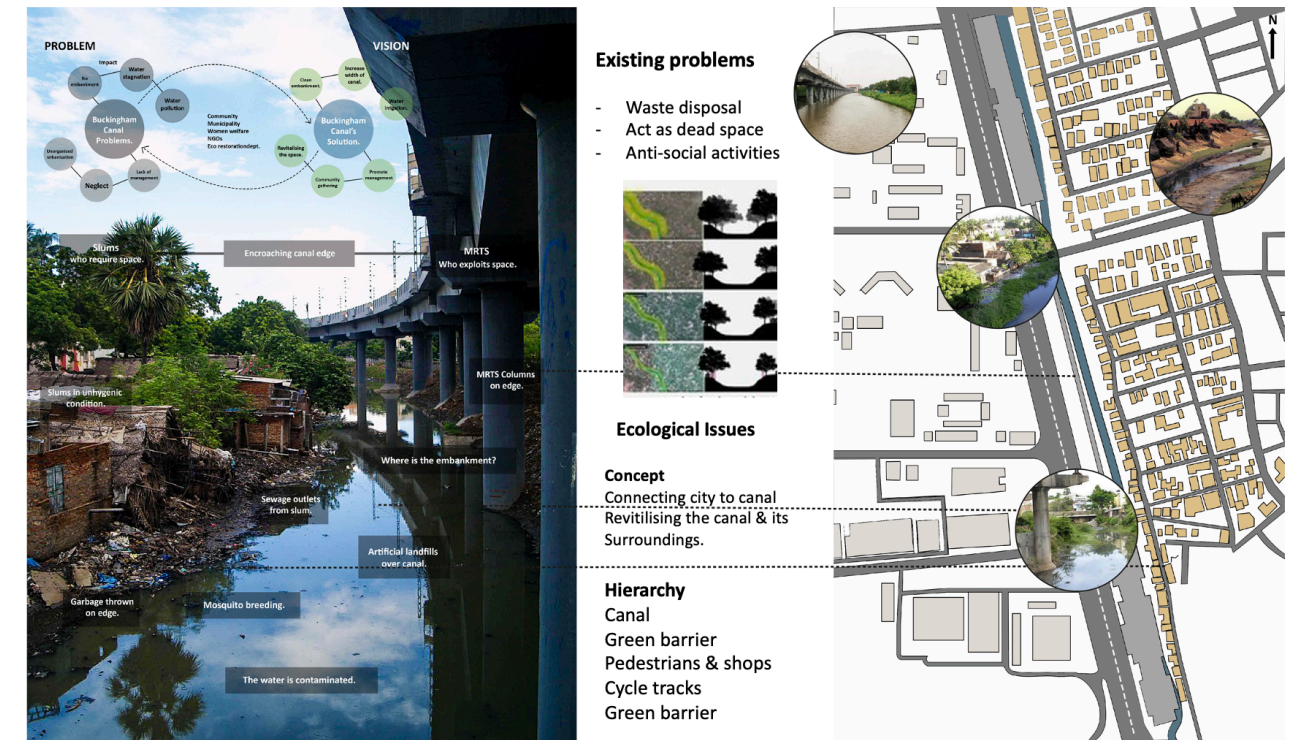


Fig 5.20 Present Existing Problems and Solutions

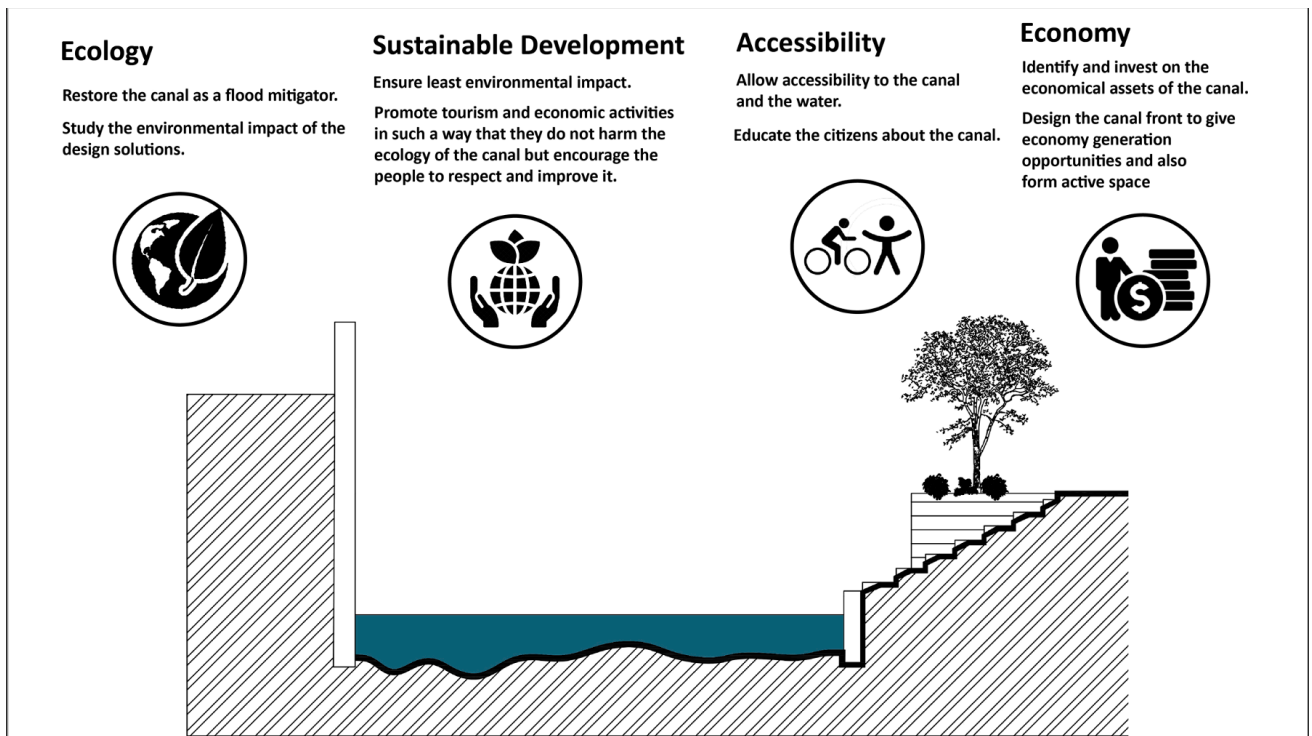


