Sponsored Thesis Project Competition on

"RE-IMAGINING URBAN RIVERS"

Season- 2

Project Title : Blue-Green Infrastructure Planning for a Sustainable Development - Tirunelveli

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Abstract

The Blue-Green infrastructure concept alludes to urban planning in which water bodies and land are intertwined and flourish together, resulting in environmental, economic and social advantages. Though we are relatively familiar with the terms and approaches of nature based solutions, they are frequently assessed in terms of a particular objective, either green infrastructure or water sensitive planning. We need to understand that these environment are dependent on each other and flourish together. Hence, integrated system of both blue and green spaces are needed for the world.

The Gap between Blue and green infrastructure has been studied and importance of multi-scale solutions in the network has been understood, with the help of literature study and case studies of various cities in national and international context.

The study ultimately tries to deal with some of the most common issues and problems associated with the urban rivers and water bodies of the Indian cities. It addresses issues and topics like water pollution, flood risks, water availability, urban biodiversity degradation, negligence of importance of water bodies, lack of citizen engagement with urban rivers, flood plain encroachments, etc. With the help of Reconnaissance survey, the whole water network was analysed to improvise the infrastructures and; with water demand projection and SCS-CN method, runoff was calculated to increase the water availability. Interventions to enhance the Eco sensitive regions eliminating pollution and threats around the rivers/water bodies are recommended. The method of combining both green infrastructure and water sensitive approaches for better planning aspects can be understood with this study.

Keywords: Blue-Green infrastructure, Green infrastructure, Water sensitive planning, conservation, water bodies.

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1 Introduction

Following the pandemic, there is widespread recognition of the need for long-term rehabilitation of urban areas, which are particularly vulnerable to climate change, human comfort, and environmental issues. In many Indian cities, rapid urbanisation has resulted in the loss of green and blue components. Tirunelveli, a city in Tamilnadu State, has likewise suffered environmental losses, making long-term development nearly difficult. Climate-proofing the promoting resilient urban development are top priorities.

Existing urban infrastructure will need to be upgraded and made more resilient for climate change adaptation as well as for future shocks and disasters. To address these difficulties, more attention must be paid to the potential role of blue (rivers, lakes, canals, floodplains, wetlands, and water utilities) and green (trees, parks, gardens, hedgerows, fields, and woodlands) environments; this integrated system is known as "Blue-Green Infrastructure".

Though we are relatively familiar with these terms, the solutions are frequently assessed in terms of a particular objective, either green infrastructure or water sensitive planning. We need to understand that these environment are dependent on each other and flourish together. Hence, integrated system of both blue and green spaces are needed for the world.

The Blue-Green infrastructure concept alludes to urban planning in which water bodies and land are intertwined and flourish together, resulting in environmental, economic and social advantages.

1.1 Context of the Study area

The Study area is located in the Tirunelveli district of Tamilnadu State. The site area is around 29.18 Sq.km with 11% of the site covered with water bodies. The key element in the study is the Thamirabarani River which is the only existing perennial river of Tamilnadu now. It stretches for 4.66 km and runs through the city. The river originates in Western Ghats and runs through two districts of Tirunelveli and Tuticorin. The location of the study area is given in the map below:

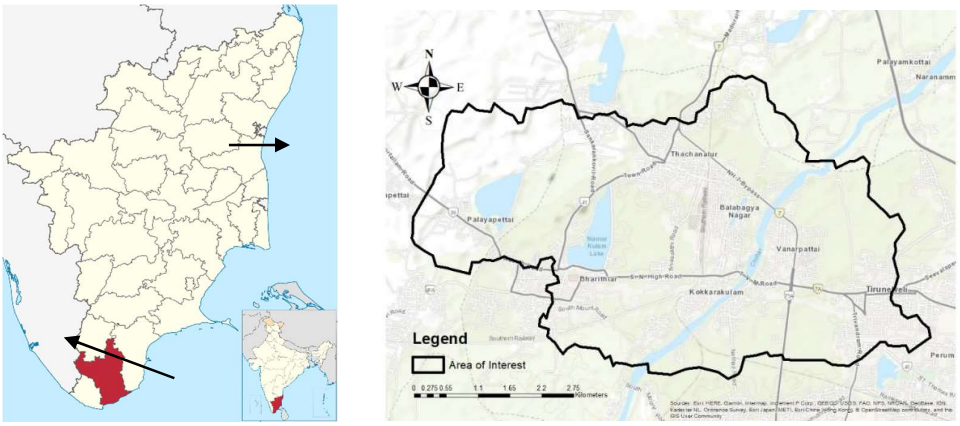


Figure 1: Study area and its location
Source: Author

1.2 Justification of the study

Over the decades, the amount of blue and green spaces in the city is reducing drastically. The water bodies which holds the sustenance of the human settlement is losing its significance gradually. With all the anthropogenic activities, the pollution in the water bodies is a matter of concern. With an integrated network of blue-green spaces which would hold the connection with society, will revive the environment and protect/enhance the functionality of overall urban areas eliminating all the following environmental challenges prevalent in the city.

- The dumping of wastewater, paper mill and industrial effluents, and other pollutants into the river is a matter of concern.
- Illegal bank encroachment is also a rising problem.
- Many enterprises have sprung up along the river's banks in and around.
- Unattended and polluted natural tank-pits.
- Dumping of garbage, plastics and sewer into the water bodies and polluting it to the extent of destroying the biodiversity.
- Urban heat island effect and Ecological consequences due to rapid urbanisation and lack of green policies for regulations.

2 Defining the Study

2.1 Aim and Objectives of the study

The Aim of the study is to contribute & protect hydrologic and ecological values of Tirunelveli city, through resilient blue-green infrastructure networks, built in Multi-scales.

The following objectives are looked into and proposed to enable a decision support for the blue-green infrastructure planning in Tirunelveli:

1. To enhance the functionality of the city with Blue and green networks.
2. To reduce the water pollution and rejuvenate the water bodies
3. To provide year-round recreation to strengthen the connections between society and nature as well as protect urban biodiversity
4. To future-proof and increase water availability of the city

2.2 Scope of the study

- To address the ecological significance, the role of water bodies and green spaces through BGI planning measure.
- To mitigate climate change effects through a well-connected network of Blue and green in various scales like “meso, nano, macro and micro”.
- To provide not just the river centric urban planning but also an interconnected system of all water bodies, green and urban spaces.

2.3 Limitations of the study

- Challenges that might arise in primary data collection due to dynamic nature of the ongoing Covid pandemic.
- The disadvantages that some of the data could be outdates; (Eg: Census of India, 2011)
- The study area does not have an administrative boundary but is based on sub-catchments, even though it is bounded with the district.

3 Literature study

3.1 Blue-Green Infrastructure

The Blue-Green Infrastructure Planning is a strategic planning approach that aims to develop networks of green and blue spaces in urban areas, designed and managed to deliver a wide range of ecosystem services and other benefits of environmental, economic and social aspects. (E2Designlab, 2017)

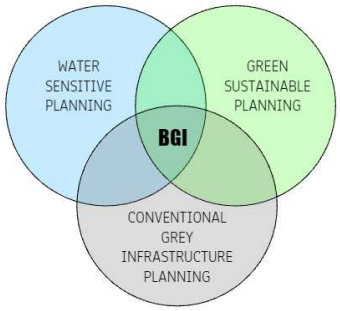


Figure 2: Concept of BGI

Source: Author

3.2 Addressing the Blue-Green Gap

Figure 3: Blue-Green Infrastructure Planning and gap between green and blue strategy

Source: (E2Designlab, 2017)

There is often a defined awareness of both the potential and limitations impacting the implementation of green-blue infrastructure at a municipal level, either formally through documented initiatives or indirectly through officer expertise and ongoing support. Nevertheless, the solutions are frequently assessed in terms of a particular objective, such as "storm water management, water security, flood management, tree health, recreation needs, or biodiversity." Natural systems' innate multi-functionality necessitates an equally integrative method for identifying, prioritizing, and implementing programs that would result in eco - friendly alternatives, better prosperous settlements (E2Designlab, 2017).

The goal of BGI is to look for complementary possibilities of coordinated greening and water management results, eliminating the gap between them, as well as to provide a structure for coordination among various stakeholders (E2Designlab, 2017).

3.3 Importance of scale in Blue-Green Thinking

The Effective BGI planning necessitates the unification of several planning and operational scales. As a result, BGI planning will most probably apply for an entire city or watershed, but it will have to take into account prospective initiatives throughout all sizes, along with their long term effect (E2Designlab, 2017).

Figure 4: Importance of scale in BGI
Source: (E2Designlab, 2017)

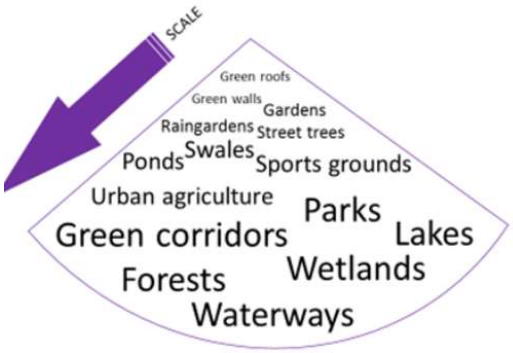


Figure 5: Scale of interventions in BGI
Source: (E2Designlab, 2017)

3.4 Core Principles of BGI

3.4.1 Integration IN Multi-scales

The goal of BGI planning is to integrate and coordinate urban Blue and green areas with several other amenities like transportation and services. BGI may be structured from a building aspect towards a more locally integrated approach due to its versatility and ingenuity in multiple scales ranging from meso, through nano, micro and macro-scales perspectives (Climate-KIC, 2019).

3.4.2 Connectivity

The connectivity planning entails establishing and recovering links to enhance and safeguard operations, functions, and advantages that isolated green spaces cannot deliver on their own (Dalal-Clayton & Sadler, 2005).

3.4.3 Multi-Functionality

BGI planning strives to bring together many activities in order to improve the potential of urban green space to offer numerous advantages – generating efficiencies with minimizing disputes and barter (Climate-KIC, 2019).

3.4.4 Social Connectivity

The goal of BGI planning is to create procedures that are participatory and socially inclusive. That implies that planning procedures are accessible to everyone and take into account the information and requirements of a variety of stakeholders (Climate-KIC, 2019).

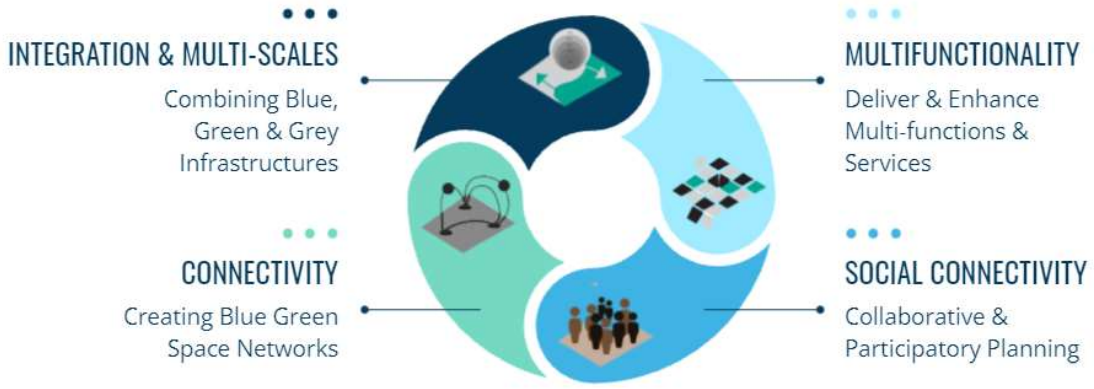


Figure 6: Core principles of BGI
Source: Author

3.5 Inclusive list of Blue-Green Components

Through urban woods to green roofs, urban green and blue areas are very diverse. A few of these places are already taken into account in structure, while others "especially private green spaces like gardens, as well as urban farmlands", have gotten insufficient emphasis in study and application. Their significance to UGI systems is frequently underappreciated.

To fill this information vacuum, a paradigm of Blue-green spaces was created, consisting of 58 components organized into seven groupings and linked to empirical evidence on the ecological services they provide.

If all of these elements may be taken into account when developing the interventions, urban "blue-green infrastructure" is far more than a phrase of traditional landscape features. It is feasible to establish one of these spaces as a part of the city's BGI System using the concepts of "connectivity and multi-functionality", and where it is essential whether to upgrade the effectiveness of existing pieces into new ones to boost connection (Dreiseitl, 2016).

Figure 7: Elements of green and blue in paradigm
Source: Author

3.6 Ecosystem services and Benefits

When the elements mentioned above are incorporated to form a BGI connected network by the four principles derived, it is feasible to form an effective Multi-scale BGI system in the urban environment, as well as provide various ecosystem services natural for the settlement's development (NMCG & SPA, 2021).

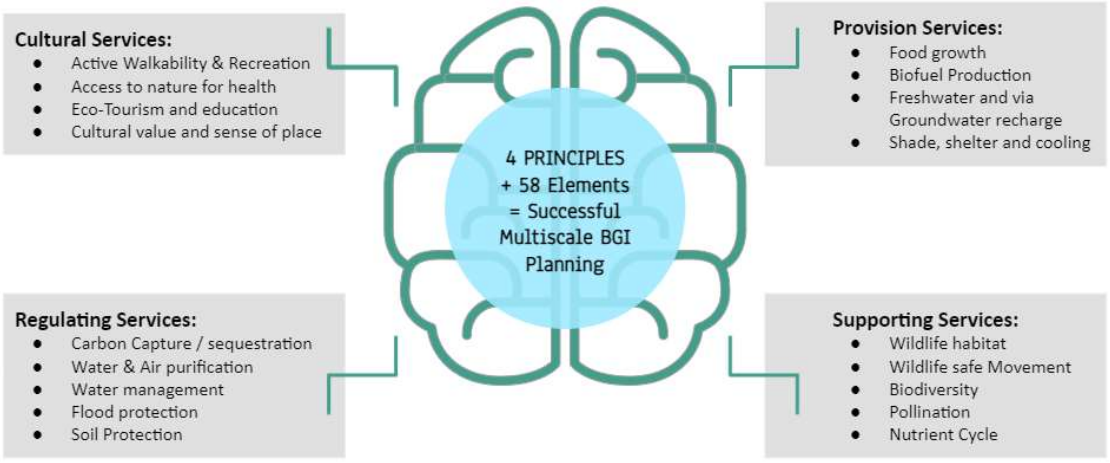


Figure 8: Ecosystem services and its classification
Source: Author

3.7 Potential Interventions

3.7.1 Connected Blue-Green Corridors

In urban contexts, waterways and green corridors provide essential continuous linkages that can integrate ecological and recreational routes. Green corridors are often linked with river corridors as well as the accompanying "flood-prone terrain", and they're often formed as a result of historical paths and other clearance routes (E2Designlab, 2017).

Table 1: Possible initiatives for Walkable BG corridors

Source: (E2Designlab, 2017)

Possible Interventions	**Objectives**	**How to Boost the incentives**
Vegetative Wetlands	Ecological Preservation	- Using indigenous species, -To delay and control streams, use ground coverings. -Link storm water pipes to waterways to encourage penetration and low subsurface flows. - Water ecosystems benefit from plants that improve riverbank's stability, offer shelter, and supply organic detritus. Biodiversity is provided by a contiguous corridor with a diverse construction.
Green Spaces in Floodplains	Leisure Spaces & Biodiversity Urban amenity, Social connections, Usable spaces and Tourism	- Provision of multiple recreational activities which are relevant for the waterway use and adjacent land uses (e.g. cycle and pedestrian pathways, sporting fields) - Work in tandem with the urban design approach to produce well-designed public areas that are both sheltered and secure.
"Floodplain wetlands"	Flood management Bio diversity	--Spaces around wetlands are utilized to hold floodwaters in the case of a deluge. - Water quality can be improved by constructing local "storm water treatment wetlands." - "Natural floodplain wetlands" can be improved to offer living environment and increase ecological biota as well used for retention purposes.

3.7.2 Residential Streets

Residential streets include vegetation and landscaping that provide vital nesting sites birds as well as cover and amenity for people. Walkability and leisure spaces are also encouraged by providing sheltered avenues which connect urban transport centres, playgrounds, and essential institutions. Streets also contribute significantly to storm water runoff and pollutants. It can offer natural purification for surface runoff and encourage plants vitality via passive irrigation by integrating greenery and soils throughout the roadways (E2Designlab, 2017).

Table 2: Possible Initiatives for Local Streets

Source: (E2Designlab, 2017)

Possible Interventions	Objectives	How to Boost the incentives
Streetscape bio retention / water sensitive urban design	Functional places, Urban amenity, Community connections	-To guarantee evidence based runoff management, size and place water sensitive urban design guidelines in roads. -Allow for more verge width to integrate bio retention with routes. -Place "bio retention" on public places, where there is usually greater room. -Establish a vegetation model in conjunction with homeowners when upgrading existing roadways. - Allow water to settle for a short time.
Passively watered street trees	Leisure and Biodiversity preservation, mitigation of urban heat	- Native species will improve the ecosystem of the area. -Plants that produce fruit can be used as a local produce supply. - Trees should be planted in an uninterrupted sequence along major sidewalks to transportation, playgrounds, rivers, and amenities to provide shade. -To reduce surface rise and root incursion, use passive watering. -To extend "soil pits beneath parking and road areas, use structural soil or soil cells (increasing soil volume)".

		-Passive drainage encourages bigger cover canopies and reduces the temperature of the environment through evaporation.

3.7.3 Parks and Playgrounds

Parks are essential for urban ecology and biodiversity because they provide relief, quiet, leisure and green space. As a result, they are quite valuable when they are verdant, lush, and shaded. Rainwater collection may directly facilitate natural fields while also benefiting the ecosystem. "Constructed wetlands and bio retention systems" are examples of BGI that could be implemented into landscapes to give various benefits (E2Designlab, 2017).

Table 3: Possible Initiatives for parks and playgrounds

Source: (E2Designlab, 2017)

Possible Interventions	Objectives	How to Boost the incentives
"Storm water harvesting"	Water supply substitutes	-Seek for low "storm water pipes" that will capture or redirect overland streams from nearby paved areas lots. -Surplus waters could be redirected to collection, purification, and recycling if streams or canals run through parks. -Regarding "water quality control", purify storm water in marshes or bio retention installations. -Rainwater collection methods with "wetlands and lakes" contribute to the aesthetic appeal and give possibilities for peaceful leisure. -The use of "wicking beds for passive watering of grass kick and throw zones" can save money. -Where area is small, subsurface storage is an option.
"Wetlands / Bio retention or swales for storm water treatment"	Operational spaces and Inundation strategy	-Cultivate a range of natural plants that are adapted to different water depths. -Provide pedestrian overpasses and observation decks to weave into the parks.

		-Street art, literature, natural play, and informative signs should all be included.

3.8 Guidelines

3.8.1 RCUP– Guidelines By MoHUA

The "River Centric Urban Planning by MoHUA gudielines" suggests three strategies for the sustainable development.

Strategy 1: "River Ecology Conservation Plan"

The measures to reduce the water contaminants naturally with the list of native species which eliminates the contaminants needs to be taken. The aquifer recharge can be provided with bio-retention tanks and ponds. Preservation of natural environment needs to be the first priority. Natural wetlands and unique assemblages of plant and animals are used to conserve natural regions. Farming and related activities are encouraged. High level of entertainment spaces can be promoted to strengthen the society's bond with the nature (MoHUA, 2021)

Strategy 2: "Integrated Development scenario"

The key attributes of "eco-based solutions" such as CSO controls, GW recharge, and conservation. Allocation of the interventions needs to be done only after proper feasibility and demand analysis study. The potential to change the land use in order to enhance the ecosystem quality can be promoted. Financial feasibility needs to be taken into consideration with "integrated tourism spots with high recreational activities in it" (MoHUA, 2021)

Strategy 3: "Post Channelization development scenario"

Decrease in the rate of storm water released at its apex. Hydrostatic rules are in place to protect local drains from backing up and damaging the area. Spiritual and other water-based pursuits are assigned in a small proportion of cases. (MoHUA, 2021)

3.8.2 Urban Wetland Management - Guidelines by NMCG & SPA

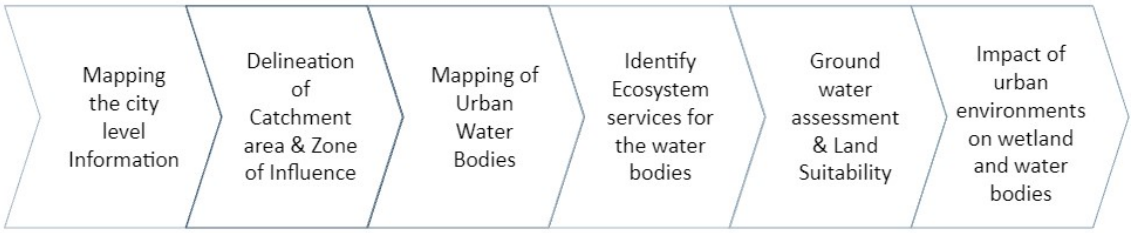


Figure 9: Steps to manage Water bodies

Source: Author

The "National Mission of Clean Ganga" and SPA Delhi provides toolkit for the management of water bodies and wetlands with 6 steps as given in the above figure.