Fig 5.21 Possible developments

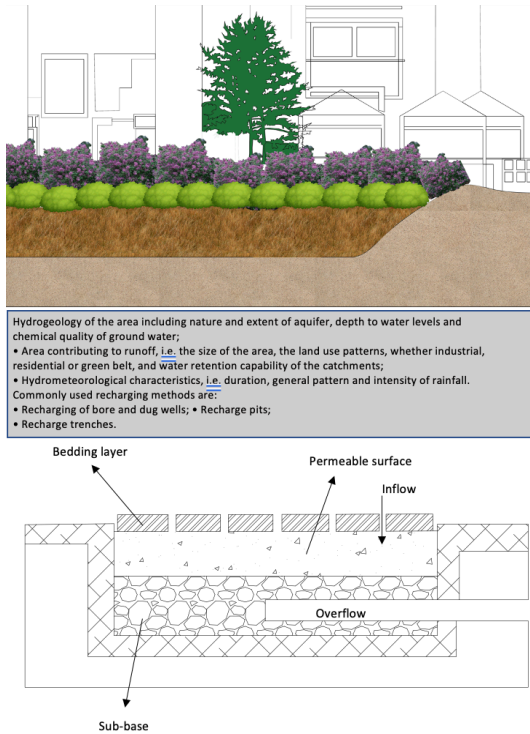


Fig 5.22 Sectional view .