Step 1: "Mapping of City level information"

Where all the geographical boundaries and data sources such as (the existing infrastructure, the blue and green resources, the geographical studies such as precipitation, erosion, water levels, and drainage system etc) that we collect in the next stage of framework are mapped out in this step (NMCG & SPA, 2021). The data are to be arranged as per the layers given in the figure **10**

Step 2: "Delineating the watersheds"

Where the water bodies are delineated from basin, then sub-basins and then the admin boundary has to be overlapped on the basin and one water catchment area is prioritised finally as the study area (NMCG & SPA, 2021). Refer figure 10

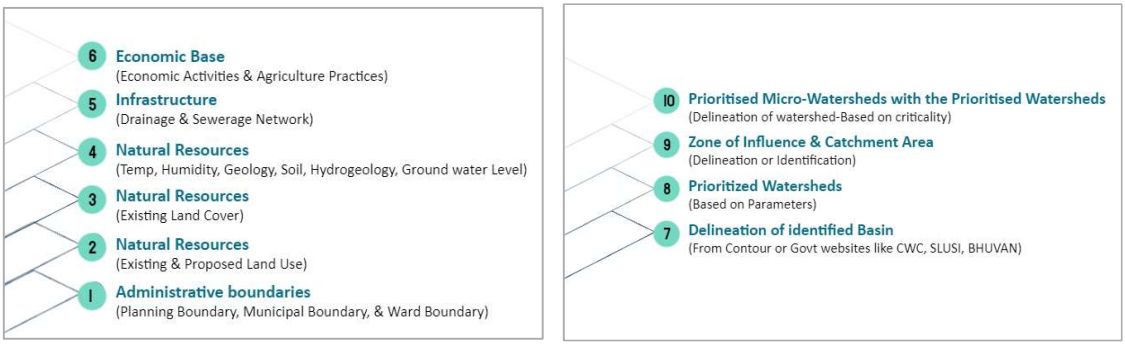


Figure 10: Step 1 (left side) and Step 2 (Right side) of Managing water bodies
Source: Author

Step 3: "Mapping the exisiting Urban waterbodies"

With the sub-basin being derived, the water bodies in the region are further analysed and prioritised as micro watershed, classification of all waterbodies needs to be done as per atlas and the list of waterbodies to be made which are considered in the study (NMCG & SPA, 2021). Refer figure 11

Step 4: "Exploring and evaluation of ecosystem services"

With the list of waterbodies, the ecosystem services provided by them needs to be ranked as per the rating system prescribed. The common ecosystem services are classified as 4 types with "Provisional, Cultural, Regulating and Supporting services" (NMCG & SPA, 2021). Refer Figure 11

Figure 11: Step3 (left side) and Step 4 (Right side) of Managing water bodies

Source: Author

Step 5: "Assessment of Groundwater level"

The whole study area has to be studied for underground water study along with their drainage intensity runoff and then the land cover has to be overlapped on the study to see its potentiality (NMCG & SPA, 2021). Refer figure 12

Step 6: "The impact of urban development"

With the assessment being done, the extent of impact of urban developments of the water bdoies has to be studies to see potentials and threats in the planned infrstructures. The measure to protect or enhance the blue and green spaces needs to be taken (NMCG & SPA, 2021). Refer figure: 12

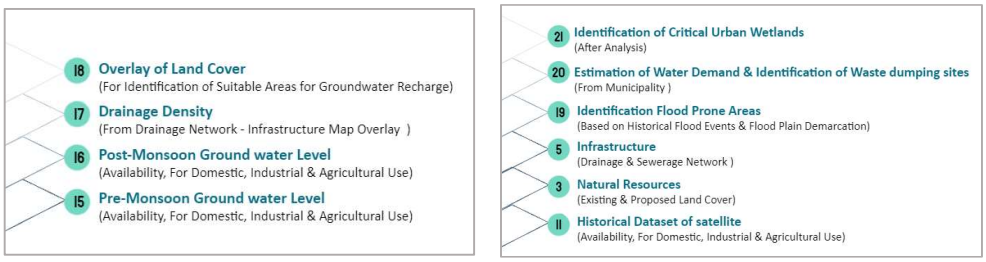


Figure 12: Step 5 (left side) and Step 6 (Right side) of Managing water bodies

Source: Author

3.9 Policies

Figure 13: Policies applicable for water bodies and rivers

Source: Author

The above mentioned policies in the picture were studied and their application with the context of the study has been noted. The river Conservation act of 1884 takes about the preservation of

wetlands and Eco sensitive areas around the river and the importance of role of native species in the ecosystem. National Water policy and TNPCB orders has overlay with the pollution control levels and others related with the river and water bodies.

3.10 Summary of Literature Study:

Table 4: Summary of Literature study and Takeaways

Source: Author

3.11	Literature Study	Takeaways
i)	Concept of Blue-Green Infrastructure	To comprehend what blue spaces and green spaces are, and how they constitute a network in urban areas that is intended and managed to provide a wide range of environmental, economic, and social advantages.
ii)	Understanding Blue-Green Gap	To recognise that the urban ecological problem stems from the defined objectives that separate blue from green, emphasizing the necessity for an integrated Blue-Green network.
iii)	Importance of scale in BGI	To realise that efficient BGI planning necessitates the unification of components at various scales in order to maintain their long-term effect.
iv)	Core Principles of BGI	To develop a greater understanding of how multiple concepts interact in an overall blue-green system and to arrive at four core principles for the endeavour.
v)	Ecosystem Services and Benefits	To comprehend all of the cultural, provisional, regulating, and supporting services that nature-based solutions provide over traditional infrastructure.
vi)	Urban Wetland Management Guidelines and other Policies	To gain a better understanding of the various approaches and degrees of conservation of wetlands and water bodies, as well as guidelines and regulations for their management and preservation.

4 Case Studies in successful BGI implementation

4.1 Case study 1: Singapore "Ang-Mo-Kio Park"

Figure 14: Map showing Ang Mo Kio Park

Source: Mapnik

Location: Situated in Singapore, "Ang Mo and Bishan Neighbourhoods", near the "Kallang River"

Brief: Conversion of a constructed canal into a bio-engineered channel, benefiting ecology and community

Background: Bishan-Ang Mo Kio Park is a major recreational park in Singapore that connects the 1970s-built neighbourhoods of Bishan and Ang Mo Kio (BAMK) . For flood prevention in the early 1980s, "a concrete canal" was created that cuts through the park. The canal gathered rainwater from nearby communities and channelled it into the "Kallang River basin", which is at present, the part of Singapore's water recycling network (Dreiseitl, 2016).

Figure 15: Map Showing Park and the river

Source: (Dreiseitl, 2016)

"The canal was in a desperate need for repair while the recreational area was not at its best, so when the Bisahn was selected as one of the prototype initiatives in the city's "National ABC

water Program -1 in 2006", they saw the potential to rejuvenate the two elements and make it available for the better future. The "Public Utility Board (PUB)", which oversees city's Singapore's drinking water Situations, came to a conclusion that the recreational area along with the constructed canal should be a prototype initiative which preserved the conventional canal's capabilities while also improving quality and reducing rainwater flow through the idea of enhacing the green spaces (Dreiseitl, 2016).

Key Drivers / Issues: The need to rejuvenate the canal and under-utilised large recreational area

Objective: To create a natural based solution to rejuvenate the environment and also to redesign it for the future extreme shocks and calamities, allowing people to connect with the nature.

Figure 16: Bio-engineered river
source: (Dreiseitl, 2016)

Implementation of the project: There was also a potential to connect water management functions with local entertainment. PUB collaborated with the [Parks Board of Singapore], and the finances of both agencies were combined. The "award-winning] design" that resulted eliminated the concrete canal and reused the aggregate debris in various landscaping elements. The environment was created to resemble a tiny, flowing creek that enables biological cleaning of storm water by bio retention and purification in place of the channel. In seasons of heavy downpours, the channel's level rises and overflows the neighbouring vegetation, illustrating BGI's capabilities to react to harsh climatic occurrences (Dreiseitl, 2016).

Figure 17: Before (left side) and after (right side) the project

Source: (Dreiseitl, 2016)

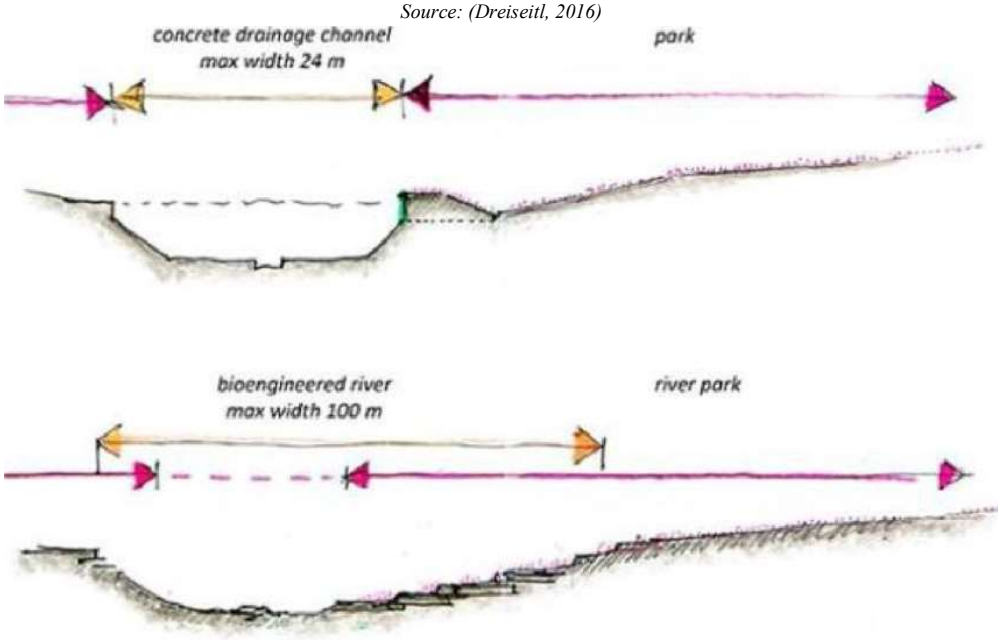


Figure 18: Section of the channel before and after the project

Source: (Dreiseitl, 2016)

Figure 19: Recreational spaces in the park along with channel

Source: (Dreiseitl, 2016)

Figure 20: Aerial View of the park

Source: (Dreiseitl, 2016)

Figure 21: People's connection with the nature

Source: (Dreiseitl, 2016)

Inference: As it exceeds the borders between the park as open public space and the semi-natural canal, the park now serves not only as a regional park for indigenous citizens, but also as a rare chance to reappraise ecology, wildlife, and freshwater in Singapore.

Table 5: Showing the inference of the case study 1

Source: Author

Motivation for BGI	Functionalities of BGI	Main Facilities	Policy Information
Adaptation to climate change	Rainwater Management (Flood Prevention, Groundwater Level, Quality improvement, etc.)	Playground, water playground	Active, Beautiful, Clean Waters (**ABC Waters**) programme
Restoration & denaturation of infrastructure	Retention System, Water Drainage,	Community space	
flood prevention, groundwater level	Open Water System, Closed Water Loop, etc.	Pet area	Partly Supported by guidelines, but it did also function as a **pilot project**
Water pollution, water recycling	Climate Change Adaptation etc.	Wetland biotope/ cleansing biotope	completely funded by the government
Recreation in dense settlements	Recreation zone	Cycle path	Public or private Stakeholders: engagement was made with various schools. (Herbert Dreiseitl)
Increasing Biodiversity	Large Open space	Sunbathing lawns	
Increasing Permeability	Urban gardening and farming	Open Cafes	

4.2 Case study 2: Gorla Magiore Waterpark, Milano

Location: Situated in Milano in the country Italy.

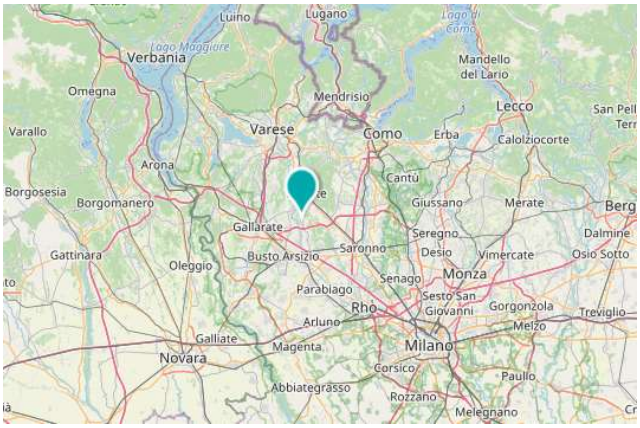


Figure 22: Location of Case study Gorla waterpark

Source: Mapnik

Brief: Nature-based solutions, such as built wetlands, could serve an important in decreasing inundating threat and controlling contaminants at the macro scale, even while benefiting ecology, desirability, and economics.

Figure 23: Picture showing Sediment tanks

Source: (Climate-KIC, 2019)

Background: The Gorla Maggiore is a town in the Milan Located in the northern part Italy with a population of around five thousand people. The BGI consists of a series of built wetlands (CW) encircled by a recreational area on the "Olona River's bank" in a region that was formerly used for "poplar" planting. (Dreiseitl, 2016)

It consists of:

a) A contaminant removal zone with a grid, a sedimentation tank, and four vertical sub-surface flow CWs;

b) A surface flow CW with multiple functions, including pollution retention, flood buffering, biodiversity preservation, and recreation; and

c) A recreational park with restored riparian trees, green open space, information panels, walking and cycling paths, and other services . The total area is 6.5 hectares. (Dreiseitl, 2016)

Figure 24: Pictures showing the sediment tank and pisary spots

Source: (Climate-KIC, 2019)

Key drivers / Issues: The need for control of contaminants in CSOs was the key driver to adapt to BGI system

Objective: Exploring the viability of using BGI to handle wastewater overflows rather than standard infrastructure, as well as examining the various advantages of BGI and its significance for water management.

Implementation: The major objective of the project was to explore the benefits of BGI instead of the conventional approach. Efficient resource utilization for the greater good of the group and ecology; Making an assertion that BGI system deliver extra services in compliance with existing water guidelines. (Dreiseitl, 2016)

This techniques and findings might provide effective strategies for using "ecosystem services" to choose the safest alternative between multi-purpose BGI and a grey alternative, and to conduct a financial analysis, and interact with participants and society. This may raise public understanding of the advantages that emerging or rejuvenated environments may offer.

Inference: For water treatment and flood mitigation, BGI (that is, "Constructed wetlands and parks") performs better than the grey infrastructure. It has equivalent expenses and delivers extra advantages ("wildlife support and recreation") that are particularly valued by surrounding communities and participants.

Table 6: Inference of case study 2

Source: Author

Motivation for BGI	Functionalities of BGI	Main Facilities	Policy Information
Flood Reduction	Pollution removal through retention/absorption	Recreational Park with riparian treen	Naturvation Programme (100 Countries- Nature based solutions) -International Project
River Pollution Reduction	Flood Risk buffer space		
Ecosystem Services	Maintenance of Biodiversity	Cycling Path	
Biodiversity increase	Sedimentation tanks (Surface & Subsurface Flow Approach) • Water collected from Combined Sewage Flow	Piscary (Fishing spot)	Funded by European commission
Carbon Sequestration			
Sustainable Urbanisation approach	Bio-Habitat Creation	Green walking street	

4.3 Case Study 3: Hanover- Kronberg, Germany

Location: Kronberg Situated in Hanover City in the country Germany.

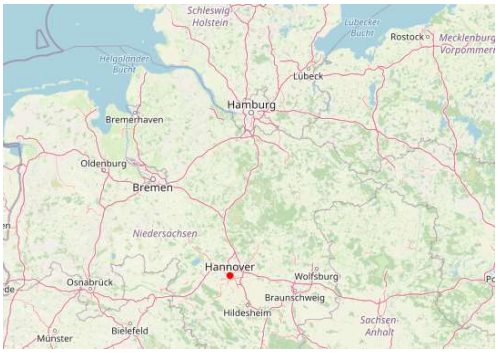


Figure 25: Picture showing location of Case study

Source: Mapnik

Brief: The Kronberg was conceived as an innovative concept that'd mix city development with "sustainable housing", through an emphasis on storm water management to maintain the aquifer's resilience.

Background: The Hannover is located on the Elbe River and has one of Europe's biggest harbour. Severe floods and accompanying consequences are rapidly threatening downtown Hamburg, which is barely 6m in altitude and is rapidly impacted by heavy downpours ("e.g. in course of Xaver storm in 2013"). Inundation is more likely because to the high building concentration and impermeable surfaces. (Dreiseitl, 2016)

Key drivers / Issues: The need to adapt to climate change and flood risks mitigation.

Objective: To limit the consequences of urbanization on the groundwater sources equilibrium and to preserve permeability and replenish the aquifer, a semi-natural runoff strategy is to be used.

Figure 26: Drainage strategy in the housing project

Source: (Dreiseitl, 2016)

Implementation: In 2009, Hanover launched the "RISA project", which requires all relevant authorities ("water, parks and urban green, traffic, and the environment") to collaborate and establish complete and integrated principles for an effective infrastructure initiative. Specific, and relatively small BGI initiatives ("e.g. Kleine Horst in Hamburg Ohlendorf") have shown to be incredibly effective, thus BGI was chosen to play a significant place in the transformation project. (Dreiseitl, 2016)

Figure 27: Semi nature drainage

Source: (Dreiseitl, 2016)

Figure 28: Green corridor and plan of the Hannover housing project

Source: (Dreiseitl, 2016)

Inference: With "every single drop matter" concept, the rainwater harvesting was given more priority, with a semi-natural runoff strategy, and emphasis on preserving the aquifer's status constant in the local area is well taught.

Table 7: Showing the inference of case study 3

Source: Author

Motivation for BGI	Functionalities of BGI	Main Facilities	Policy Information
Rainwater management	Retention System, Water Drainage	Playground	Pilot-project for ecological construction
Increasing permeability	Open Water System, Closed Water Loop,	Community space	Part of World Exposition 2000 in Hannover
Recreation in dense settlements	Climate Change Adaptation	Cycle path	Under the Water Concept, Hannover
Renaturation	Recreation zone	Green corridor	Guidelines: The Drainage Regulations for the Regional Capital Hannover
	Open space		financed by public and private investors
	Street greening, green roof		

4.4 Case study 4: Delhi "Master Plan 2041"

Location: Situated in the capital city of India.

Brief: In the awake of pandemics, the need to integrate both blue spaces and green spaces was realised and the framework to initiate the BGI projects were proposed in this master plan. Introduction to "Blue-Green Factor" in a city. (DDA, 2021)

Background: The

Key drivers / Issues: The need to protect the polluted river and water bodies; also to increase the level of green percentage in the city.

Objective: To enhance the BGI through integrated Blue spaces and green spaces, for them to flourish together and to enhance the sustainability of urban ecology.

Framework Details: (DDA, 2021)

i) Enhancing the value of assets:

- Organisms that degrade the environment are being restored with native flora and fauna.
- Tree Planting and Reforestation
- Biodiversity Enhancement for Environments
- Sewage outflows into rivers and other waterways are carefully scrutinized.

ii) Strengthening the bond between society and nature:

- Regions to become interactive between each other
- Increased recreational provision along the corridors of waterways and green spaces.
- "Active and passive recreational activities" such as educational trips to the nature, wildlife tours, camping, workout in the parks and service areas.
- "No public access" to the fragile areas of the ecosystems

iii) Interventions for the Ganges:

- *"*Comprehensive River development plan for Yamuna by Delhi Development of authority (DDA)" will be prepared to monitor the conservation of the river.
- A three hundred meter "buffer" needs to be provided and greened to preserve the river.
- To strengthen the bond between people and the river, a green corridor of hundred meter is to be provided.
- By re-stilting the "wetland" and planting trees to ensure the debris from being fed into the river and to control the contamination; ultimately "restoring the ecosystem".

iv) The Buffer spaces:

- The drains are to be protected and the major channels needs to be preserved by creating a "buffer" along them.
- To increase pedestrian safe paths and NMT provisions along the streams and channels.

- Biological purification of rainwater from the storms
- "Bio-Drainage, Groundwater recharge points and sponges for the floods" are to be provided along the drains, channels and streams.

v) Other initiatives:

- *"*Aquifer recharge ponds and public parks retention" strategy along the terrain slopes.
- The provision of "storm water drainage" along the terrain, leading to "Rainwater harvesting sumps"
- Activities such as agriculture or horticulture or allied activities like GW recharge waterways that make use of recycled water are welcomes and to be provided at various places

Inference: For the preservation of environment and enhancement of urban development, an integrated network of BGI is to be provided through the city to ensure city's resilience against major future shocks and calamities. A "Blue-Green Policy" is drafted for the nation (DDA, 2021).

4.5 Case study 5: Philadelphia "Green city clean water plan"

Location: Situated Philadelphia of Pennsylvania State in United States.

Brief: "Green City, Clean Waters" is Philadelphia's 25-year strategy to maintain and improve the city's basins by using sustainable infrastructure with a focus on manage storm water.

Background: The "Green City-Clean Waters" initiative in Philadelphia. It has been praised for its innovative strategy of collaboratively updating its hundred-years-aged drainage systems at a local level and at a minimal incremental cost utilizing sustainable vegetation and green technology. The project scale was macro and city wide scale. The project duration was from 2018 to the present, as it is an ongoing project. (commision, 2019)

Key drivers / Issues: The need to control CSOs and provide alternative water source while also effectively reducing contaminants in the water and cooling down the city from urban heat effects by greening the city. (commision, 2019)

Objective: To upgrade the "storm water and sewer systems with sustainable right-of-way" projects (ROW).

Figure 29: Before and after pictures of saylor groove
Source: (commision, 2019)

Figure 30: Before and after picture of Creek
Source: (commision, 2019)

Implementation: The past plays a very crucial role in the city's development. This project has embraces it past with "5 paradigms" of infrastructure system and successfully renovated its century old drainage system and implemented rainwater harvesting management throughout the city, with bio swales, retention tanks, drainage channels. The water is retained in bio-wetlands and reused after recycling biologically. They are also let into filtration spots along the green corridor for purification and penetrate to the groundwater level. This increases the watershed resilience. (commision, 2019)

Figure 31: Adaptation of green roofs wherever possible
Source: (commision, 2019)

Figure 32: Infiltration in small and large scales
Source: (commision, 2019)

The grey water is treated and is reused for irrigational purposes after purification by species in the wetlands. They use "Treated water for portable uses and untreated water for no-portable uses". A "triple bottom line" analysis was carried out i.e. "social, economic and environment assessments" (commision, 2019)

Figure 33: Before and after pictures of Streets and School grounds
Source: (commision, 2019)

Inference: This project was city wide level with a collective initiatives such as "storm water tree trenches, planters, pump outs, rain gardens, basins, storage or infiltration trenches, porous paving projects, bio swales, wetlands, downspout planters etc." From meso scale to macro scale, every project is connected in a BGI network for the whole betterment. (commision, 2019)

4.6 Comparison of all case studies

Table 8: Comparison of all case studies
Source: Author

	Flood Prevention	Reduce Pollution	Cleansing Biotope	Sediment Tank System	Groundwater /Aquifer Recharge	Permeability (Urban)	Biodiversity	Carbon Sequestration	Ecosystem Services	Pisary	Urban Farming	Cycle & Green corridor	Afforestation & Recreational spaces
SINGAPORE	●	●	●	○	●	○	●	○	●	○	●	●	●
MILANO	●	●	●	●	○	○	●	●	●	●	○	●	●
HANNOVER	○	●	○	○	○	●	○	○	○	○	○	●	●
DELHI	●	●	○	○	●	●	●	○	○	○	●	●	●
PHILADELPHIA	●	●	○	○	●	●	●	●	●	○	○	●	●

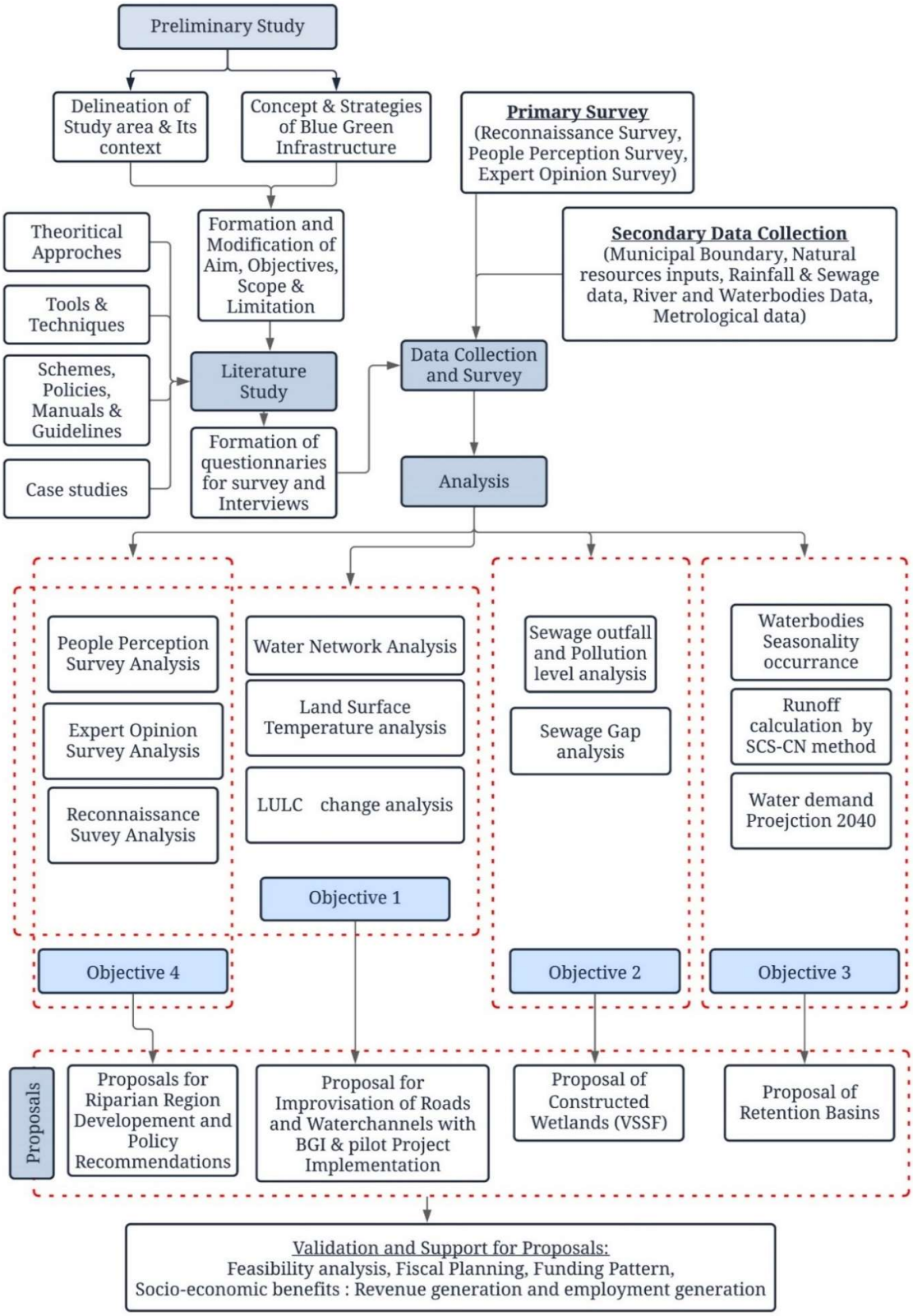
4.7 Lessons Learnt from Case studies

Table 9: Summary of all case studies with lessons learnt

Source: Author

Case studies		Key Element	Takeaways
i)	Ang-Mo-Kio Park, Singapore.	Bio-engineered River	To learn how a nature-based intervention, such as a bio-engineered river transformed from an ancient canal, can provide greater benefits than grey infrastructure.
ii)	Gorla Magiore Waterpark, Milano	Bio retention –sediment tank in constructed wetlands	To understand how engineered wetlands work as both a sediment tank and a bio-retention tank, proving that they are not only equivalent but also provide additional advantage over conventional infrastructure.
iii)	Hanover-Kronberg, Germany	Sustainable network in a group housing.	To have a better understanding of the strategy for conserving every drop of water through sustainable storm water management on a micro level, as well as to maintain water quality and resilience.
iv)	Delhi 'Master Plan 2041'	Green-Blue Policy	To realise that the only way to truly protect and enhance the environment while also improving the urban functionality, is to implement an integrated blue-green system.
v)	Philadelphia 'Green city clean water plan'	Strom water Management/	To comprehend how each element, from micro to macro, plays a role in a blue-green system that is sustainable.