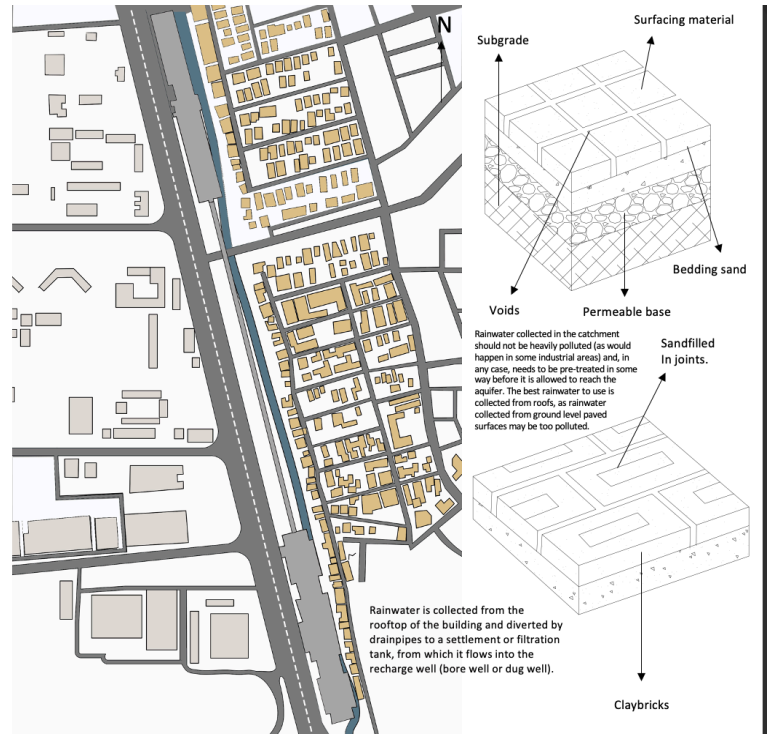


Fig 5.23 Pavers sections

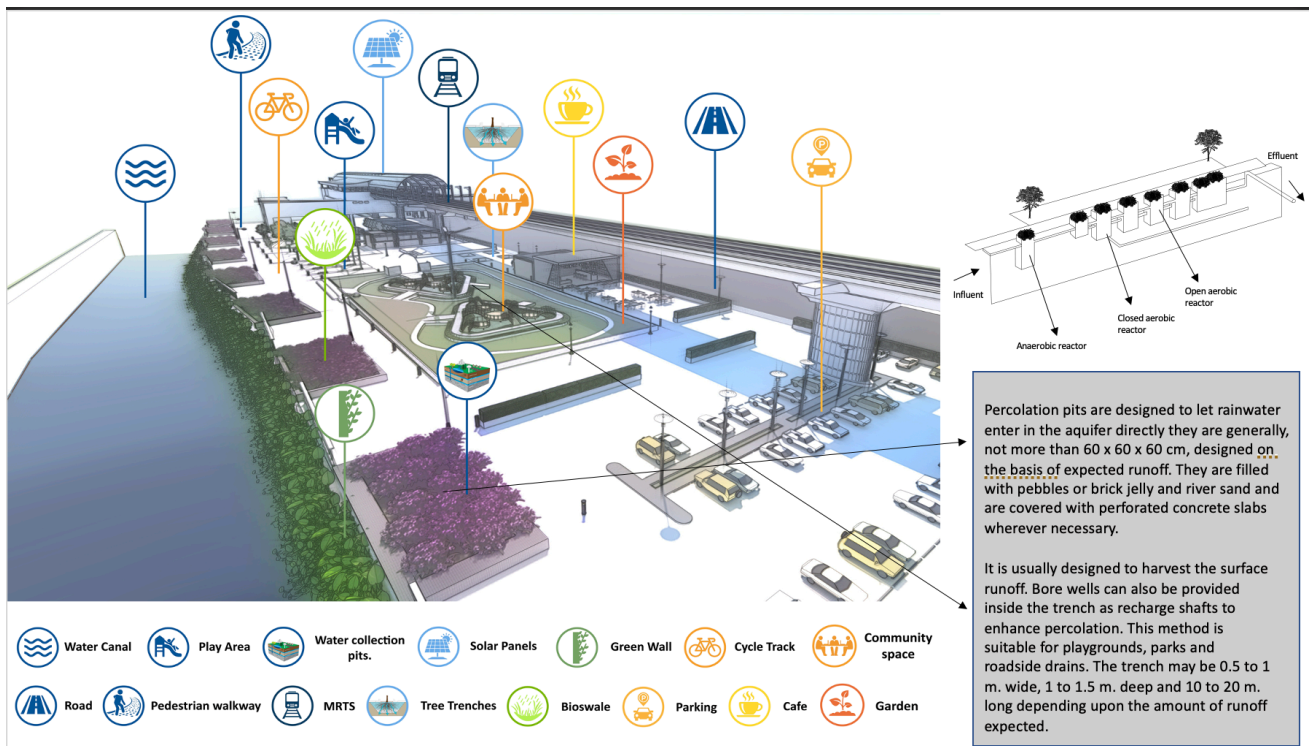


Fig 5.24 Recreated area mapping

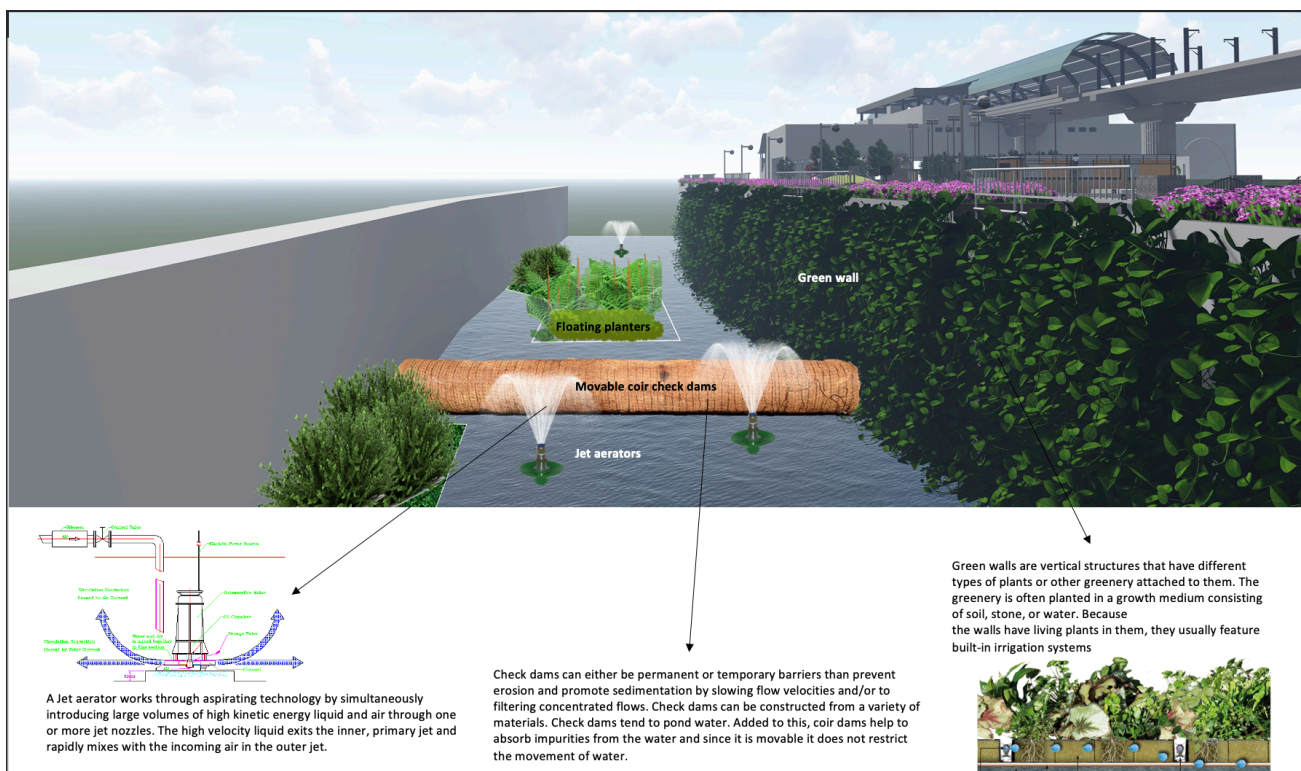


Fig 5.25 Canal Restoration Proposal



Fig 5.26 Market place view



Fig 5.27 Recreational Space view



Fig 5.28 Resilient feature of Canal view

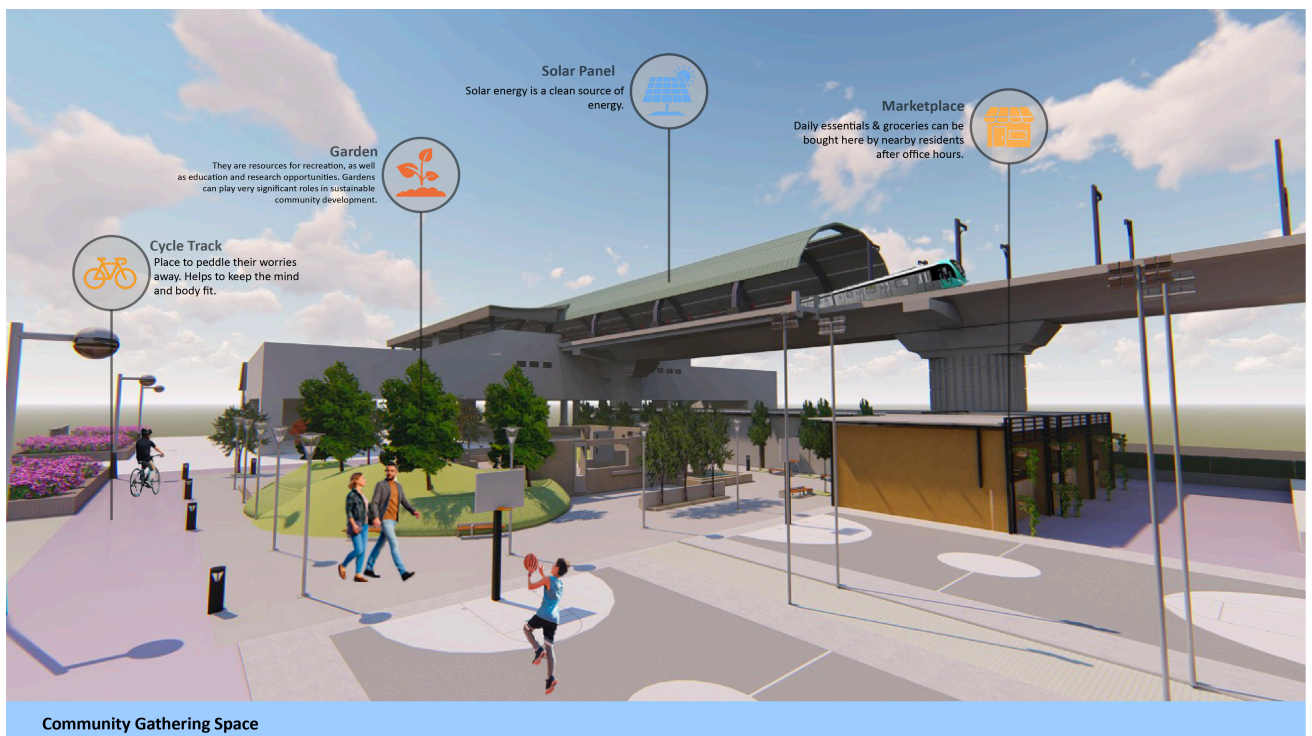


Fig 5.29 Community Gathering Space View



Fig 5.30 Cycle Track View