5 Methodology:



6 Data collection

6.1 Primary data Collection

Primary Data	Type of Sample Collection	Context	Respondents	Analysis to be carried out
People's Perception survey	Questionnaires	Use of Blue & Green spaces in the city	Residents of the zone	Identification of possible zones for development and conservation.
		Rating of Attributes of Blue & Green spaces		
		Condition of the water bodies		
		Condition of local streets during floods		
		Condition of houses during rainy season		
		Availability of groundwater		
		Use of Rainwater harvesting devices		
		Preferred places for recreation		
		Willingness for the implementation of green-corridors around water bodies		
Expert Opinion Survey	Interview Questions	Importance of the Thamirabarani River to Tirunelveli	PWD officials, Mayor & Commissioner of M.Corp.	Identification of Development Priorities
		Issues related with the river		
		Concerns regarding Encroachment of the flood plains		
		Pollution levels of the water bodies and the river		
		Condition of the Recreational spaces in the zone		

		Techniques & Approaches suggested for Development		
Reconnaissance survey (Water Network & Eco-sensitive areas)	Observations Photographs, Sketches	Land Use Update	Author	Identifying priority water bodies and how land use impact the water bodies
		Timely Activity Pattern around the water bodies		
		Condition of the sewage outfall spots		
		Availability of land		
		Urban Characteristics & Visual Environments		

6.2 Secondary Data collection

Secondary Data	Source	Context	Use / Analysis to be carries out
Land Use map	M. Corporation	Land Use	Impact of land use on eco-sensitive areas and water bodies
			Availability of land
Hydrological & Administrative map	PWD –Water resource Department	River Basin, River Stream line, watersheds	Identifying the Location of river, and water bodies
Details of tanks	Nellai Neervalam	Tank Capacity, Area	Identification of water availability and water demand gap;
Soil and Geology Map	PWD-WRD	Soil typology and Geology	To identify Potential GW Zones
Water demand projection	PWD-WRD	Water demand projection for the 2040 year (All sectors)	To find the potential to increase the water availability
Ground water Data	PWD- WRD	Groundwater availability	
		Potential Groundwater zones	
		Groundwater pollution levels	To study the GW contamination level
Rainfall data	CHRS Portal	Daily rainfall data. & Rainfall volume	To find the Runoff volume in the zone
Sewage outfall data	CPCB	Sewage outfall spots	To study the contamination effect on river
		Pollution level of sewers	

Sewage treatment capacity	CPCB/M.Corp	Sewage generation & Gap	The need for new STP
Landsat Image-8	Sentinel (SRTM)	Land cover data	Identification of land cover and its change over the zone, from 1999 to 2022
DEM	Sentinel	Slope & Elevation	Feasibility of the interventions
		Contour study	Delineation of study area; and for Intervention suitability
		Stream line order	Drainage pattern study
Metrological data variables	NASA power	Precipitation (1975-2021)	Rainfall trend
		Temperature (1975-2021)	Temperature changes
		Earth Skin temperature	Identifying Urban heat island effect with urbanisation land cover.

7 Tirunelveli Profile:

7.1 Location and Regional Setting:

The study area is located in the district of Tirunelveli in the Indian state of Tamil Nadu. The Study area lies inside of the Uppar Vaippar River Basin, with a Major Perennial River "Thamirabarani" flowing through it, with a total area of 185 sq.km. The Delineation of the study area was done on the basis of Contours, Hydrological Basins and catchments. The district holds a population of 30.8 lakhs (Census 2011), while the municipality corporation houses 4.73 lakhs population.

Figure 34: Map showing Location of Tirunelveli in India

Source: Mapnik

The municipal corporation is the HQ of the Tirunelveli District. The Junction town is located on the north bank of the Thamirabarani River; its twin city "Palayamkottai" is on the south of the river

Tirunelveli has a hot semi-arid climate (Köppen). The district is majorly an agrarian district and holds about 1237 water bodies along with the Thamirabarani River. The Thamirabarani, the only existing perennial river in tamilnadu that "originates from the Agastyarkoodam peak of the Western Ghats, above Papanasam in the Ambasamudram taluk".

7.2 Demographic Profile:

Table 10: Basic Demographic Profile of Tirunelveli district

Source: Census 2011

S. No.	Demographic Characteristics	Tirunelveli District
1	Area in sq.km	3907 sq.km
2	Population	3,077,233
3	Male	1,520,912
4	Female	1,556,321
6	Sex ratio	1,062,747
7	Literates	2,273,457
8	Literacy Rate	73.9%
9	Male Literate	1,210,710
10	Female Literates	1,062,747

7.3 Precipitation

From the rainfall data collected from NASA power portal, for last four decades, The average of annual precipitation found in this area is 700 mm. Urbanisation has not affected the precipitation rate in this zone. The highest rate of rainfall seen in this history is 1250 mm annually in 1977 and 1140 mm in 2015. The months of September, October, November, and December gets a higher rate of rainfall when compared with other months of the year.

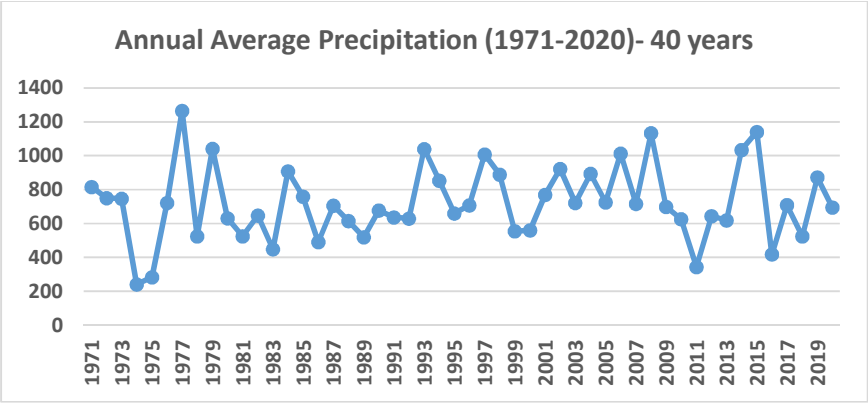


Figure 35: Annual Average precipitation (1975 -2020)

Source: NASA Power

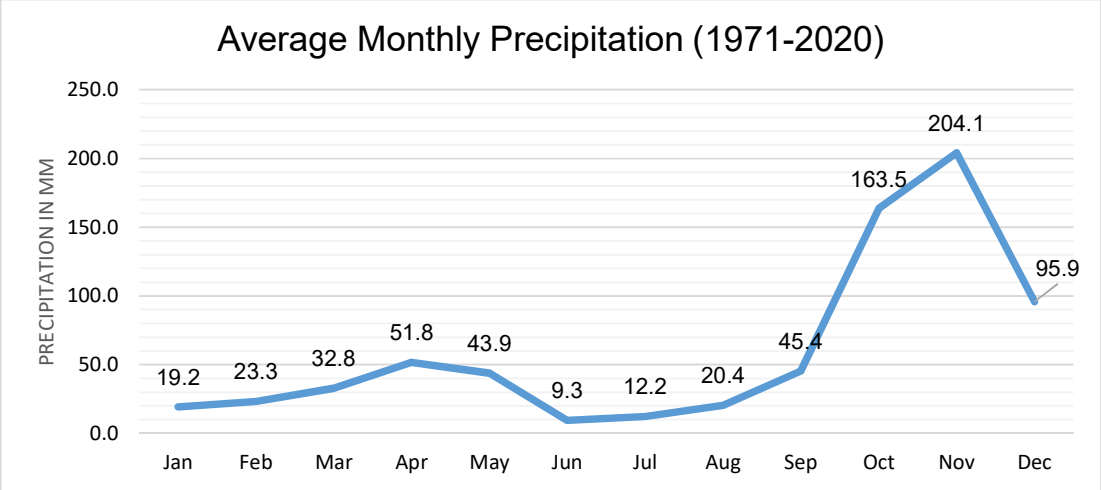


Figure 36: Average Monthly Precipitation (1971-2020)

Source: NASA Power

7.4 Temperature

The temperature of last two decades were analysed and from that it is observed that the annual average temperature is 26 degree Celsius. The months of March, April and May experiences highest degree of 29 C to 35 C. Average maximum is 29 C.

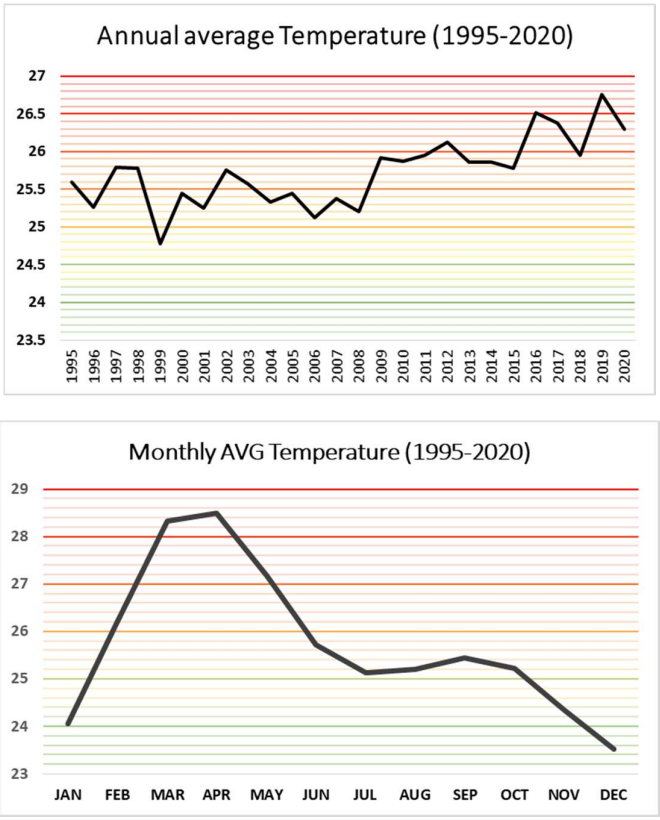


Figure 37: Annual Average Temperature and Monthly average temperature (1995-2020)

Source: NASA Power

7.5 Land Use of the Study Area

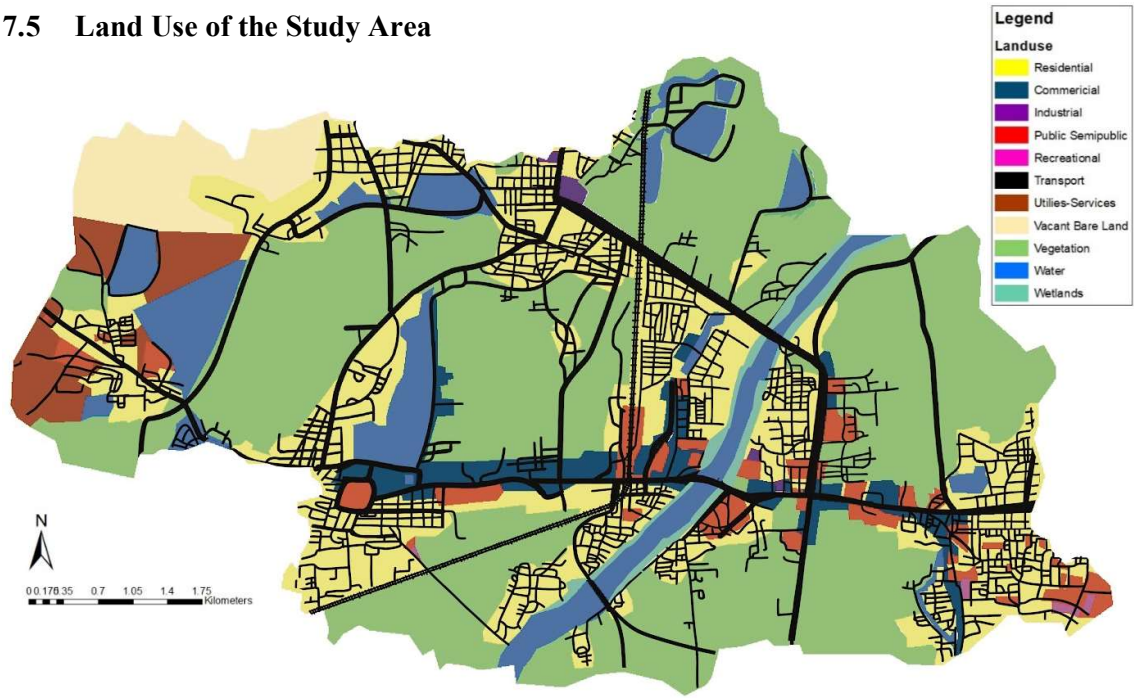
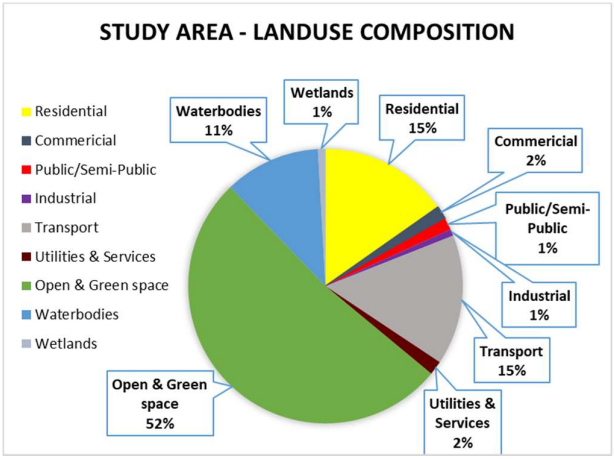


Figure 38: Land use Map of the study area

Source: Author using GIS



Landuse Category		%
	Residential	15.23
	Commericial	1.55
	Public/Semi-Public	1.43
	Industrial	0.77
	Transport	15.33
	Utilities & Services	1.65
	Open & Green space	51.71
	Waterbodies	11.28
	Wetlands	0.90
Total		100.00

Figure 39: Composition of land use in the study area

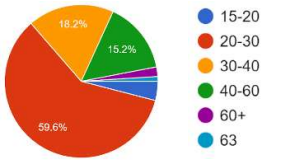
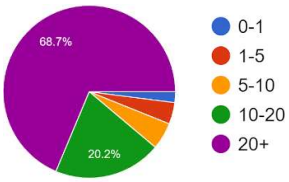
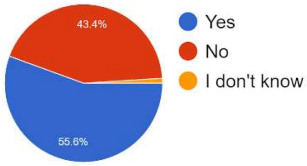
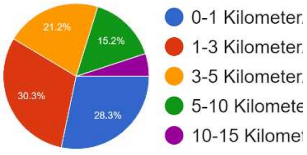
Source: Author

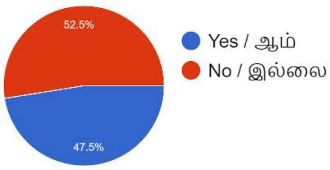
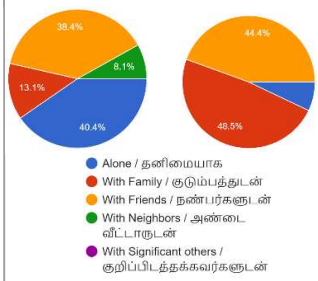
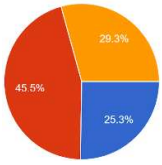
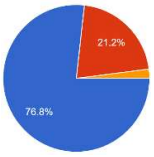
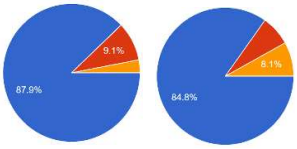
The study constitutes of 11% water bodies and 52% green spaces. The zone has more potential to form a network weaved between blue and green infrastructures.

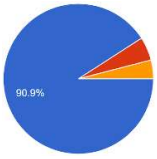
8 Analyses

8.1 People's Perception Survey - Inference

The people Perception survey has been analysed from the respondents and the inference that we get from the analysis is that,

Information	Question	Response	Interpretation
Basin Information of the Respondents	Age		Majority people belong to 20-40 age group
	Living in the city-years		70% of the respondents were living more than 20+ years in Tirunelveli City
Use of Blue and Green spaces /Infrastructures	Availability of Park/Leisure Space within walkable distance		Half of them does not have a Green/leisure space near their home
	Distance people travel to Green/Leisure space		70% of the respondents had to Travel more than 1-3 km while 20%of them travel more than 5km
Use of Blue and Green spaces /Infrastructures	List of Blue/Green Leisure Spaces people use (Tvl.Corp)	• VOC ground by Most people; • Riverside Sightseeing; • Science Centre; • Open grounds/Fields • Nearby park = by few people	Tirunelveli Needs more recreation spaces and the Existing parks does not have many amenities

	Parks with Greenery		53% - not enough greenery in the existing leisure spaces
	1. Frequency of use of BGI Spaces 2. Mostly visited with whom?		50% uses BGI spaces Frequently; mostly with their friends
	Mode of Transportation to BGI /Leisure Spaces	<u>NMT:</u> 31%=Walk; 7% = Cycle <u>MT:</u> 57% = Bike ; 25% =Car 7% =Bus ; 1%=Auto	Only 37% uses Non Motor Transit to reach these spaces while 63% uses Motor Transit
Rating the attributes of Blue-Green spaces Agree Neutral Disagree /Infrastructures	Tvl Corp. has variety of leisure spaces with water bodies and greenery		Only 25% agrees and Tirunelveli need more recreation spaces
	Thamirabarani RIVER is very polluted		77% perceives high pollution with the river
	It would be nice if there is a recreation space around the 1.Thamirabarani river 2. Other water bodies		Majority people wants Recreation near/around river & water bodies

	Drainage system in TVL corp. is either poorly planned or unplanned.		Majority of the people agrees

Information	Statement	Response
Water-logging & Flood	Flood/Water logging in the area	60% = No Flood in Area ; 40% - Floods Sometimes
	Water logging in House	79% = No Water Stagnant in their House 12% = Floods up to 10 cm in their house 7% = Floods up to 1 feet in their house 2% = Floods up to 2-3 feet in their house Reason: Improper Drainage/slope & Encroachment
	Water logging in street after rain	60% = No water logging in their streets 20% = Yes but can walk 8% = yes and Impossible to walk 11% = yes and impossible to drive a bike/car
Ground water	Availability of Groundwater in your area	60%= Sufficient quantity 40% = less or no availability
	Rainwater Harvesting Devices	53% Installed RWH pit Motivation: To increase Groundwater and To conserve Water

- Nearly half of the respondents claim they don't have access to any green or leisure spaces near their home, with majority of the people saying they have to travel more than a kilometre up to 5 kilometres to reach these places.
- People prefer to go by automobile rather than walking to these locations because they are not nearby by, and so they visit them less frequently.
- Even in neighbourhoods with these amenities, only half of respondents believe there is adequate green elements.

- Many people prefer to spend their time relaxing near water bodies, which are rare found in Tirunelveli. The river and water bodies are perceived to be highly polluted by two thirds of the respondents.
- About 20% of users indicate that their streets are flooded, making it difficult to walk or ride a bike across them. The cause is said to be a poorly designed road drainage system.
- About 40% claim that groundwater availability is decreasing, whereas half the respondents have built rainwater harvesting systems for conservation motives.

8.2 Expert Opinion Survey – Inference:

Experts	Opinions /Takeaways
Commissioner of Tirunelveli Municipal Corporation	Advised that the roads and settlements along the river are not conventional enough, resulting in increased traffic and connection issues. He also suggests repaving the old river bank road.
Mr. Gnanasekar Superintendent engineer of water resources department of Tirunelveli	Points out that encroachment in the river's flood plains is a growing problem, and that land use must be managed in accordance with the eco-sensitive area. Also proposes that the underground sewage system be completed in order to avoid direct sewage water discharge into bodies of water and strongly urges the development of more recreational spaces in the future.
Mr. Ramesh Assistant engineer of PWD-WRD, Tirunelveli	Encourages strengthening people's connections with nature so that they value and protect the natural assets. Also, he points out the tourism and heritage opportunity available around the Nainar lake.
Mr. Annadurai Former Executive engineer of PWD, Tirunelveli	Recommends the local authorities to properly maintain water bodies, particularly the river, because untreated sewer water is directly fed into the river, resulting in the creation of contaminations like E.coli in the river water; and that other tank pits are extremely contaminated due to the dumping of waste and effluents. Recommends a public awareness campaign for the same

8.3 Water Network Analysis:

The entire water network of the study area was examined, and it was discovered that it follows a traditional water storage network, in which water is transported from one water body to another by water channels, which are then drained into the river once they are saturated. In the study area, there are 13 water tank pits, two water channels that weave through the zone and connect various water bodies, and the Thamirabarani River.

There are a few locations in the water channel that need to be de-silted and cleaned in order for the water to flow properly in this network. While having aquatic plants on the surface of many water bodies is beneficial for the environment, it restricts people's interaction with the water bodies. As a result, individuals underestimate the significance of natural resources. The tank pits in urban areas appear to be contaminated, but there is evidence of interaction between people and water channels in densely populated areas.

Figure 40: Water Network Analysis
Source: Author

8.3.1 Water bodies' Reconnaissance Survey Analysis:

8.3.1.1 Water body No.1: Kandiaperi Lake

Kandiaperi Lake is the largest lake in the study area with Area of 161.81 Hectare. Its capacity is 0.947 MCM. The whole lake was filled with aquatic plants with little water visible to the

eye. The residents around mentioned that it holds rich bio-diversity. It is totally disconnected from human interactions being an inaccessible asset. Interventions providing recreational opportunities can be done with the help of its untouched aesthetics. And also because of its close proximity with many other water bodies like Nainar Lake.

Figure 41: Kandiaperi Lake: Visual Survey

Source: Author

8.3.1.2 Water body No.2: Seeniappanthiruthu kulam

Seeniappanthiruthu Pond has an Area of 30.4 Hectare. Its capacity is 0.0125 MCM. This pond is behind a stretch of houses, shops and temples, invisible to visitors who pass by the road unless looked for. It's a hidden gem and is also maintained in a good condition. Fishing activities are said to be done periodically in this pond.

Figure 42: Seenithirukulam Pond : Visual Survey

Source: Author

8.3.1.3 Water body No.3: Ilandaikulam

Ilandaikulam has an Area of 30.42 Hectare. Its capacity is 0.0782 MCM. This pond has a road parallel to its form, green way corridors can be an excellent opportunity to enjoy the view. This pond currently is not in bad shape, but can certainly be improved in maintenance aspects.

Figure 43: Ilandakulam Visual Survey
Source: Author

8.3.1.4 Water body No.4: Thennerkulam

Thennerkulam has an Area of 10.715 Hectare. Its capacity is 0.0049 MCM. This pond runs parallel to the road and leads into sub-urban region, lack of any interaction between people and pond is noted. Aquatic plants hinder providing the pleasant view for the drive road.

Figure 44: Theneerkulam Visual Survey
Source: Author

8.3.1.5 Water body No.5: Krishnaperi Kulam

Krishnaperi Kulam has an Area of 178.87 Hectare. Its capacity is 0.0127 MCM. This pond is basically a continuation of the water channel as it flows into other water bodies in a system. Though the area is vast, its depth is observed to be shallow. It has opportunity to hold more water if the depth is increased. Fishing is done in lease contracts.

Figure 45: Krishnaperi Kulam Visual Survey
Source: Author

8.3.1.6 Water body No.6: Nainar Lake

Nainar Lake has an Area of 148.11 Hectare. Its capacity is 0.3797 MCM. This lake is one of the biggest in the study area, and hold a lot of recreation, heritage and tourism opportunity with Nellaiappar temple at a very close proximity. Right now, it has the surrounding structures like footpath and toilets is in a very bad condition. Though many renovations had been done previously, it seems to be a failure with lack of maintenance and unsafe perceptions related with this lake. Proper interventions targeting all the lessons learnt from its previous renovation can actually make this area generate social, economic and environmental benefits.

This Lake has 30 score in the ranking of ecosystem services survey done, **refer to annexure 4** for detailed analysis of the same. An activity pattern study is done in the section --------

Figure 46: Nainar Lake Visual Survey
Source: Author

8.3.1.7 Water body No.7: Udaiyarpatti kulam

Udaiyarpatti kulam has an Area of 27.96 Hectare. Its capacity is 0.0365 MCM. Being amidst urban settlement, this pond collects the discharge from the sewers directly, which gets collected from the surrounding neighbourhoods. It is opposite to a famous theatre and is nearby to the CBD of Tirunelveli junction. Providing a recreational space around this waterbody can hold more value to the people, place and also generate revenue.

Figure 47: Udayarpatti kulam Visual Survey
Source: Author

8.3.1.8 Water body No.8: Sendimangalam

Sendimangalam has an Area of 54.18 Hectare. Its capacity is 0.0642 MCM. It is connected with Aruganкulam, Pirayankulam and Alanganeri ponds. They all are just separated by part of land. They serve the purpose of flood mitigation, irrigation, storm protection and are rich in bio-diversity.

Figure 48: Sendimangalam Visual Survey
Source: Author

8.3.1.9 Water body No.9: Pirayankulam

Pirayankulam has an Area of 18.46 Hectare. Its capacity is 0.0952 MCM. As said earlier, it is connected with other water bodies like alaganeri, arumuganeri and sendimangalam. No interaction with this pond as it is in remote area.

Figure 49: Pirayankulam Visual Survey
Source: Author

8.3.1.10 Water body No.10: Alanganeri

Alanganeri has an Area of 20.77 Hectare. Its capacity is 0.0809 MCM. The flora and fauna cover most of the area and is inaccessible to humans, and used for irrigation, storm water protection and flood mitigation. It is connected with the traditional system. It is the largest among the set of 4 nearby waterbdoies, thereby holding more water in it.

Figure 50: Alanganeri Visual Survey
Source: Author

8.3.1.11 Water body No.11: Sambankulam

Sambankulam has an Area of 15.18 Hectare. Its capacity is 0.0256 MCM. This pond holds its water for Agricultural purpose and storage purpose. It is in the sub-urban and people rarely comes around this pond as it is in the middle of the field. It is in a good condition. Aquatic plants cover most of the surfaces.

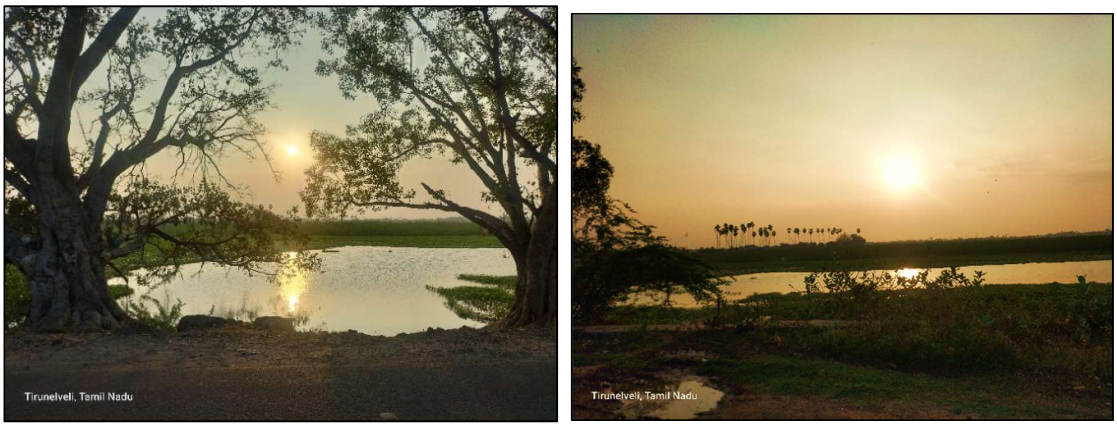


Figure 51: Sambankulam Visual Survey
Source: Author

8.3.1.12 Water body No.12: Arugankulam

Arugankulam has an Area of 33.24 Hectare. Its capacity is 0.1382 MCM.

Figure 52: Arugankulam Visual Survey
Source: Author

8.3.1.13 Water body No.13: Mullikulam

Mullikulam has an Area of 94.01 Hectare. Its capacity is 0.0092 MCM. Since it is in the middle of the dense urban settlement, activities like Bathing & Washing clothes are carried out in the channel which is very close by 50m, But the Pond is untouched due to its pollution & unusable due to water plants. This makes people to use this pond for drain grey water into the pond, and degrade it further more. Lack of connection makes people disconnected with the pond.

Figure 53: Mullikulam Visual Survey
Source: Author

Many areas are inaccessible due to fencing done by community people. Therefore, people spend their leisure time in the banks of the channel rather than have any interaction with the pond. Kids are diving and playing in the nearby palay channel. Urination at the corner of the pond makes it more unhygienic and unsafe

8.3.1.14 Water channel 01: Town Channel

Town Channel is the water channel which in the left side of the river in the twin city town. In the city, the water channel is heavily polluted, yet as it flows, it rejuvenates itself in the suburbs. The canal has become a dump for waste and construction materials as a result of urban interaction, and as the line goes, it carries sewers from surrounding neighbourhoods, polluting the area further. There must be immediate effort made to raise awareness and maintain the water channel. This is the waterway that connects all of the water bodies on the river's western bank. The water that comes from this route is stored in every water bodies, removes pollutants as the water flows from one to another in a traditional approach. Nainar Lake which is rich in bio-diversity is affected a lot because of the close proximity to this polluted place in the water channel.

Figure 54: Town Water Channel (In the admist of urban dense areas)

Source: Author

Figure 55: Town Water channel (in the sub-urban regions)

Source: Author

8.3.1.15 Water channel 02: Palay Channel

Palay Water Channel is more polluted when compared with other channels in tirunelveli, as it passes through various dense urban settlements like melapalayam, Palayamkottai before it merges with the river. Rejuvenating nature based solutions needs to be given in various stretch of the stream in intervals for purification purposes. Interaction with channel is seen in many places of urban centres, where they bath, wash clothes, kids dive into the water.

Figure 56: Palay Water Channel (in the dense urban settlements)
Source: Author

8.3.2 Ranking of Ecosystem services of the water bodies:

All thirteen tank pits in the study area was ranked for their ecosystem services, such as provisioning services, regulating services, cultural services and supporting services, with 36 points in total. The water bodies performing above 26 are considered in excellent condition with better opportunities, while the water bodies which have rank between 19-26 are considered to be in good condition; those which are between 10-18 are considered to be not bad and finally the one below 10 are considered to be in poor condition and in critical stage.

This analysis is based on the ranking system suggested by NIUA urban wetland management guidelines. **Refer Annexure 4** for the detailed ranking of the water bodies under each services typology.

Table 11: Ranking of ecosystem services for all water bodies and Prioritization of water bodies
Source: Author

ID:	Water body Name	Ranking (out of 36)	Remarks
WB1	Kandiaperi Lake	21	Good
WB2	Seeniappanthirukulam	14	Not Bad
WB3	Ilandakulam	16	Not Bad
WB4	Theneerkulam	18	Not Bad
WB5	Krishnaperi Kulam	21	Good

WB6	Nainar Lake	30	Excellent
WB7	Udayarpatti kualm	10	Not Bad
WB8	Sendimangalam	20	Good
WB9	Pirayankulam	20	Good
WB10	Alanganeri	22	Good
WB11	Sambankulam	14	Not Bad
WB12	Arugankulam	20	Good
WB13	Mullikulam	8	Poor & Critical

From the results of this ranking tool, Nainar lake has the highest ranking of 30 out of 36 and is found to be in excellent condition with better opportunities for tourism and recreations. While Mullikulam is considered to be in a critical stage and needs immediate attention.

8.3.3 Timely activity pattern around the water bodies:

The timely activities carried out around the water bodies were observed through a weekday and in weekends. Apart from the basic anthropologic activities of bathing, washing clothes, and swimming; people also wash their automobiles on the flood plains; religious rituals are performed in a few locations along the water bodies; and leisure activities such as sightseeing, sketching, and so on are observed. Despite the lack of a walkway or seating area near the water bodies, people do have certain level of interaction with the assets.

8.3.3.1 Activity pattern around River:

Figure 57: Picture showing the Landuse around the River and view from the bridges
Source: Author

Looking into the river stretch and the landuse around it, the urban settlement is concerntrated in the centre and rest all are agricultural land adjoining the flood plains, which is not a conventional landuse as agricultural land would have chemicals which would be discharged into the river. This needs to be regulated.

Figure 58: Activities observed around the river

Source: Author

Common river oriented anthropological activities like washing, bathing, regilious ritural perfomances, happen in the banks of the river. Apart from it people take their vehicles down the flood plain and clean it off, which is harmful to the environment and river. Kids use the old mandapa to dive into the river when the river discharge is in high level. People sit in the Broken pipes and stones, as there isn't any seating space nor a walkway for the people to enjoy their time with the river. People desire to have close relation with the river, and providing a propoer recreational spaces around the riparian region is recommended.

Table 12: time Frame Activity pattern around the river

Source: Author

Time Frames for Observation	**Thamirabarani River**
Morning 6 am to 10 am	• Bathing (Many) • Washing Clothes • Kids Swimming Practices • Thithi rituals (on particular dates like Feb 3,2022)
Afternoon 11 am to 3 pm	• Washing Clothes • Bathing (Very few)

Evening 3 pm to 5 pm	• Vehicle Washing (Like Auto) • Bathing & Washing cloth
Evening 5 pm to 6.45 pm	• Sightseeing & Leisure • Walking in the River road • Couples Spending time • Feeding the fishes

8.3.3.2 Activity Pattern around Nainar Lake:

Figure 59: Landuse around the Nainar Lake
Source: Author

- This lake has been renovated n number of times, but seems to be a failure after every implementations. Poor Maintenance is the cause of the failure of renovations
- This lake serves as the main sustenance of surrounding areas along with few other smaller lakes.
- It has high Tourist opportunity because of "Nellai Temple" and its heritage importance. And this temple is said to be the trial version for the temple architecture of Meenakshi Amman Temple of Madurai.
- Migrating Birds Visit the pond regularly. About 92+ Species are spotted in this lake.
- Leased Fishing activities are carried out periodically and a highly busy commercial street is situated in the southern side of the lake. It is one of the CBD of the Tirunelveli town area.
- There is high walkability issue around the lake, even though it has a footpath, which is in a dilapidated stage. Maintenance of the lake needs to be addressed and many engaging amenities needs to be added to add more value to the lake so people recognise its worth and value this natural asset.

Figure 60: pictures showing the current situation around the Nainar lake, (Old bus-stand, Litters around the corners, Public Toilet, Trucks parked, Unused Picnic Deck, Aquatic plants covering the lake)
Source: Author

Figure 61: Panaromic View of the Nainar lake with footpath.
Source: Author

Figure 62: Pictures showing the pollution in the water channel and the budy commercial street near the Nainar Lake

Source: Author

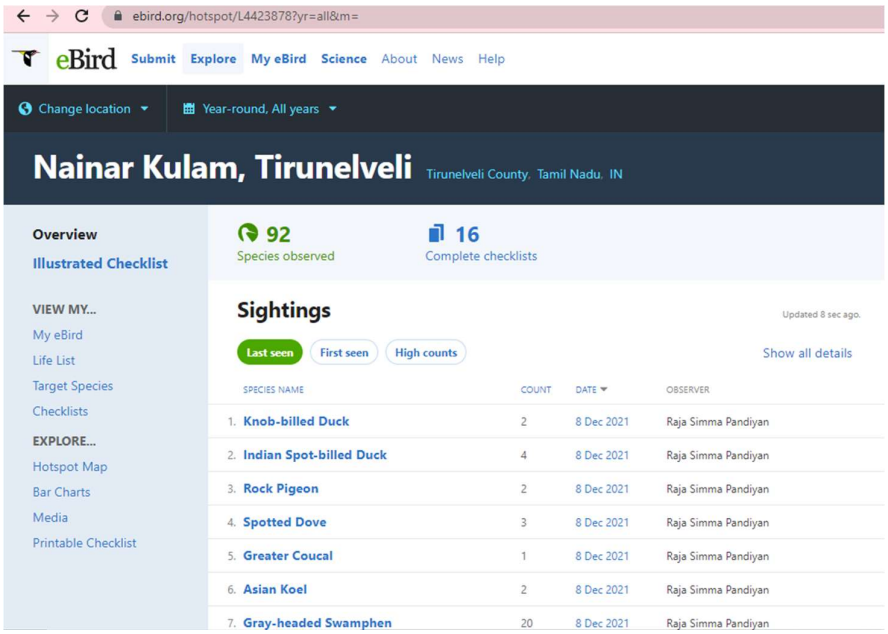


Figure 63: Website for the Migration birds spotted in Nainar lake

Source: ebird.org

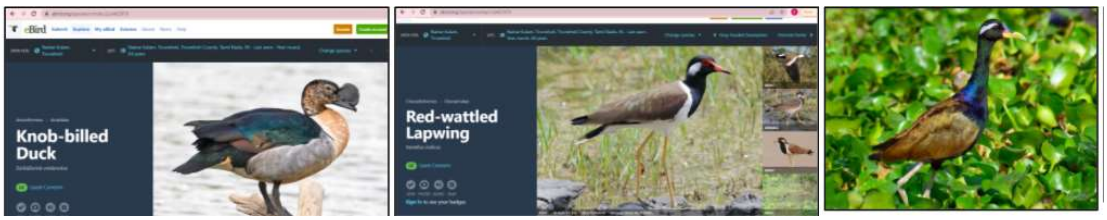


Figure 64: Pictures showing the some of the migrated birds that visit Nainar lake

Source: ebird.org

Table 13: Timely activities observed around the Nainar Lake
Source: Author

Time Frames for Observation	Activities Around Nainar Lake
Morning 6 am to 10 am	• Morning walk around lake • Trucks Vehicles parked in the front of the lake (always)
Afternoon 11 am to 3 pm	• Leased Fishing Activities • Litter dumping in the corners • Urinating behind the trucks
Evening 3 pm to 5 pm	• Bird Watching • Urinating behind trucks
Evening 5 pm to 6.45 pm	• Busy Commercial Street near the lakefront. • But no proper interaction with lake. • No one in the picnic Gazebo

8.4 Seasonality Occurrence Analysis:

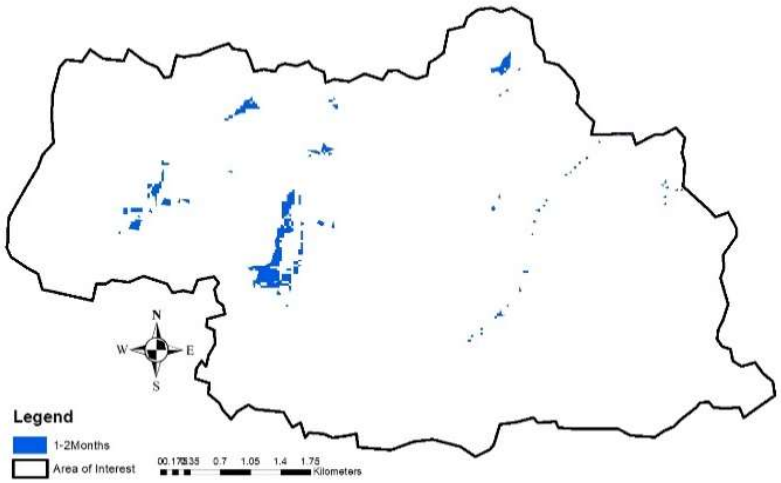


Figure 65: Water bodies seasonal Occurrence for 1-2 months
Source: Author

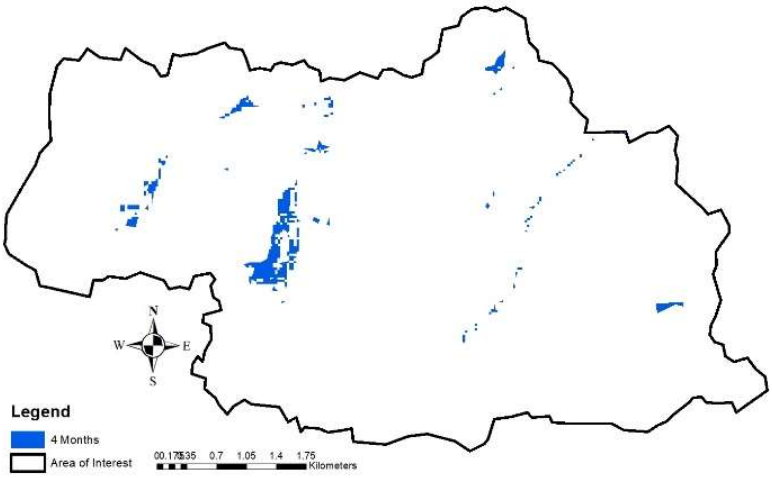


Figure 66: Water bodies seasonal Occurrence for 4 months

Source: Author

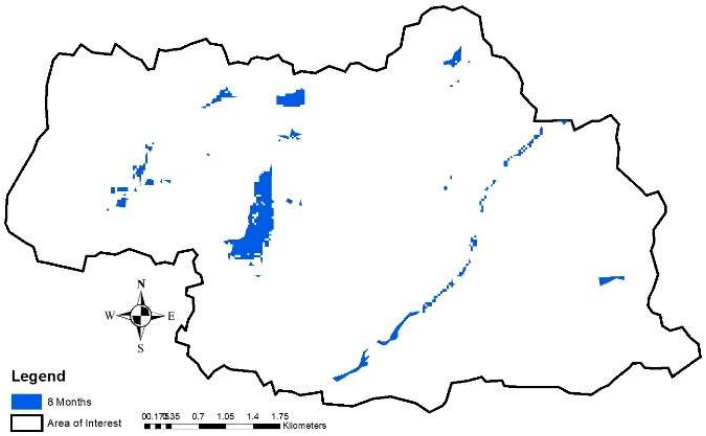


Figure 67: Water bodies seasonal occurrence for 6 months

Source: Author

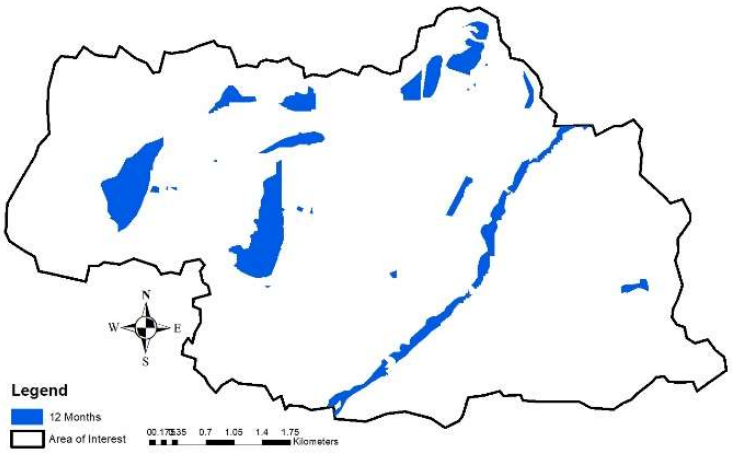


Figure 68: Seasonality analysis of the water bodies, seasonal occurrence of every 12 months

Source: Author

The water bodies and their seasonality occurrence has been analysed with the data obtained from the JRC global water data and the results shows that most of the water bodies present in the study area occur and retain the water for only for 4-6 months while fewer water bodies like Nainar lake, Kandiyaperi lake and Arugangulam retain water year round. The findings point to the possibility of increasing the depth of these water bodies and find measures to increase the water availability through the year.

Also, when comparing all the water bodies, Nainar Lake has the highest score of availability followed by theneerkulam and kandiaperi. There, Nainar Lake has better potential in terms of implementing the interventions in regards to its availability.

8.5 Water demand & availability projection for 2040 year

From the data obtained from the public work department, in the whole Thamirabarani basin, only 1740 MCM of water is available, combining all surface water, ground water, recycled water, and the water from de-silt.