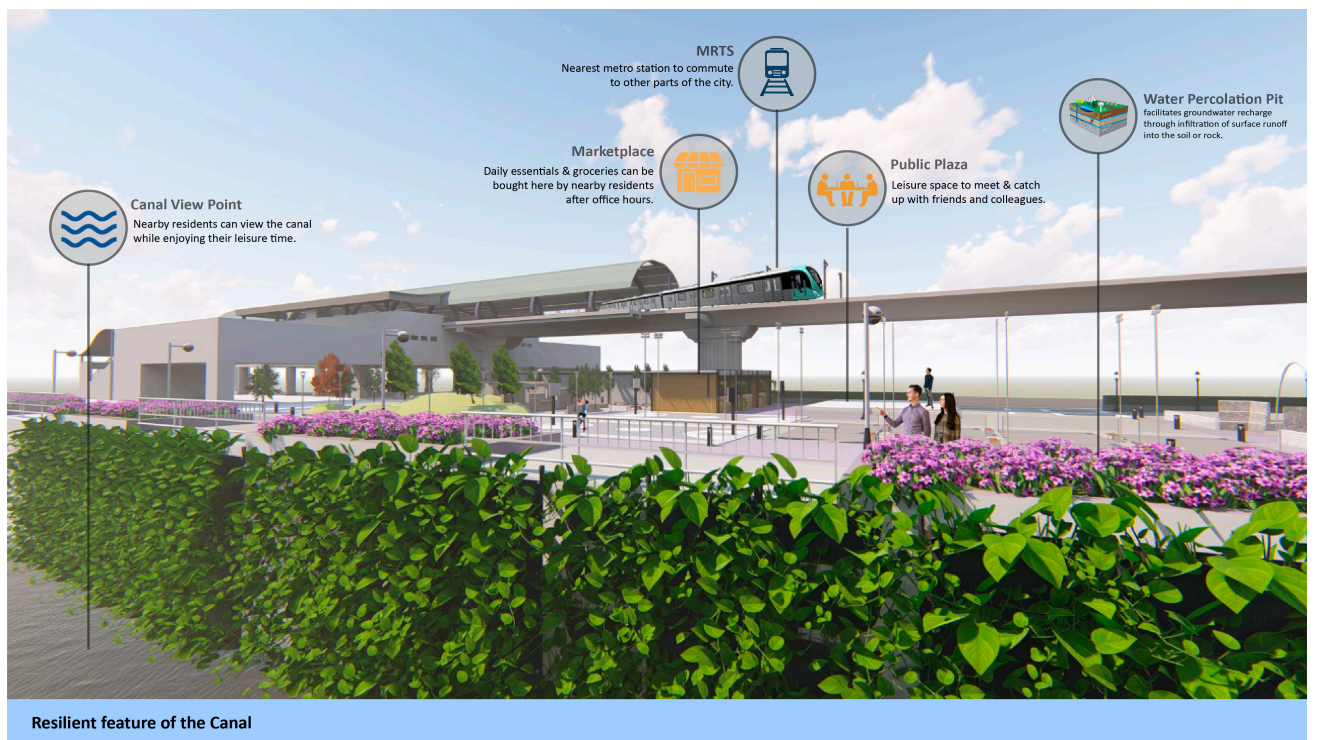


Fig 5.31 Resilient Feature Canal view

REFERENCES

Regional Study, Adyar River Revitalization, 2007 <http://cgwb.gov.in/watershed/about-ws.html>
<http://slusi.dacnet.nic.in/watershedatlas/indexnew.html>

http://www.twadboard.gov.in/twad/watertesting_charges.aspx

Source: <http://chennaicorporation.gov.in/>

Regional Study, Adyar River Revitalization, 2007

<http://riverfrontrevitalization.com/https://www.downtoearth.org.in/news/climate-change/rewind-2018-how-much-india-changed-with-climatechange-62609>

<https://www.indiaspend.com/sanitation-does-not-end-with-flushing-a-toilet-a-tamil-nadu-town-shows-how-to-complete->

CMDA Website

[**https://www.researchgate.net/publication/283579736 Rapid Assessment and SWOT Analysis of Non-technical Aspects of Natural Wastewater Treatment Systems/figures?lo=1**](https://www.researchgate.net/publication/283579736)

<https://www.sciencedirect.com/journal/journal-of-hydro-environment-research>

<http://www.springer.com/series/5637> The 4th International Conference on Water Resource and Environment (WRE 2018)
IOP Conf. Series: Earth and Environmental Science 191 (2018) 012099, IOP Publishing doi:10.1088/1755-1315/191/1/012099

<http://www.cmdachennai.gov.in/>

riverlifepgh.org/resources

<http://www.iaeme.com/IJCIET/index.asp>

<https://www.urbangreenbluegrids.com/measures/bioswales/>