Table 14: Water Availability from various sources

Source: PWD, Tirunelveli

Water Availability (MCM)				
Surface water potential	Groundwater potential	Quantity of recycled water from sewage	Quantity of water from de-silting	Total
883.00	812.08	123.81	44.88	1739.96

With the water demand from the various sectors are projected till the year 2040, total of 1604 MCM of water is demanded from various sectors, where irrigation is considered the same with a constant demand of 1055 MCM every year and other sectors are projected for the future. The surplus amount of water available is only 135 MCM when water availability and water demand are compared. It's evident from the results that in 20 years the water demand and water availability meets. And therefore the water availability needs to be increased after determining the potential to increase the same.

Table 15: Water Demand projection for all sectors

Source: PWD, Tirunelveli

Year	Demand of water in various section (MCM)					Total water Availability in MCM	Surplus in MCM
	Irrigation	Domestic	Industries	Others	Total Demand		
2017	1054.57	79.56	63.24	59.57	1256.94	1739.96	483.02
2020	1054.57	83.88	79.98	59.03	1277.46	1739.96	462.50
2030	1054.57	100.14	172.04	58.35	1385.10	1739.96	354.86
2040	1054.57	119.66	371.06	58.93	1604.22	1739.96	135.74

8.6 Run-Off calculation using SCS-CN Method

The annual runoff from the watershed was calculated using the Soil Conservation Service – Curve Number (SCS-CN) method to understand the runoff potentiality and to determine the possibility for increased water availability. This tools estimates curve number of the watershed using the land cover data, slope data and soil data. The daily antecedent moisture condition (AMC) is calculated using daily rainfall data and curve number for different AMC conditions are estimated depending on the season of either dormant or growing condition.

Table 16: Daily Antecedent moisture condition
Source: Author

Total Rainfall in previous 5 days		
AMC Condition	**Dormant Season**	**Growing Season**
I	<13 mm	<36mm
II	13 mm to 28 mm	36 mm to 53 mm
III	>28mm	> 53 mm

Table 17: Hydrological Soil Group category
Source: Author

Hydrologic Soil Group	
A	Low runoff potential (Soils having high infiltration rates: deep sand, deep loess, aggregated silt)
B	Moderately low runoff potential (Soilhaving moderate infiltration, shallow loess, sandy loam, red loamy soil, red sandy loam)
C	Moderetely high runodd potential (Soil having low infiltration rate; Clayey loam, shallow sandy loam, soil usually high inclay)
D	High runoff potential (Soils having very low infiltration rates; Heavy plastic clays, certain saline soils and depp black soils)

From LU/LC and HSG group of the soil, the Weighted CN is derived, which will be considered s CN2 and from daily rainfall data obtained from CHRS potral, AMC Condition is applied for dormant and growing season to derive CN2, CN3 Numbers, which will further be fed into the simulated runoff (S) formula to get the potential maximum runoff retention and then the Quantity of daily runoff depth (Q) from the catchemnt is calculated.

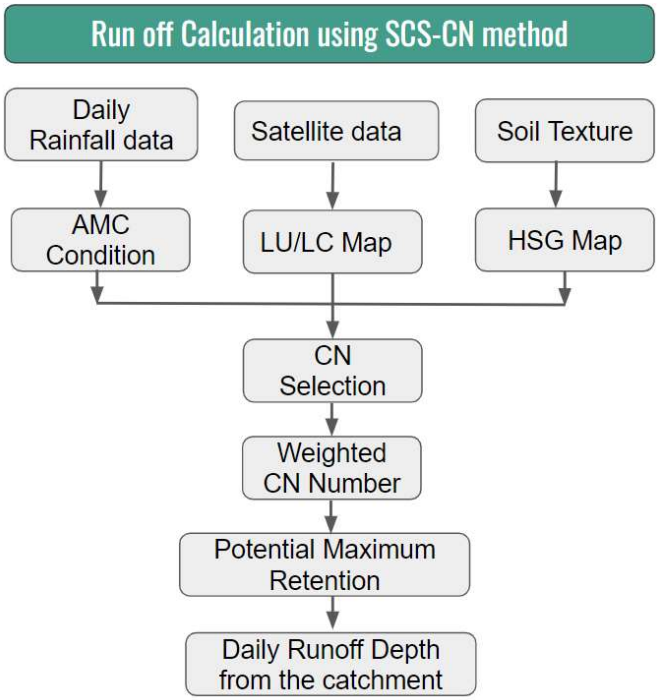


Figure 69 : Method to calculate Annual Runoff usuing SCS-CN Method
Source: Author
Methodology Source: Dhawale, A.W (2013)

The formula for the calculation of Curver number from the weighted curve number is

$$CN1 = \frac{CN2}{2.281 - 0.01281CN2}$$

$$CN3 = \frac{CN2}{0.427 + 0.00573CN2}$$

The formula for the Simuated Runoff (S) is,

$$S = \frac{25400}{CN} - 254$$

Where, CN is either CN1, CN2, CN3 based on the AMC condition

The formula for the Quantiy of daily runoff depth (Q) is

$$Q = \frac{(P - Ia)^2}{(P - Ia + S)} = \frac{(P - 0.2S)^2}{P + 0.8S}$$

For $P > 0.25$
Where $P =$ Daily Rainfall depth
And $Ia =$ Initial Abstraction $Ia = 0.25$

Applying procedure of the SCS-CN method for the whole watershed, we get the following data as per analysis.

Table 18: Weighted CN number calculation from the LULC and Soil data

Source: Author

	Whole Watershed- HSG C			
ID	**LU category**	**Area (Sq.km)**	**CN**	**Weighted CN**
1	Water bodies	0.9898	96	3.20
2	Forest	0.0887	70	0.21
3	Wetlands	0.1974	96	0.64
4	Bare land	0.1468	73	0.36
5	Cropland	12.7116	88	37.71
6	Shrubs	1.8081	73	4.45
7	Built-up	13.7217	90	41.63
	Total	**29.6641**		**88.20**

Table 19: Calculation of Cumber numbers from Weighted Curve Number

Source: Author

CN II	88.2029

Applying formula, we get

CN I	76.6236
CN III	94.5975

Foremost, the Daily rainfall data of the zone has been obtained from CHRS, the Landuse Land cover data along with their distribution, derived from the supervised classification done earlier and Soil data which is determined to be of Class C in HSG has been used to calculate the Weighted Curve Number. And the AMC Condition has been applied based on the Dormant and growing seasons of the year. We got CN2 as 88.20 for the whole study area, and CN1 as 76.62 while CN3 as 94.60. Then it is then fed into the simulated runoff calculation for finding the maximum potential runoff retention of the catchment areas. Which is further used to find the Runoff depth and Volume of the catchments. The result of the analysis is:

Table 20: Result of Runoff calculation for the whole watershed

Source: Author

Total Rainfall in year	1555.56 mm	**Total Runoff in year**	526.78 mm
Total Rainfall Volume in year	46.14 MCM	**Total Runoff volume in year**	15.63 MCM
Percentage of runoff from Rainwater		34%	

The analysis shows that in the whole study area, the yearly rainfall volume is 46.14 MCM of water while 34% of them were converted into runoff, the runoff volume is 15.63 MCM, which

either is discharged into the river or is wasted combing with the sewers. In addition, the entire watershed has been divided into seven smaller catchment zones. Their individual runoff volume and depth have also been calculated following the same procedure.

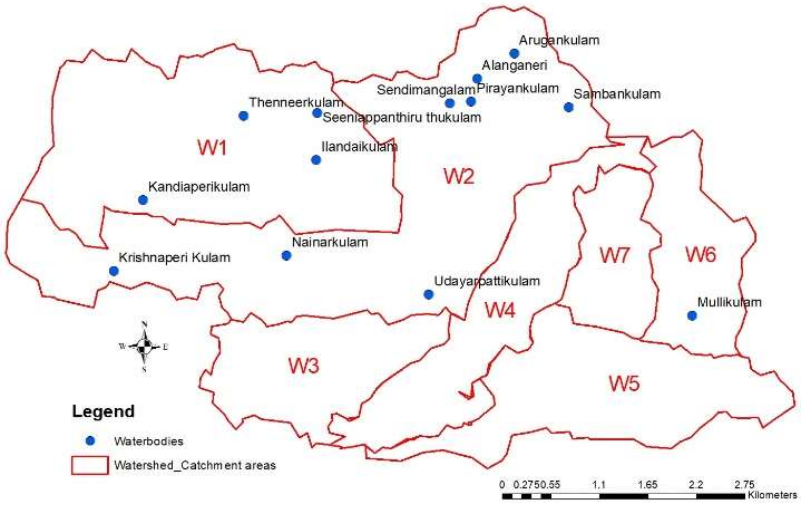


Figure 70: Smaller catchment areas inside the watershed, along with the placement of water bodies
Source: Author

The whole watershed was divided into seven catchment area, delineated with the help of DEM and contours in GIS. Watershed/Catchment W4 has the river running through it, and all the water collected in this watershed cannot be used for retention purposes of that area. Because of the river movement. While in the other watersheds, the runoff can be collected and used for retention or storage purposes

Table 21: Calculation of weighted CN & Curve number by AMC condition for watersheds (W1, W2 & W3)
Source: Author

			Watershed/W1		Watershed/W2		Watershed/W3	
ID	**LU category**	**CN**	**Area (Sq.km)**	**W.CN**	**Area (Sq.km)**	**W.CN**	**Area (Sq.km)**	**W.CN**
1	Water body	96	0.3050	4.26	0.2122	2.17	0.0000	0.00
2	Forest	70	0.0103	0.11	0.0265	0.20	0.0000	0.00
3	Wetlands	96	0.0491	0.69	0.1203	1.23	0.0000	0.00
4	Bare land	73	0.1465	1.56	0.0003	0.00	0.0000	0.00
5	Cropland	88	3.0640	39.28	3.9505	37.09	1.1834	40.11
6	Shrubs	73	1.4529	15.45	0.1133	0.88	0.0000	0.00
7	Built-up	90	1.8366	24.08	4.9495	47.53	1.4128	48.98
	Total		**6.8644**	**85.43**	**9.3726**	**89.11**	**2.5962**	**89.09**
	CN2		**85.43**		**89.11**		**89.09**	
	CN1		**71.99**		**78.20**		**78.16**	
	CN3		**93.21**		**95.04**		**95.03**	

Table 22: Calculation of weighted CN & Curve number by AMC condition for watersheds (W4, W5, W6, W7)
Source: Author

		Watershed/W4		Watershed/W5		Watershed/W6		Watershed/W7	
LU category	**CN**	**Area (Sq.km)**	**W.CN**	**Area (Sq.km)**	**W.CN**	**Area (Sq.km)**	**W.CN**	**Area (Sq.km)**	**W.CN**
Water body	96	0.4669	13.68	0.0000	0.00	0.0035	0.22	0.0010	0.05
Forest	70	0.0485	1.04	0.0032	0.06	0.0000	0.00	0.0001	0.00
Wetlands	96	0.0061	0.18	0.0064	0.16	0.0107	0.66	0.0048	0.21
Bare land	73	0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00
Cropland	88	0.8281	22.24	1.4382	33.19	0.8058	45.58	1.4169	58.36
Shrubs	73	0.0084	0.19	0.2286	4.38	0.0000	0.00	0.0000	0.00
Built-up	90	1.9185	52.70	2.1366	50.43	0.7356	42.56	0.7137	30.07
Total		**3.2765**	**90.02**	**3.8129**	**88.22**	**1.5556**	**89.02**	**2.1365**	**88.69**
CN2		**90.02**		**89.02**			**88.69**		
CN1		**79.82**		**78.04**			**77.46**		
CN3		**95.48**		**95.00**			**94.84**		

As a result, the comparison of the rainwater volume and runoff volume of all the watersheds are listed in the table below. Individually, the smaller catchment watersheds has the runoff percentage varies from 30% to 35%, which indicates that there is excellent potential to increase water availability in the area, if the runoff is collected by storage or infiltration in the zones.

From 15.63 Runoff volume of the whole area of interest, Excluding W4, all other watersheds provide 13.76 MCM of water available as Runoff volume for future retention.

Table 23: Comparison of Rainfall volume and Runoff volume of all the watersheds in the zone.
Source: Author

Watershed	**Area(Sq.km)**	**Yearly Total Rainfall (MM)**	**Total Rainfall Volume (MCM)**	**Yearly Runoff (mm)**	**Yearly Runoff Volume (MCM)**	**Percentage Of Runoff**
Area of Interest	29.66	1555.56	46.14	526.78	15.63	33.86%
W1	6.86	1555.56	10.68	459.26	3.15	29.52%
W2	9.37	1555.56	14.58	552.00	5.17	35.49%
W3	2.60	1555.56	4.04	551.46	1.43	35.45%
W4	3.28	1555.56	5.10	579.56	1.90	37.26%
W5	3.81	1555.56	5.93	527.24	2.01	33.89%
W6	1.56	1555.56	2.42	549.46	0.82	34.72%
W7	2.14	1555.56	3.32	540.11	1.15	34.72%

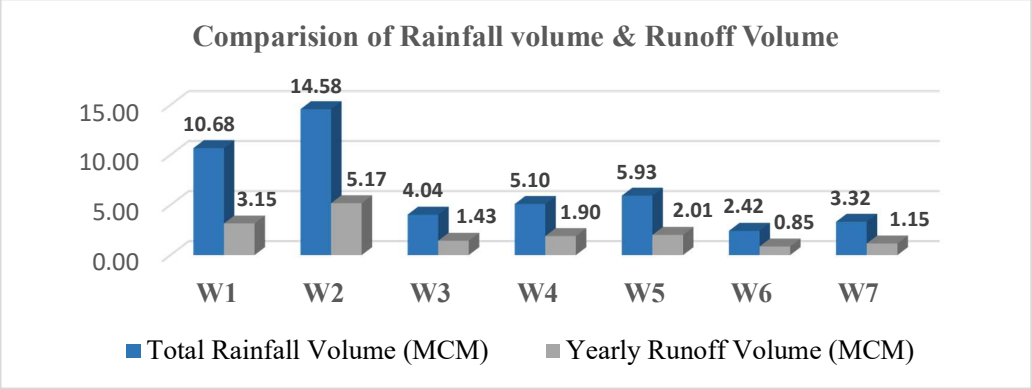


Figure 71: Bar chart showing comparison of Total rainfall volume and Runoff volume
Source: Author

8.7 Potential to increase water availability

Table 24: Showing Potential to increase water availability from runoff volume
Source: Author

	Name of Tank	Tankpit Area / Ayacut in Ha	Tankpits' water Capacity in MCM	(Existing) Total watershed's water storage Capacity in MCM	Water shed ID	Runoff Volume in that watershed area (MCM)	Potential to increase water availability= Runoff - Capacity (MCM)
1	Kandiaperikulam	161.81	0.947	1.0426	W1	3.15	2.1100
2	Seeniappanthirukulam	30.4	0.0125				
3	Ilandaikulam	30.42	0.0782				
4	Thenneerkulam	10.715	0.0049				
5	Krishnaperi kulam	178.87	0.0127	0.833	W2	5.17	4.3407
6	Nainarkulam	148.11	0.3797				
7	Udayarpattikulam	27.96	0.0365				
8	Sendimangalam	54.18	0.0642				
9	Pirayankulam	18.46	0.0952				
10	Alanganeri	20.77	0.0809				
11	Sambankulam	15.18	0.0256				
12	Arugankulam	33.24	0.1382				
13	Mullikulam	94.01	0.0092	0.0092	W6	0.85	0.8456
No water bodies in these catchment areas (W3, W5, W7)		0.00	0.00	0.00	W3	1.43	1.43
		0.00	0.00	0.00	W5	2.01	2.01
		0.00	0.00	0.00	W7	1.15	1.15
Total Capacity of all waterbodies =			**1.8848 MCM**	**Potential to increase Water Availability**			**11.89 MCM**

With the runoff depth computed and the storage capacity of the water bodies present in the watersheds, the potential to augment water availability for the entire study zone, excluding the watershed with the river, is found to be 11.89 MCM. Despite the fact that the Watershed W2 has several water bodies, the region still has the capacity to increase 4.34 MCM. In addition, the depth of the water bodies in the Watershed W1 can be increased to retain more water with a potential of 2.11 MCM within the watershed; and smaller retention ponds can be provided in the Watershed W3, W5, W6, and W7 because there are no water bodies in the area, thereby increasing water availability in the zone overall.

8.8 LU/LC change detection and comparison with Surface Temperature:

Landuse Land cover analysis was done for three decades for the year 2000, 2010 and 2021. Landuse Changes in land cover were identified and analysed, and the loss of water bodies and forest regions became apparent over time. Because of rapid urbanisation, the larger water bodies were preserved, while the smaller ponds and creeks were gradually changed into other land uses. The development appears to be along one of the major transit lines that connects the CBD to the suburbs.

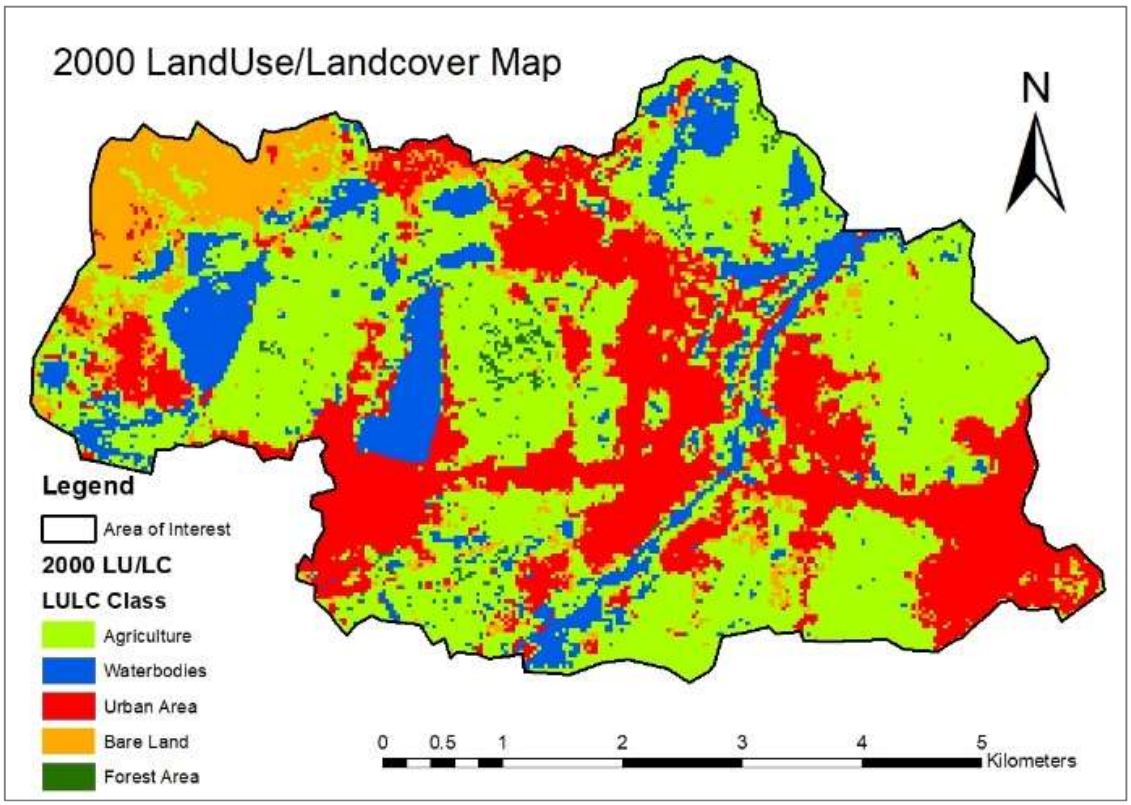


Figure 72: Landuse/Land cover Map of 2000 Year
Source: Author using GIS software

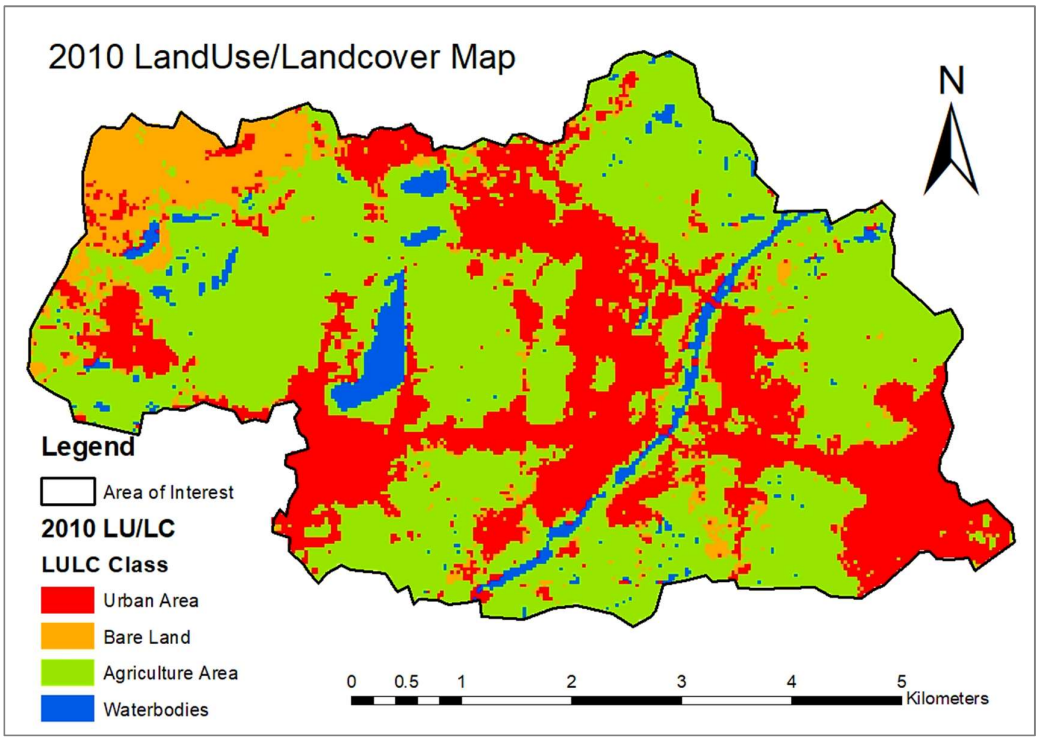


Figure 73: Landuse/Land cover Map of 2010 Year
Source: Author using GIS Software

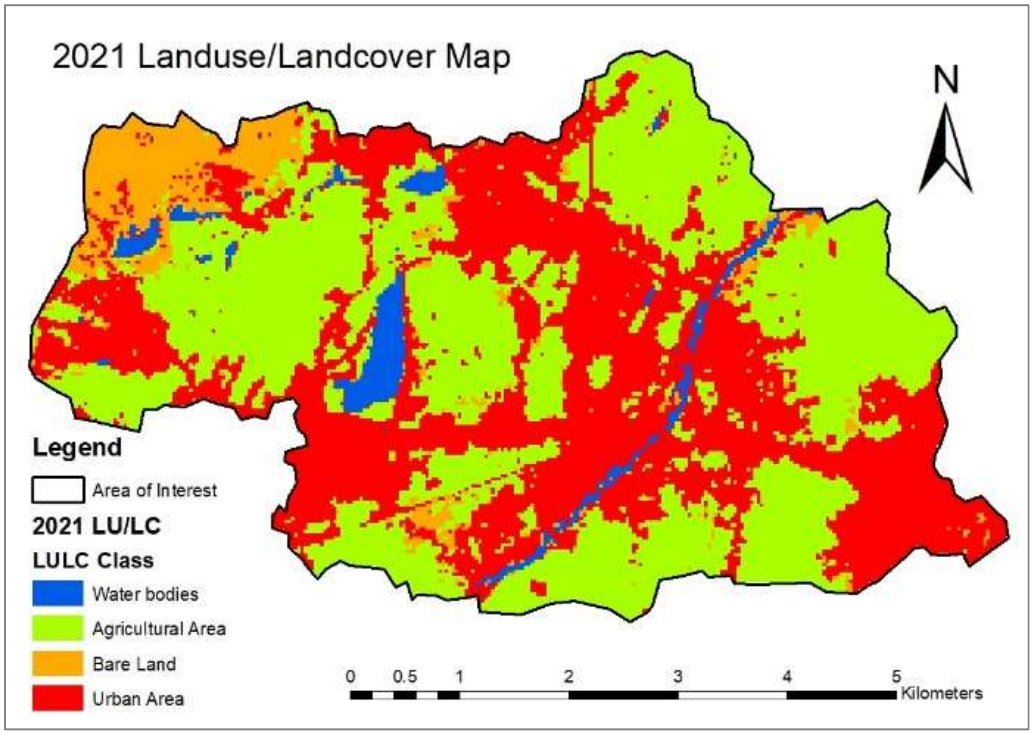


Figure 74: Landuse/Land cover Map of 2020 Year
Source: Author using GIS Software

Land Surface Temperature (LST) mapping using the Landsat 8 bands in GIS
In particular, band 10 as the thermal band, and bands 4 and 5 to calculate the Normal Difference Vegetation Index (NVDI).

1.Calculation of TOA (Top of Atmospheric) spectral radiance.

$TOA\ (L) = M_L * Q_{cal} + A_L$
→ TOA = 0.0003342 * "Band 10" + 0.1

2.TOA to Brightness Temperature conversion

$BT = (K_2 / (\ln (K_1 / L) + 1)) - 273.15$
→ BT = (1321.0789 / Ln ((774.8853 / "%TOA%") + 1)) – 273.15

3.Calculate the NDVI

NDVI = (Band 5 – Band 4) / (Band 5 + Band 4)

4.Calculate the proportion of vegetation P_v

P_v = Square ((NDVI – $NDVI_{min}$) / ($NDVI_{max}$ – $NDVI_{min}$))

5.Calculate Emissivity ε

$\varepsilon = 0.004 * P_v + 0.986$

6.Calculate the Land Surface Temperature

LST = (BT / (1 + (0.00115 * BT / 1.4388) * Ln(ε)))

Source: Ugur Avdan, Gordana Jovanovska, "Algorithm for Automated Mapping of Land Surface Temperature Using LANDSAT 8 Satellite Data", *Journal of Sensors*, vol. 2016, Article ID 1480307, 8 pages, 2016. https://doi.org/10.1155/2016/1480307

Figure 75: The methodology followed to obtain the LST map of the zone
Image Source: Author; Methodology Reference Source: Ugur & Gordana, (2016)

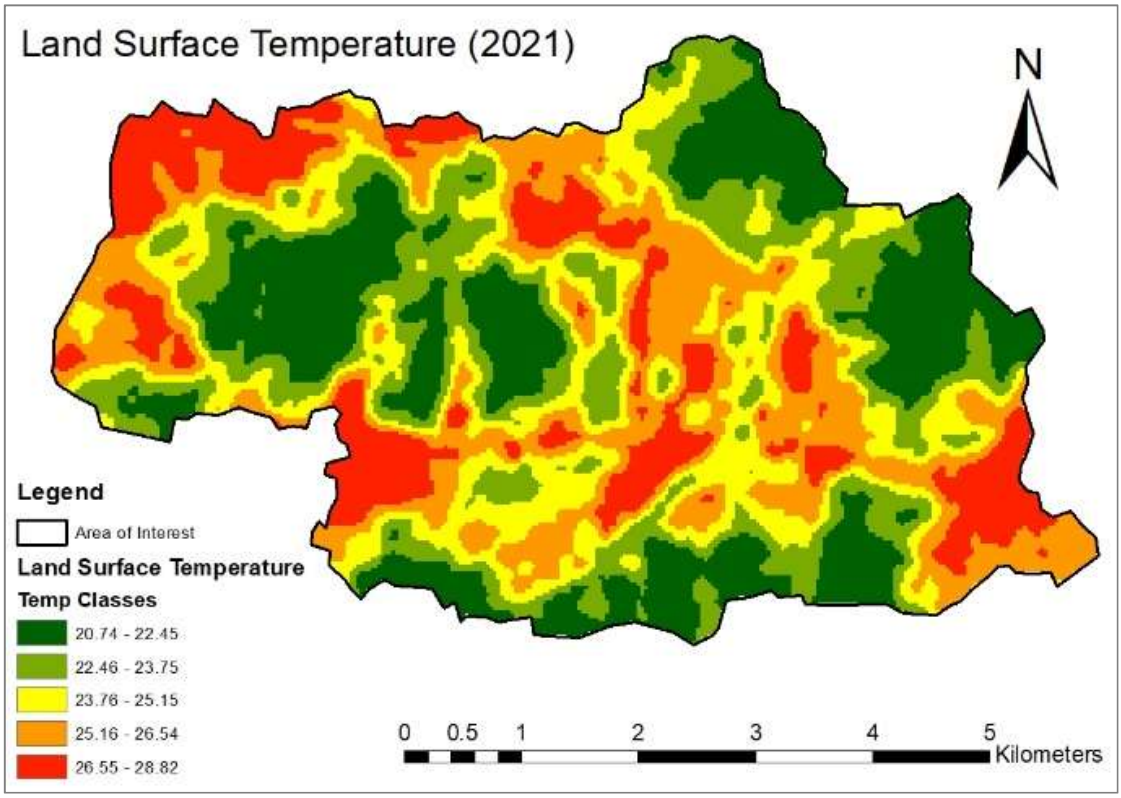


Figure 76: Maps showing the LU/LC classification of 2000, 2010, and 2021 years; and LST map
Source: Author

Between the city and the suburbs, there is a significant difference in surface temperature. The urban heat effect occurs in dense urban locations such as the old city core surrounding the

temple, the old settlement by the river, and so on, while the places around the water bodies and crops remain cooler.

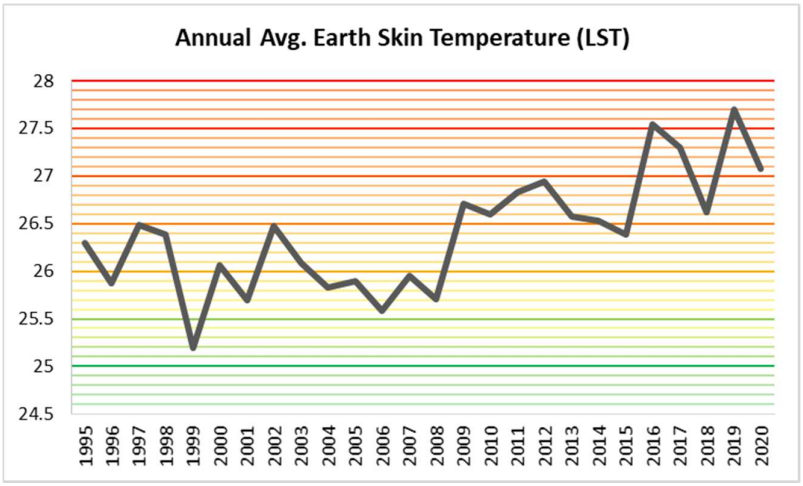


Figure 77: Chart showing the average annual Earth skin temperature from 1995 to 2020
Data Source: NASA Power

Due to rapid urbanisation, the urban heat islands are formed in the urban centres. From the chart given above, it is evident that from 2010, the temperature has raised more than two degrees in the urban settlements indicating a heat island formation. More greenery and green norms needs to be adopted to mitigate this effect.

8.9 Sewage Outfall and Contamination level analysis:

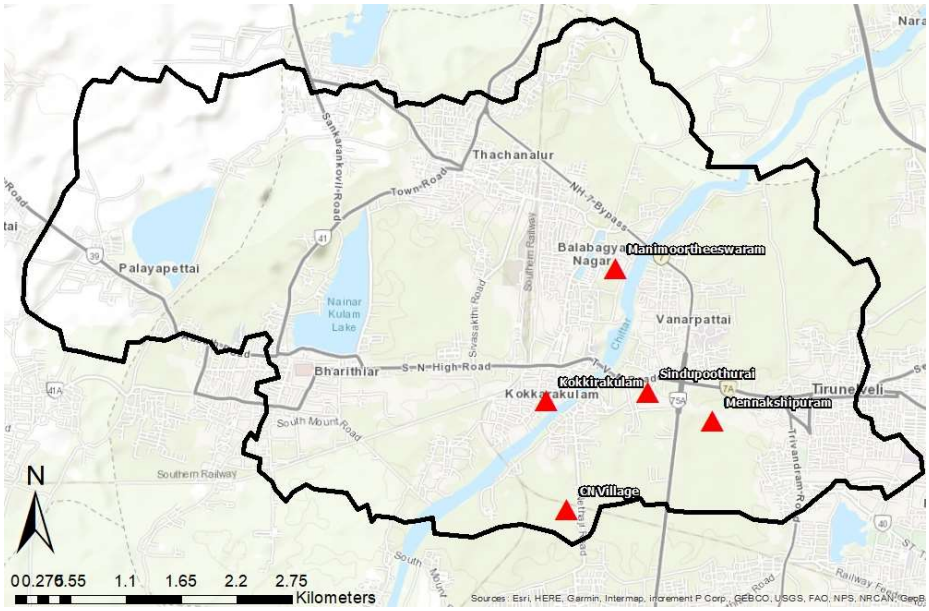


Figure 78: Sewage Outfall Spots in the study area
Source: Author

There are five sewage outfall points in the study area and The water quality of river Thamirabarani collected at the samples has been analysed in comparison with standards from the effluent discharge norms for inland surface water as per schedule –VI of E(P) Rules 1986. The water quality of the samples satisfies both class-B standard and Class-C standards (For Drinking water source with conventional treatment followed by disinfection).

BOD was found in the range 2.97 to 5.94 mg/l
Total Coliform was found in the range of 6 to 17 MPN/100ml
Fecal Coliform was found in the range of 2 to 6 MPN/100ml (Source: CPCB, Tirunelveli)

Table 25: Showing sewage outfall spots' Pollution level
Source: CPCB, Tirunelveli

Sl No	Sewage Outfall spot	pH	TDS	COD	BOD	Cu	Zn	Pb	Cd	Ni	Fe	T Cr	
Standards	Effluent Discharge norms for inland surface water as per schedule-VI of E(P) Rules 1986 in mg/l except pH	5.5 to 9.0	-	250	30	3	5	0.1	2	3	3	2	**Class-B standard & Class-C standards**
1	CN Village	7.22	124	40	3.94	0.02	0.0015	0.025	0.004	0.006	0.05	0.05	
2	Sinthupoondhurai	7.03	112	32	2.97	0.079	0.052	0.024	0.007	0.006	0.203	0.05	
3	Kokkirakulam	7.01	94	32	5.94	0.068	0.0015	0.015	0.008	0.006	0.138	0.05	
4	Manimoortheeswaram	6.7	110	40	4.54	0.038	0.017	0.037	0.008	0.006	0.05	0.05	
5	Meenakshipuram	6.77	90	32	5.74	0.085	0.118	0.025	0.007	0.006	0.017	0.05	

Where among the five spots, the picture with number 3 given below, Kokrakullam is the most polluted one when observed through reconnaissance survey. Former Executive engineer of PWD claims there is E.coli present in the river water, therefore overall the quality of the sewage water can be improved with treatment before discharging into the river.

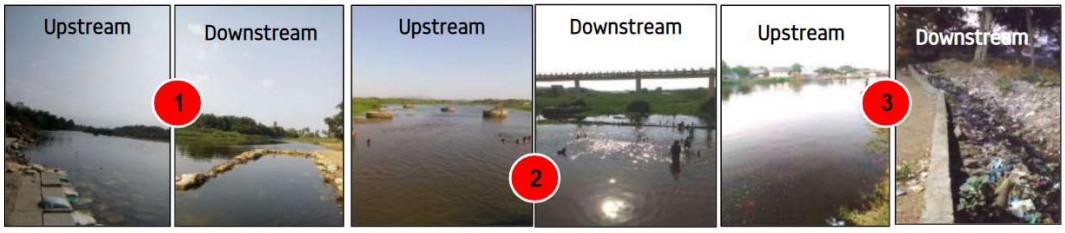


Figure 79: Reconnaissance survey pictures at sewage outfall spots
Source: Author

Also, there is 7.77 MLD gap between the water generated and the sewage water that gets treated. The 7.77MLD are discharged into the river directly through these outfall intrusion

points. This gap needs to be addressed in the intervention, and using a nature based solution could provide much more than any conventional treatment plants.

Table 26: Showing Sewage treatment Gap int the M.corp
Source: CPCB, Tirunelveli

Local Body	Total Sewage Generated in MLD	Total Sewage treated in STP in MLD
Tirunelveli M. Corp	31.97	24.2

9 Interventions to achieve the objectives:

Table 27: Showing the interventions and strategies proposed to achieve the objectives of the study
Source: Author

To achieve Objectives	Analysis	Key Findings / Present Condition	Proposed interventions and Strategies
Objective 01: To enhance the functionality of the city with Blue and green networks.	People's Perception survey analysis	Streets get water logged	**<u>Proposal 01:</u> Integration of Blue and Green in Infrastructures.** • Existing Roads are redesigned with Blue and Green elements in their ROW in five types, to improve the overall urban functionality • Existing water channels are redesigned into urban canals and urban creeks to rejuvenate as well as protect the urban bio diversity. Also to create urban oasis. • Proposal of green corridors connecting around various water bodies • They are all detailed in a pilot project around Nainar lake with fiscal plan
	Expert Opinion survey Analysis	Nainar lake has more opportunity for any pilot project implementation.	
	Water network analysis	Water channels needs to be de-silted	
	Landuse analysis	Disappearance of water bodies	
	Surface Temp analysis	Urban heat effect in the dense urban cores	

Objective 02: To reduce the water pollution and rejuvenate the water bodies	Sewage outfall pollution level analysis.	Discharge water quality needs to be improved	**<u>Proposal 02:</u> Constructed Wetlands with vertical subsurface** • Six units of Constructed wetlands are proposed in two phases. Two in Phase I and 4 in Phase II, for treating sewage.
	Gap analysis between Sewage generated and treated.	7.77 MLD gap needs to be addressed	
Objective 03: To future-proof and increase water availability of the city	Water body Seasonality occurrence analysis	Surface water availability of most tank pits are 4-6 months	**<u>Proposal 03:</u> Two Retention basins in the Watershed W2.** • Two retention basins of total volume of ~115000 cu.m is proposed in the catchment/ watershed W2 with proper Slope density planned in the neighbourhood for drainage
	Water demand Projection 2040	In 20 years, water availability and the demand meets	
	Runoff calculation	About 34% of rainwater is converted into runoff	
	Potential to increase water a availability	Potential to increase 11.89 MCM of water is possible	
Objective 04: To provide year-round recreation to strengthen the connections between society and nature as well as protect urban biodiversity	People's Perception Survey analysis	Lack of recreation spaces	**<u>Proposal 04:</u> Riparian Region Regulations and Development** • Riparian Region regulation to prevent encroachment along the flood plains. • Riparian region suitable Landuse change Proposals around the river • The Provision of Recreational spaces are in the riparian to
	Expert Opinion survey analysis	Encroachment of flood plains	
	Reconnaissance Survey analysis	Water bodies needs to be protected & rejuvenated	
		Lack of proper amenities/Facilities around the water bodies to get connected with them	

		Old settlement and Undeveloped areas around the river	increase the social connectivity with river • Green buffers and Green norms are framed with river centric planning strategies.

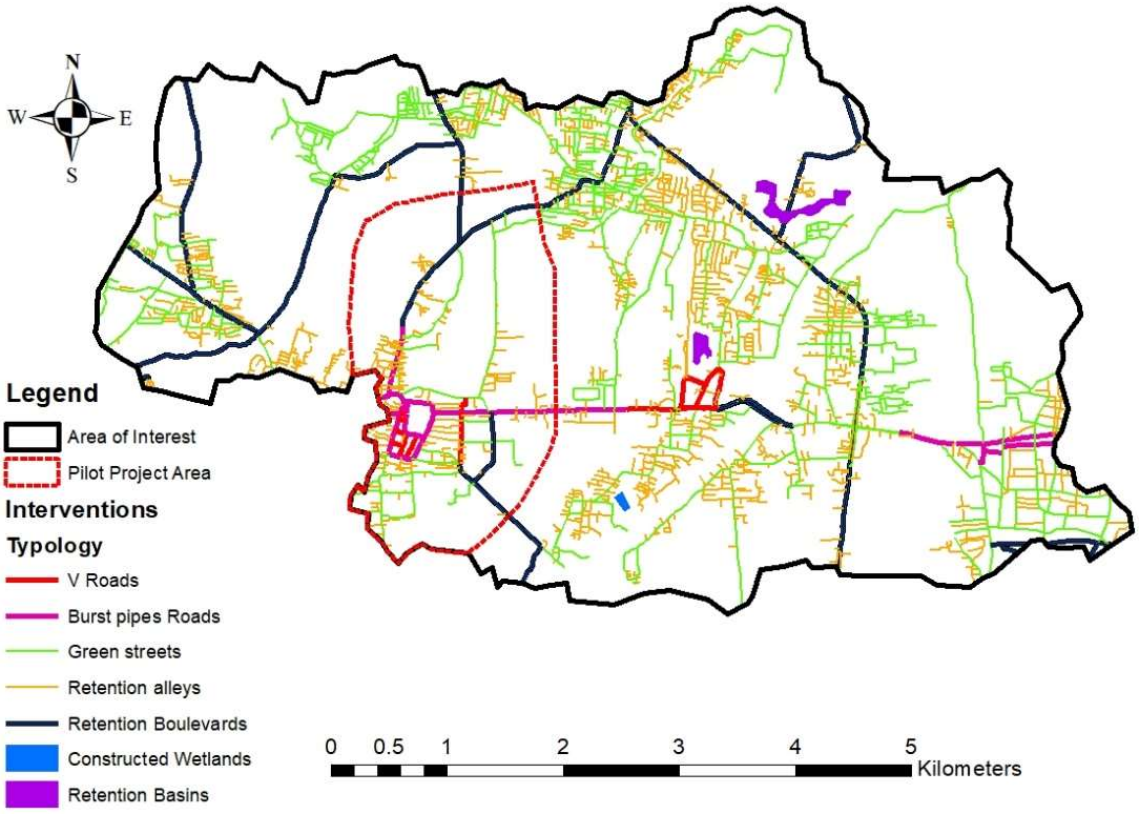


Figure 80: Map showing the Proposals and their location
Source: Author

9.1 Proposal 01: Infrastructure Improvisation with Blue and Green interactions:

9.1.1 Road Improvisation with Blue and Green elements:

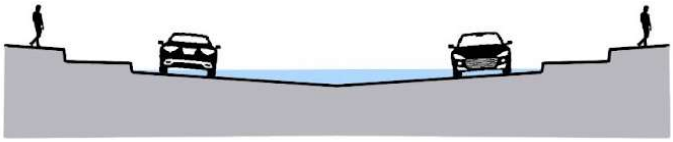


Figure 81: Typical Proposal of V roads section
Source Author

Cloudburst roads are used to channel and direct cloudburst water. These streets can be formed with a V-shaped profile and raised curbs to ensure water will flow in the middle of the road, away from the buildings. In addition, channels and swales can be established at the side of the road. *Eg: Copenhagen Cloudburst streets*

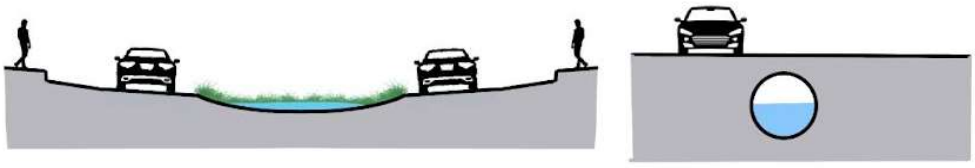


Figure 82: Typical section of Proposal of Retention Boulevards (Left) and Burst Pipe Roads (Right)
Source: Author

Retention boulevards are similar in scale to cloudburst roads, but incorporate large, green, depressed medians that can detain and retain stormwater while allowing regular traffic use of the street. They require taking away space from existing roads, but can be very effective along larger urban arteries that are underutilized. *Eg: S.A.Plads, Copenhagen*

A cloudburst pipe handles rainwater in the same way as cloudburst roads. This is placed just below street level to ensure connection to other surface solutions. This solution is used if there is limited space for above ground conveyance. *Eg: S.A.Plads, Copenhagen*

Figure 83: Typical Section of proposal of Green streets (Left and Retention Alley (Right)
Source: Author

Green streets are proposed as upstream connections to all cloudburst roads or retention areas. The green streets should be established with a combination of small scale channels and stormwater planters or permeable paving. *Eg: Watts branch, DC*

Retention alleys are typically located upstream of vulnerable low-lying areas. Detention streets allow slowed conveyance and possible retention through stormwater planters, hardscape channels, and permeable paving. *Eg: Hans Tavsens Park*

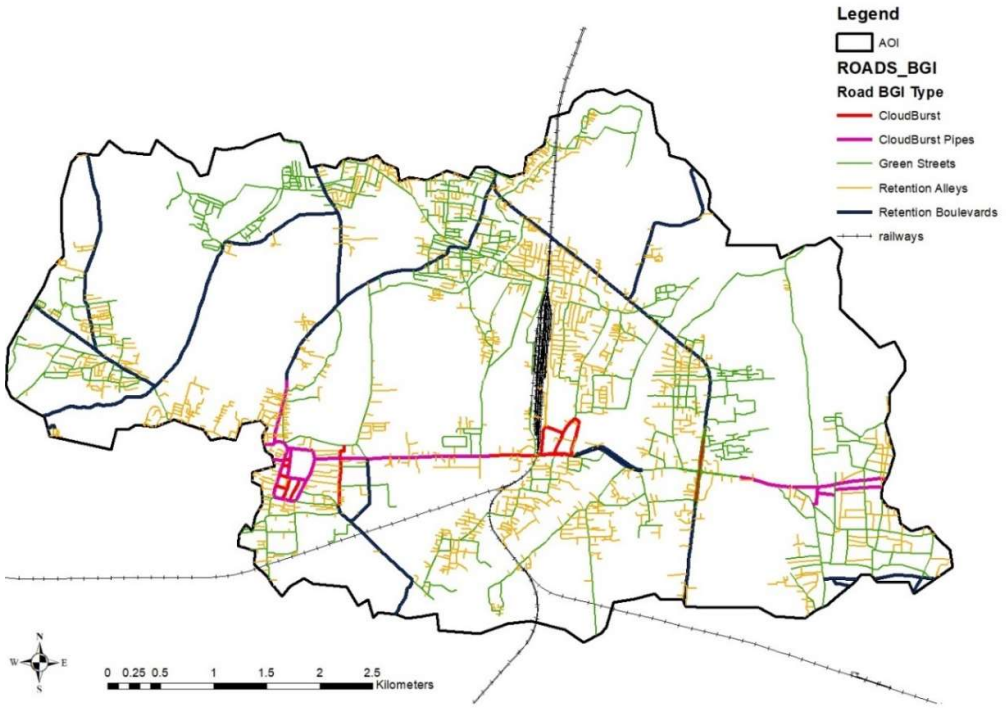


Figure 84: Road Map showing the Road improvisation with various types of roads proposed.
Source: Author

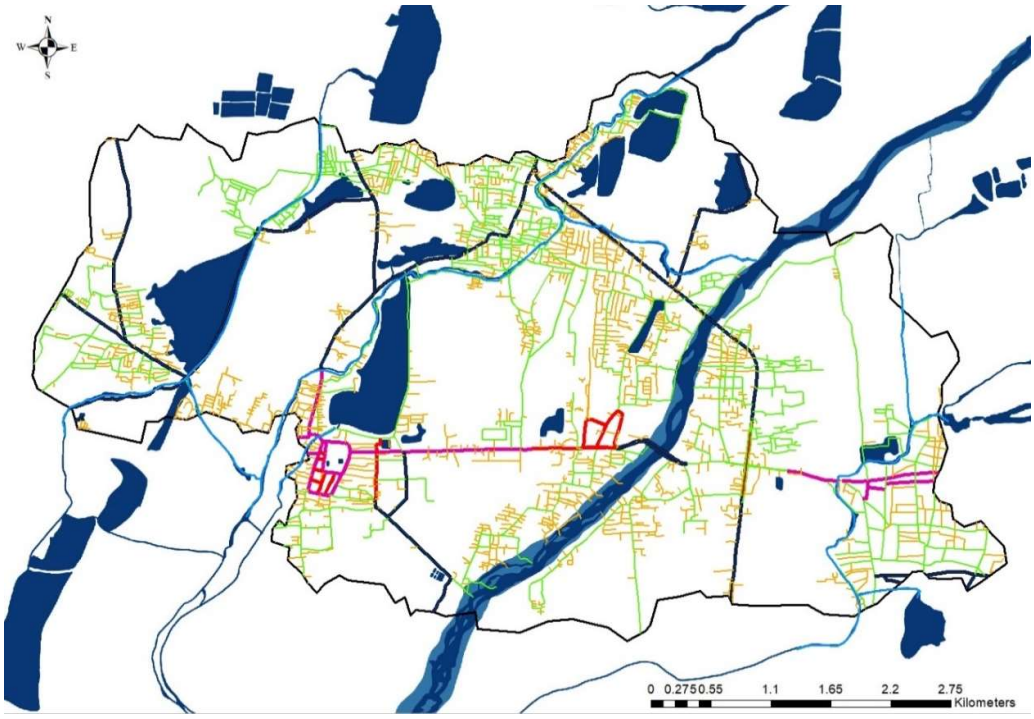


Figure 85: Map showing how roads are connected with the nearby water body for drainage of storm water
Source: Author

Table 28: The length of the road proposed.
Source: Author

Road/Street Type	Length (km)
Cloudburst Roads	4.30
Cloudburst pipe roads	6.73
Retention Boulevards	22.3
Green Streets	105.72
Retention Alleys	112.90

The BGI Road Typologies are proposed in the area of Interest after aligning with the contour. And proposed with inclination to drain the storm water to the nearby water bodies and channels. Among all the other typoogies, Green streets and Retention alley improvisation is the largest as they are implemented in the collector and local streets of the study area.

9.1.2 Water Channel Improvisation with Blue and Green elements:

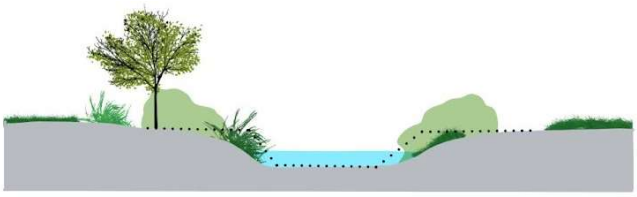


Figure 86: Showing typical section of urban creeks
Source: Author

Urban creeks can involve daylighting historic streams, as conveyance connections between other cloudburst elements. Typically smaller in scale, urban creeks can re-establish or create new neighborhood character and social spaces. *Eg: Arkadien Asperg, Stuttgart, Germany*
Urban canals are large scale infrastructure projects that typically involve day lighting of a stream/channel within a dense urban area. They can be designed to create new and healthy oases in the city while increasing biodiversity and storm water volume capacity. *Eg: Cheonggyecheon Canal, S.Korea*

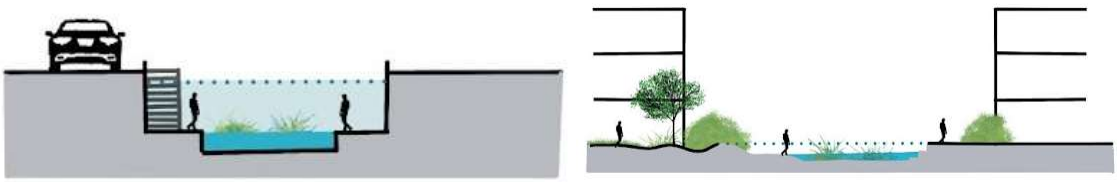


Figure 87: Showing typical section of urban canal
Source Author

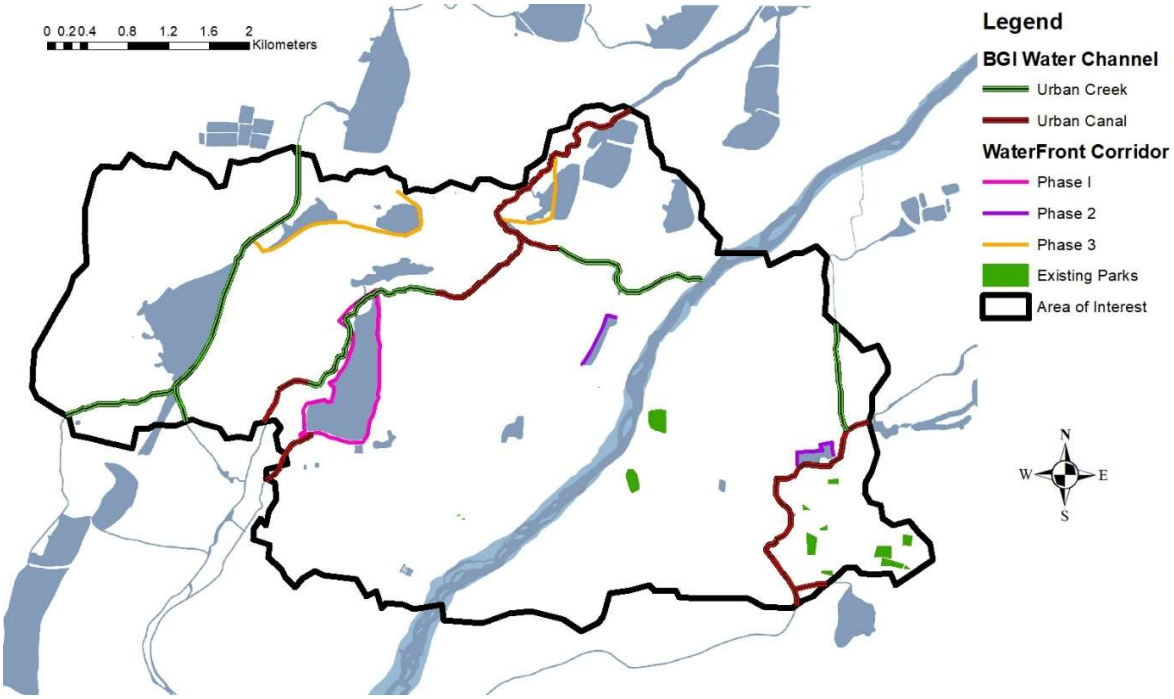


Figure 88: Map showing the proposed urban creeks and urban canals with Waterfront corridors
Source: Author

Table 29: showing the length of the water channel to be improvised with urban creeks and canal typologies. Source: Author

Water Channel Type	Length (km)
Urban Canals	8.350
Urban Creeks	9.146

Waterfront corridors are recommended in phase connecting possible water bodies, thereby creating interaction between people and water bodies, strengthening their connection with the nature.

9.1.3 Pilot Project: Implementation around Nainar Lake:

Typologies shown in the road improvisation and Water channel improvisation are demonstrated in the Pilot Project around the Nainar Lake along with its rejuvenation details.

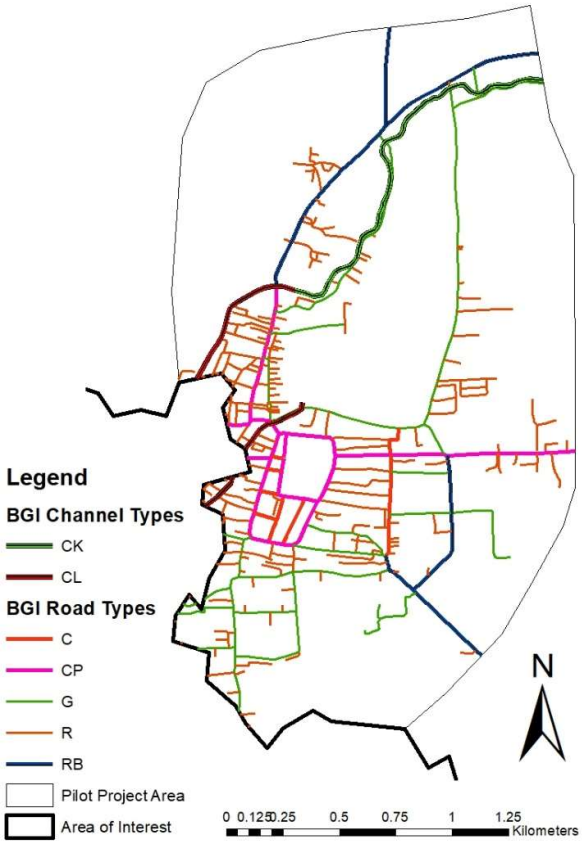


Figure 89: Map showing the proposals in the pilot project
Source: Author

Table 30: Length of road improvisation and Channel improvisation in the pilot project
Source: Author

BGI intervention in pilot project	Length (km)
V Roads	1.346
Burst Pipe Roads	3.928
Retention Boulevards	3.385
Green Streets	10.020
Retention Alley	16.627
Urban Canal	1.194
Urban Creeks	1.773

Figure 90: Sketch of footpath & overview deck proposed in the Nainar Lake
Source: Author

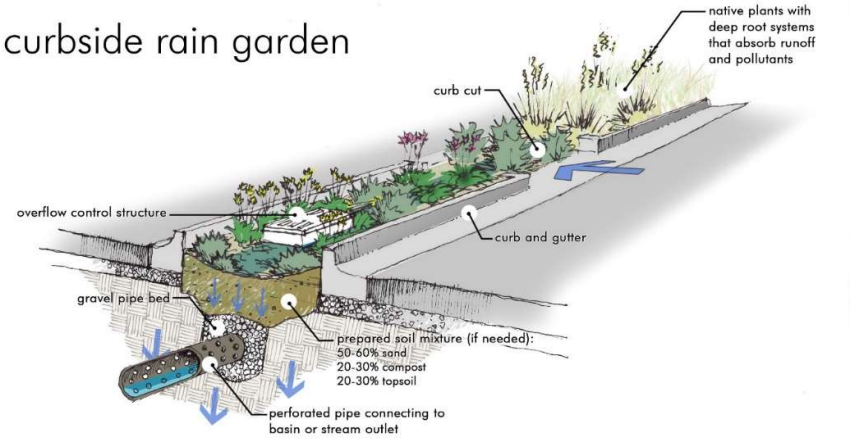


Figure 91: Bioswale Detail Sketch
Source: EDesign Lab 2017

9.1.4 Cost Estimation for the whole Pilot Project:

Table 31: Cost estimate for the Road and Channel improvisation of the Pilot Project
Source: Author

BGI intervention in pilot project	Length (km)	Estimation for one km (Rupees In Crores)	Approx. Estimation (Rs. in crores)
V Roads	1.346	15	20.19
Burst Pipe Roads	3.928	3	11.784
Retention Boulevards	3.385	18	60.93
Green Streets	10.02	10	100.2

Retention Alley	16.627	7	116.389
Urban Canal	1.194	15	17.91
Urban Creeks	1.773	8	14.184
Estimation for the Pilot Project – Road & Channel Improvisation			341.587

Rough estimate for one km of road improvisation and channel construction were studied and approximate amount of 341.6 crores estimation has been given here for the pilot project road and channel improvisation with blue and green elements. The following is the particulars and cost details of the Nainar lake rejuvenation, the cost estimation for each particulars has been taken in reference with "Kavoor Lake development of Mangalore", to the 2km Perimeter length and 168 Ha ayacut of the Nainar lake.

Table 32: Detailed Cost estimate of the Nainar Lake Rejuvenation
Source: Author

Particulars	Cost in INR
Civil work including UGD, SWM, Lake Improvement and Horticulture (168 ha)	5,57,24,000
Bird watching tower	2500000
Redesign of Picnic Deck	1200000
Boating amenities	500000
10 Over view decks every 200 m	1550000
Leisure Park	6055000
Construction of 3 Toilets	1500000
Electrical Work	3240000
Plumbing Work	540000
	7,28,09,000
Contingency 5%	3640450
Miscellaneous and Rounding off	3550550
Grand Total of rejuvenation of Nainar Lake	8,00,00,000

Total Grand of 8 Crores is estimated for the Nainar lake Rejuvenation with recreational leisure spaces around it. Summing up, a total of 367 Crores is estimated for the pilot project.

Table 33: Grand Total Cost estimation of Pilot Project with all BGI interventions
Source: Author

Intervention in Pilot Project	Cost Estimation (Rs. in Crores)
Road Improvisaiton	309.493
Channel Improvisation	32.094

Contingency & Misc 5%	17.08
Nainar Lake Rejuvenation	8
Total Estimation of Pilot Project	366.667 Crores

9.1.5 Revenue Generation for Nainar Lake rejuvenation –Pilot Project:

Table 34: Revenue generation from entry fee in Nainar lake pilot project
Source: Author

Estimate of revenue to be generated from entry fee			
Population of M.Corp	**Population preferring to visit rivers/water bodies**	**Population willing to pay for recreation**	**Annual trips made**
100%	61.60%	93.00%	
4,73,637	291760.39	271337.16	
Frequency of trips for recreation:			
	No of Days	**Response**	
Daily	365	6%	5942284
Weekly	52	22%	3104097
Twice a week	104	9%	2539716
Fortnightly	24	5%	325605
Monthly once	12	32%	1041935
Once in three months	4	26%	282191
Total annual trips made			**13235827**
Estimated annual revenue to be generated (with basic fee of Rs.20/-)			**264716537.7**
			Rs. 26.47 Crores per annum

This could be taken as an example and many water bodies can rejuvenated with recreation facilities around it, and revenue can be generated for each of the walkways.

9.2 Proposal of Retention Basins:

With 11.89 MCM of runoff available from the rainwater, to increase the water availability, two retention basins are proposed in the low lying elevations in the middle of urban settlement. The area zone is in the catchment W2. In the comparison of LULC of 2000 year and 2020 year, two water bodies have disappeared over the decades in the effects of urbanisation.

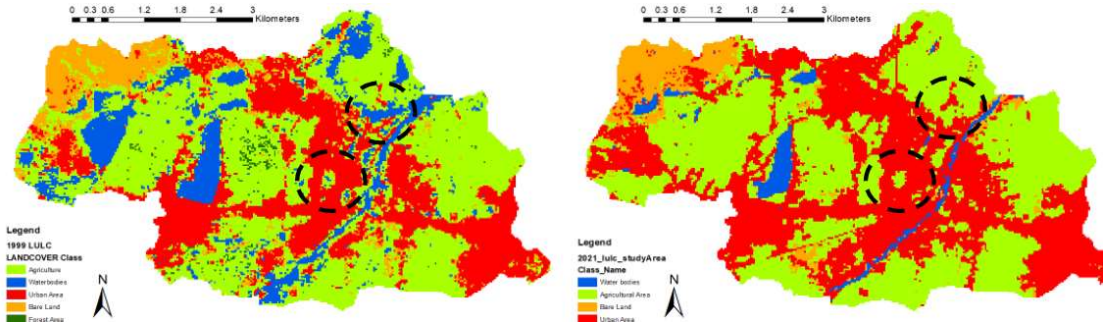


Figure 92: LULC Map of 2000 and LULC Map of 2020 showing the disappearance of two waterbodies
Source: Author

These retention basins were aligned with contours to find that they were in the low lying areas of the elevation in the study area, there by feasibility of accumulating the strom water is possible, making it suitable for the proposal.

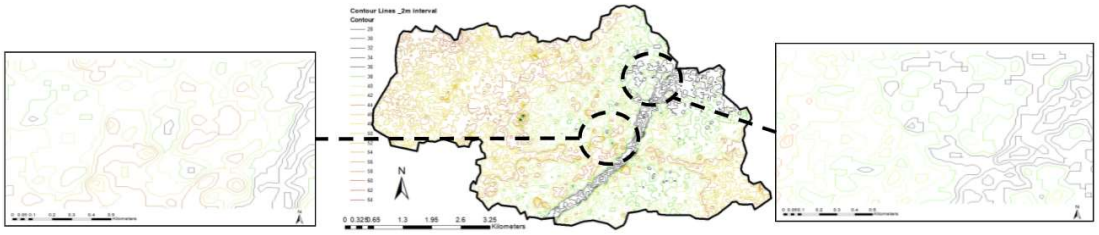


Figure 93: Showing the low elevation of the chosen area for retention basin
Soruce: Author

Table 35: Volume, Are, Depth and Cost estimate of the retention basin
Source: Author

Retention Basin	Volume (cu.m)	Area (sq.m)	Depth (m)	Approx. Cost Estimated for the R.Basin
1	191436	31906	~6.00	10.6 Cr
2	143577	93508	~4.50	9 Cr
Total	335013			20 cr

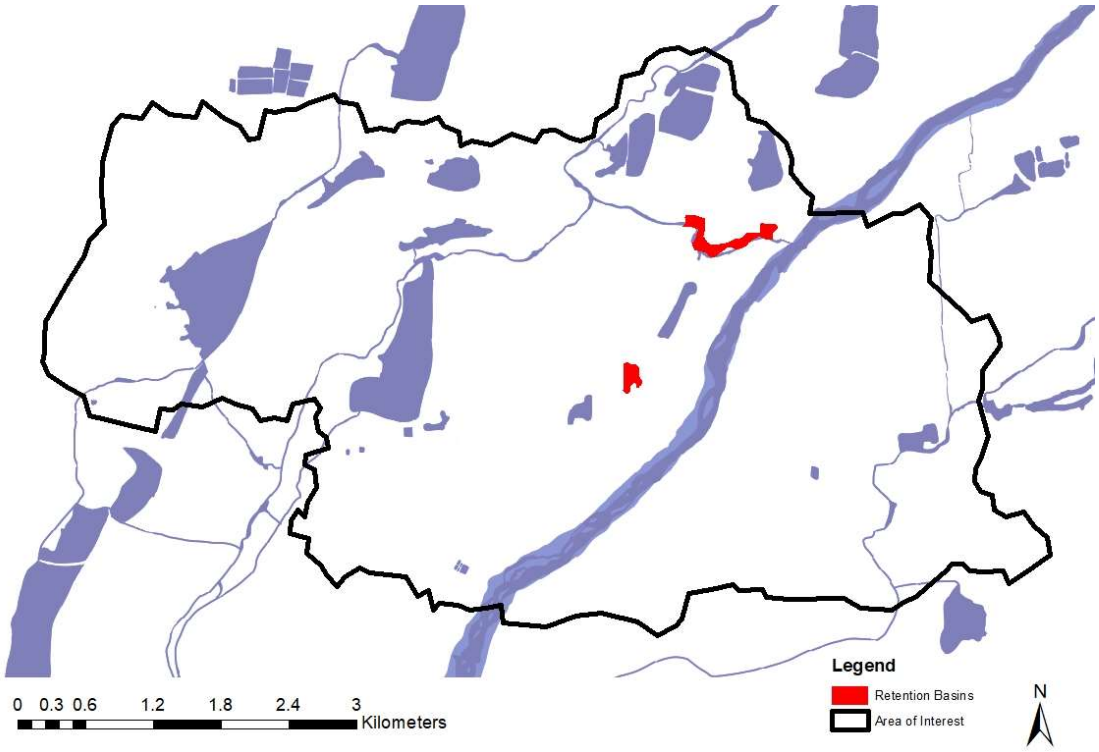


Figure 94: Map showing Placement of Retention Basin in the study area
Source: Author

9.3 Proposal of Constructed Wetlands with Vertical Sub-surface Flow

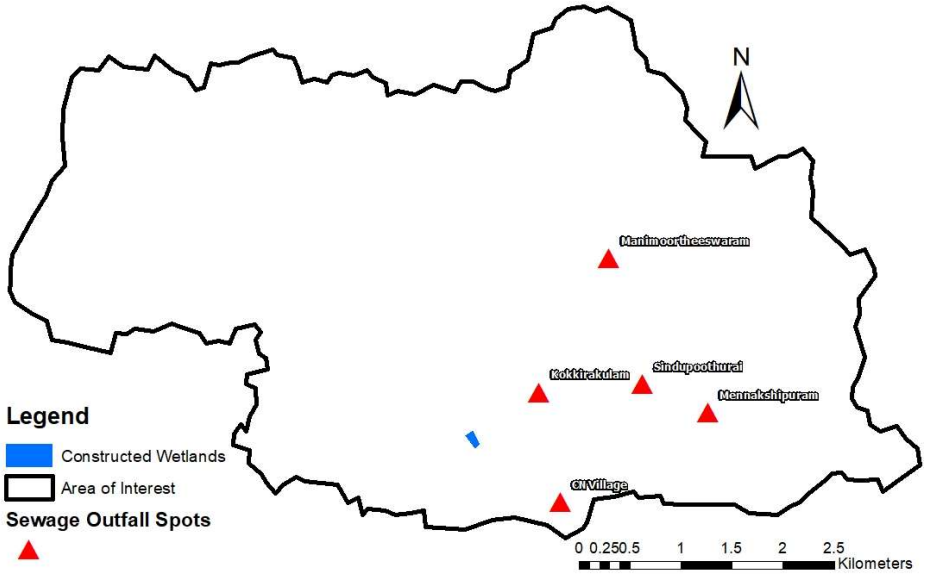


Figure 95: Map showing the proposal of Constructed wetland and the proximity with the sewage outfalls
Source: Author

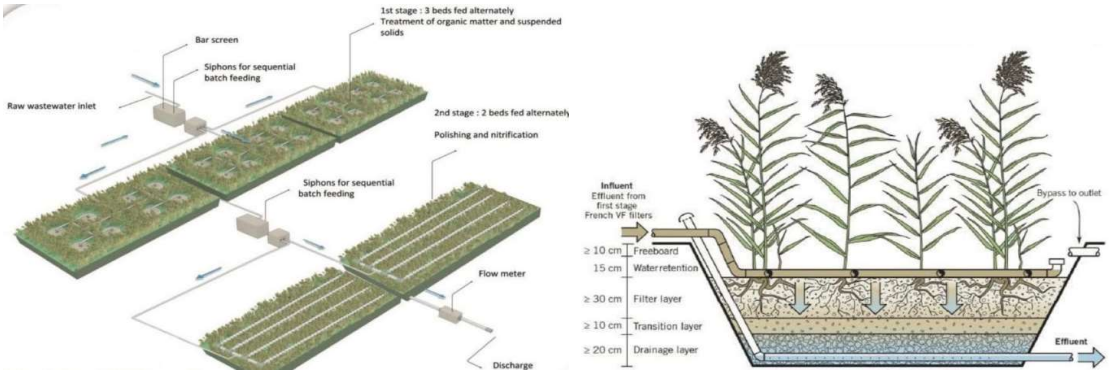


Figure 96: Recommended design adopted from the UN-Habitat manual
Source: UN habitat wetland manual

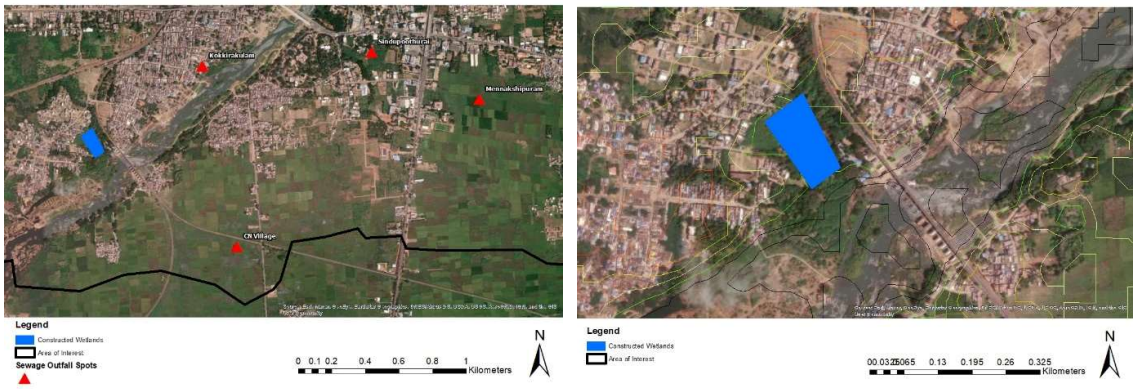


Figure 97: Satellite image of placement of constructed wetlands
Source: Author

Table 36: Area calculation for the constructed wetlands' Vertical flow bed according to UN Habitat Manual
Source: Author

Population equivalent (Specific waste water flow per person per day)=	80	litres
Average volume of Waste water =	7770	cu.m/d
Sewage treatment gap in Municipal Corp. is 7.77 MLD		
BOD -5 Concentration =	40 g * (BOD5)/(PE.D)	
BOD5 Concerntration =	40*1000/80	mg/l
BOD5 Concenration=	500	mg/l
Lets assume 30% of BOD is removed by primary treatment unit, then the influent BOD5 concerntration to the wetland (Ci)=	500 -(500*30/100) mg/l	

Ci=	350	mg/l
Effluent BOD5 Concerntration (Ce)=	30	mg/l
K-BOD (For VF Wetland) =	0.2	m/d

By substituting the values in the formula, the area of 95444.18 sq.m for vertical flow bed is:

$$A = \frac{Q(\ln Ci - \ln Ce)}{K}$$

Area of VF=	95444.18	Sq.m

A single CW with 600 kld capacity is recommended, therefore we need set of 6 units of VF-CW with each 7320 sq.m, are recommended. Implementation can be done in two phases with units of two CWs in the phase 1 and units of Four CWs in the phase 2.

Table 37: Area requirement of all units in Constructed Wetland
Source: Author

Area of VF bed	~95500 sq.m
Settler/ Primary Anaerobic Setting tank	3850 sq.m
Polishing pond	7770 sq.m
Total Area Needed	~111000 sq.m

Table 38: Cost Estimation for the Constructed wetland (6 units in two phases)
Source: Author

Generally cost of installation of CW for 8-10 KLD with cost 2.5-3 Lakhs and Annual Operation and maintenance cost Rs.5000 for 10 KLD *(Centre for science and Environment, 2022)*		
	Installation Cost	Operation /Maintenance Cost per Year

For 1 KLD	Rs. 30000 (Max)	Rs. 500 (Per Year)
For Phase 1 1200 KLD	Rs. 3.6 Crores	Rs. 6 Lakhs
For Phase 2 6570 KLD	Rs. 19.71 Crores	Rs. 32.85 Lakhs
Total	Rs. 23.71 Crores	RS.38.85 Lakhs
Total + Misc	Rs. 24 Crores	

"The plants influence the level of oxygen in the wetland bed, enable physical filtration, prevent VF-CW systems from getting clogged and offer a large surface area for microbial colonization" *(Brix 1994a, 1994b, 1997)*

***Table 39:Recommendation of Native plants for the removal of pollutants in the wetland sewage treatment Source:* (Brix 1994a, 1994b, 1997)**

Other Most Commonly Used "macrophyte" in subsurface flow constructed wetlands in the world		
1	Phragmites australis	Europe, Canada, Australia and parts of Asia and Africa
2	Typha (e.g. latifolia, domingensis, orientalis and glauca)	North America, Australia, Africa, and East Asia
3	Scirpus (e.g. lacustris, validus, californicus and acutus)	North America, Australia, and New Zealand

Figure 98: Image of Napier grass: recommendation of plants in the CW-VSSF
Source: Wikimedia, creative commons.

The use of **Napier grass (Pennisetum purpureum)** in VF-CWs has been recommended for the treatment of greywater in India *(Pillai & Vijayan 2013).* It is suitable for the growing in Tirunelveli, Tamil Nadu

9.4 Proposal of Riparian Region regulation & Development:

Figure 99: Provision of nature trails in the riparian region and 300m green buffer around the flood plains
Source: Author

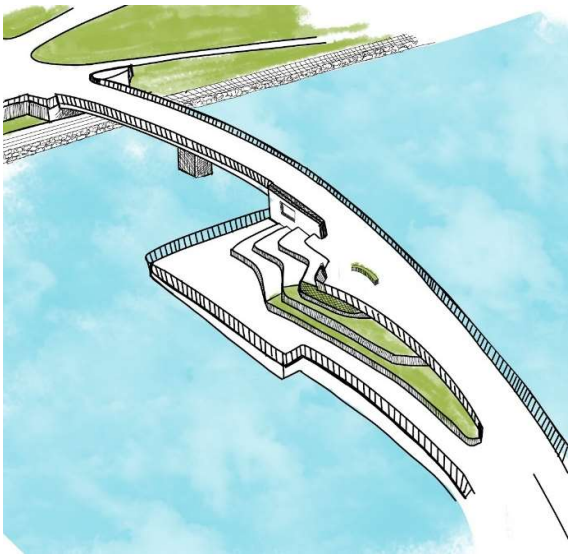


Figure 100: Sketch for the redesign of Bridge, with a over-view deck
Source: Author

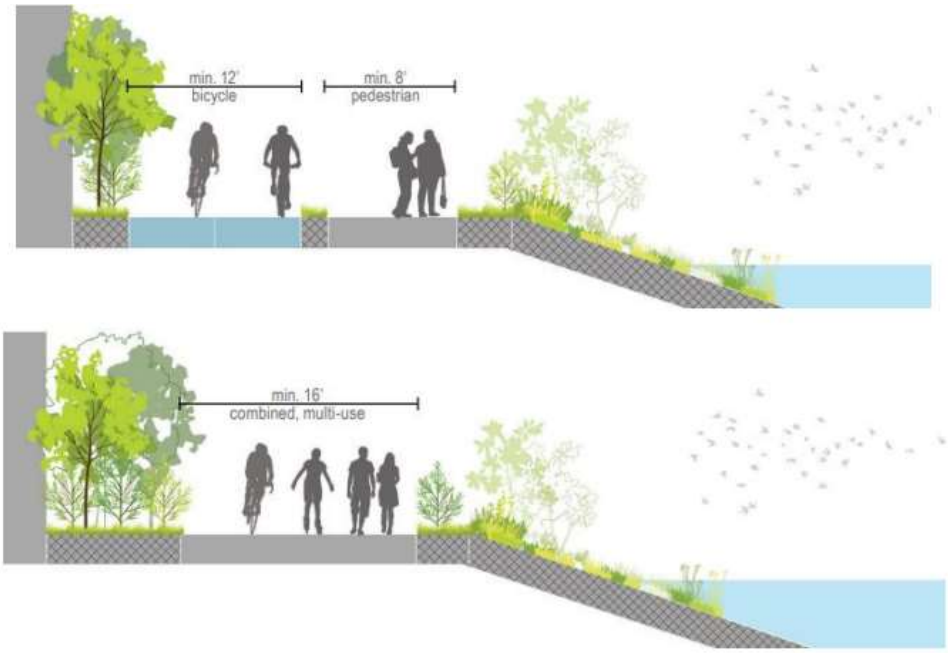


Figure 101: Sections of the footpath on the River bank corridors
Source: Author

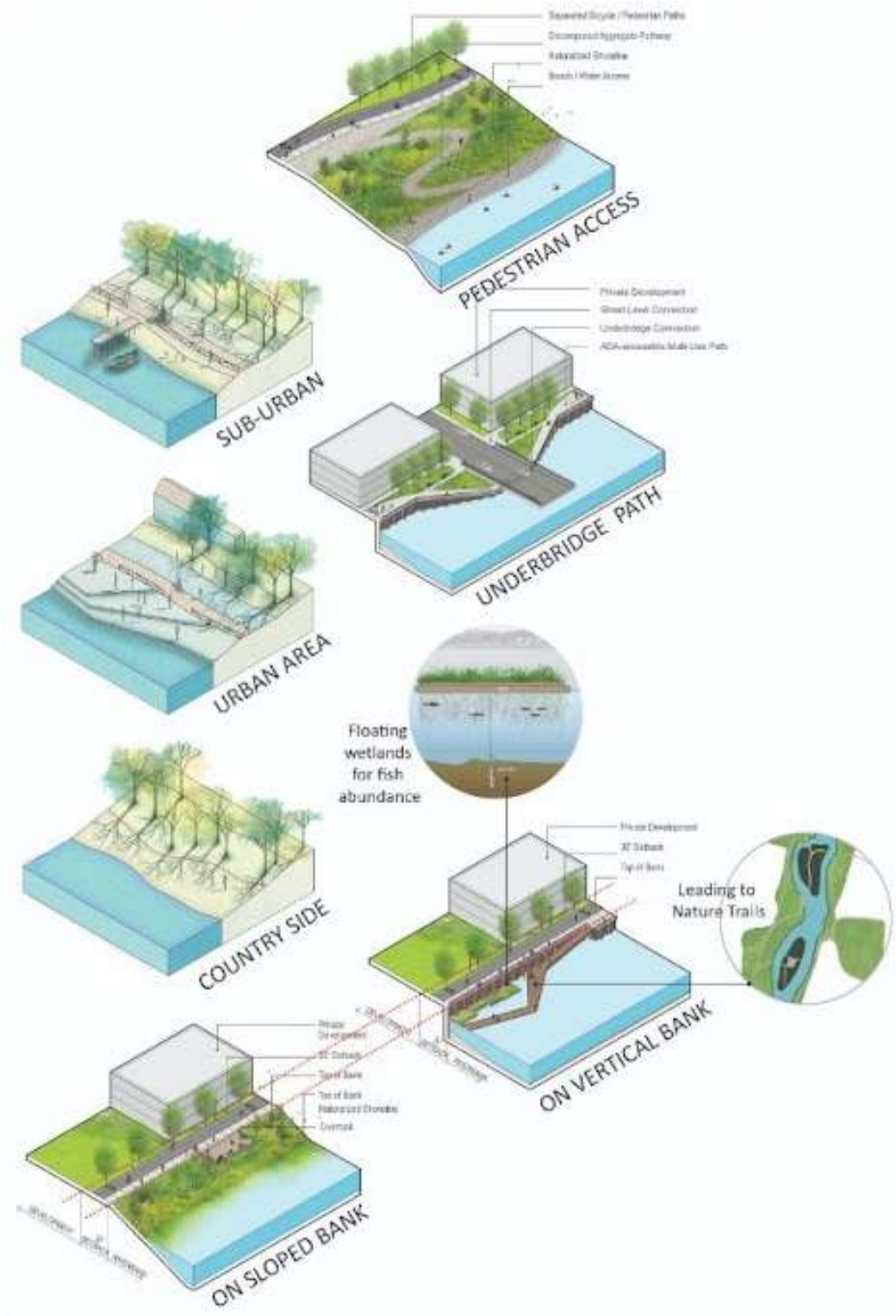


Figure 102: Collection of Riverbank Designs
Source: Author

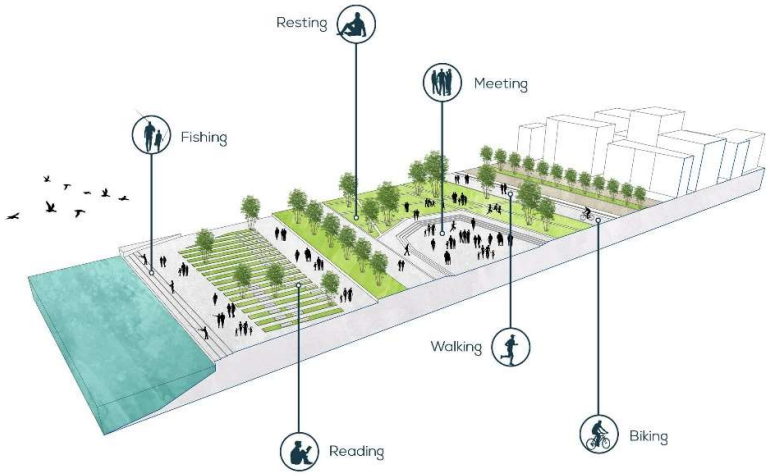


Figure 103: Northwest Bank Park of the River
Source: Author

Figure 104: Fish Hotels
Source: Author

Steel wire mesh with nylon ropes are hung from over decks for algae formation for fish habitats, thereby forming the Fish Hotels. This can be done in River as well as in Lakes and Ponds, as they can be hung from structures like overview deck, bridges, Poles etc.

The Riparian Region can aligned with the "Blue-Green Policy of Delhi Master Plan 2041" with the following focuses on it regarding the river and waterbodies:

i) Enhancing the value of rivers*:*

- Species that degrade the riparian region are recommended to be restored with native flora and fauna species
- Tree Planting and Reforestation along the banks of the river is recommended for rich biodiversity enhancement for environments
- Through the Constructed Wetland (VSSF) management, Sewage outflows into river are carefully scrutinized. Biological purification of rainwater from the storms through CW is ensured.

ii) Strengthening the bond between society and nature:

- Nature Trails during low river water level are provided in places with nature based solutions to enhance the relation between community and the river.

- Increased recreational provision along the flood plains, with greenways and cycle tracks are recommended..
- "Active and passive recreational activities" such as educational trips to the nature, wildlife tours, camping, workout in the parks and service areas to be carried out for effective awareness.
- Wetlands to have "No public access" to the fragile areas of the ecosystems.
- The existing park near the River is to be considered as a part of the recreation program to increase the footfall and generate more revenue.

iii) Interventions for the Green:

- A three hundred meter "buffer" needs to be provided and greened to preserve the river.
- To strengthen the bond between people and the river, a green corridor of two hundred meter is to be provided.
- Proper re-stilting of the "wetland" and planting trees to ensure the debris from being fed into the river and to control the contamination; ultimately "restoring the ecosystem"
- Green roofing the government buildings and Temples

9.5 Policy Recommendations for Tirunelveli:

- Zero Tolerance Policy for Combined sewer overflows (CSOs) (with the help of govt proposed UGSS & Proposed Road Improvisation intervention)
- River bank Protection Policy,
  From -encroachment,
  -foreign species,
  -Non-naturalised shorelines,
  -direct waste discharge,
  -dumping of wastes.
- Zero Plastic Pollution Policy
- Permeable streets Policy
- Water quality Milestones
- Overflow Action Days Ordinance
- Alignment with "Blue-Green Policy of Delhi 2041"
- Promotion of Green Norms in Building Construction through FSI Incentives, to increase the Green cover of the area
- Tax Exemptions for Buildings Green roofing 70% or 500 sq.m and Special tax incentives for solar proofing the rooftop.
- Compulsory Green/Solar Proofing in every Govt Building and Temple structures
- Mandatory/Strict Regulation in Rainwater Harvesting, (Year 2005, Amendments made to Section 215 (a) of the Tamil Nadu District Municipalities Act, 1920 and Building Rules 1973)
- Preservation of wetlands under National River Conservation Plan.
- River Protection Community under Nellai Neervalam Plan.

9.6 Fiscal Planning for the Interventions:

Table 40: Funding pattern, Phasing and Implementation agency details of the Proposals
Source: Author

	Name of Proposal	Policy/ Schemes Convergence	Implementing Agency	Funding Pattern (%)			Phasing & Cost (in Rupees)		
				Central	State	District	Short Term	Medium Term	Long term
1	Road BGI Improvisation	TURIF, AMRUT	PWD	75	25		310	1500 Cr	690 Cr
	Channel Improvisation	Nellai Neervalam	WRD-PWD	70	20	10	6 Cr	32 Cr	165.51 Cr
	Nainar Lake Rejuvenation	Nellai Neervalam	WRD-PWD		50	50	8 Cr		
2	Retention Basins	Nellai Neervalam	ID & WRD	70	20	10	20 Cr		
3	CW-VSSF	AMRUT	Tvl M.Corp	70	30		4.2	20.03 cr	
4	Riparian Region Development	NRC Plan (MoEFCC), TN	Tvl. M.Corp, PWD, NN	75	25		25 Cr	10 Cr	
5	Green Provisions	Smart City Mission	PWD		70	30	5 Cr	5 Cr	

10 Conclusion

This project tries to deal with some of the most common issues and problems associated with the urban rivers and water bodies of the Indian cities through interventions integrating both blue and green elements of the cities. It addresses issues and topics like water pollution, flood risks, water availability, urban biodiversity degradation, negligence of importance of water bodies, lack of citizen engagement with urban rivers, flood plain encroachments, etc.

The Rejuvenation of the whole water network with the integrated the Blue-Green network as a solution - aims protect as well as enhance the hydrological and ecological values, and future proofs the environment for climate change adaptation and prevents further loss of water bodies and vegetation. The interventions and strategies given enables the environment to be sustainable for a long term, as blue elements help strengthen the green to flourish.

Rejuvenation of lakes and tanks is an important step in an important step in recharging the groundwater and therefore it is high time that the government take steps to rejuvenate and protect the water bodies. India, in spite of being a signatory to Ramsar Convention on wetlands and the convention to Biological Diversity, there is no significant development towards sustaining these ecosystems, either due to lack of the values of wetlands among the policy makers and implementing agencies. The effective management of these wetlands requires a thorough appraisal of the existing laws, institutions and practices. The involvement of various people from different sectors is essential in the sustainable management of these wetlands

The interventions detailed out in the Pilot projects with Fiscal Planning - serves an example for such Blue-green proposals to be practised in any Indian city context.

A clear understanding with accurate knowledge and increased awareness of conservation methods for water bodies and wetlands among the stakeholders help in long term conservation of these fragile ecosystem. This would also enhance the function and value of the system in terms of natural and socioeconomic factors to satisfy critical resource needs of the human population.

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12 Annexure

12.1 People Perception Survey Questionnaires:

SURVEY QUESTIONNAIRE

BLUE- GREEN INFRASTRUCTURE NETWORK IN TIRUNELVELI

INSTRUCTIONS:

QUESTIONNAIRE ID NO:
SURVEY AREA:

Name of the students: Karpagavalli S

*The purpose of this survey is to collect data for my Master's Thesis research at Indian Institute of Technology, Kharagpur. The topic is on Blue-Green Infrastructure as Network of Spaces for Well-being of Urban Residents. This survey is to be filled in by urban residents in Tirunelveli town that have experience using the blue-green infrastructure network within the town. The study was set up to give better understanding on the uses of blue and green infrastructure and its effects to the residents. Blue-**Green infrastructure** is water bodies and greenery or open spaces linked by streets, waterways and drainage ways around and between urban areas, at all spatial scales. **Social spaces** such as home gardens are spaces that have direct relationship with urban residents, in which these are the spaces where the interaction between urban residents happen, either as individuals or in groups.*

Please answer the questions as accurately and completely as possible. The answers should reflect your experience in Tirunelveli. The answer responses from the survey questionnaire are strictly for research purposes.

COLLEGE:

Indian Institute of Technology, Kharagpur.
Architecture and Planning department
Master of City planning

ADDRESS:
18/1, Perumal North Car street, Palayamkottai- 627002

CONTACT NO:
Tel no: 8220033235
e-mail add: venilite@gmail.com

SECTION 1: PERSONAL INFORMATION

Tick (√) the box and fill in your answer in the provided blank.

Q1. Name of the applicant:

Q2. Gender:
□ Male □ Female

Q3. How old are you?
.....

Q4. Where do you live in Tirunelveli?
.....

Q5. How long have you been living in Tirunelveli? .....

Q6. Highest level of education:
□ Primary school
□ Secondary school
□ College graduate
□ University graduate
□ Others, please specify
.....

Q7. Occupation: (If applicable)
□ Professional and technical
□ Administration and managerial
□ Educational
□ Business
□ Agricultural
□ Service Job
□ Manufacturing
□ Others, please specify…….....

Q8. Monthly income in rupees: (If applicable)
□ 5000 – 10000
□ 10000 – 20000
□ 20000 – 30000
□ 30000 – 40000
□ 40000 - 50000
□ 50000 and above.

SECTION 2: USE AND FAMILIARITY OF BLUE- GREEN INFRASTRUCTURE

Q9. Where do you go for leisure outdoor activities in Tirunelveli?

……

Q10. Please tick (√) the blue-green infrastructure that you visit for activities in Tirunelveli.
(You can choose more than one answer).

- VOC Ground.
- Other Parks or Green open spaces
- District Science Centre.
- Open space near waterbodies if any ……
- Streets and green spaces along shop houses
- Open spaces in your residential area and home gardens (e.g. playground and football field).
- Pocket space of historical, institutional and government buildings (e.g. library, hospital, school, college, Nellaiappar temple).
- Pocket space in town centre (e.g. Bazaar spaces like Palay Markets & Maidhan, Bazaar Around Nellaiappar temple, South Bazaar).
- Green spaces along river (e.g. Thamirabharani river).

List other space(s) that you use for activities other than the above, if any ……

Q11. Do you frequently use the blue- green infrastructure in Tirunelveli?

Yes No

Q12. How frequently do you use the blue-green infrastructure?

- Twice a week
- Once a week
- Once fortnightly
- Once a month

Others, please specify ……

Q13. I like spending time in the blue- green infrastructure:

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Like it alone	5	4	3	2	1
With family	5	4	3	2	1
With friends	5	4	3	2	1
With neighbours	5	4	3	2	1
with significant others	5	4	3	2	1
With acquaintance who is local resident	5	4	3	2	1

SECTION 3: PROPERTIES AND ATTRIBUTES OF GREEN INFRASTRUCTURE

Q14. What mode of transportation you use to get to these blue-green spaces (e.g. to the Thamirabarani River)?

……

Q15. Why do you use the route mostly preferred to get to blue-green spaces? (You may tick more than one choice).

- The road is the fastest and shortest ways to town.
- The trees and greenery along the road are nice.
- The signage is easy to read.
- The buildings are attractive.

Other(s), please specify. ……

Q16. Features important to you for reference to get to places in Tirunelveli.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Buildings (e.g. shop houses, Temples, museum, Palay Jail).	5	4	3	2	1
Signage	5	4	3	2	1
Agriculture lands and forests	5	4	3	2	1
Thamirabharani River and water bodies	5	4	3	2	1
Institutional and governmental buildings (library, hospital, schools)	5	4	3	2	1
Streets (e.g. Bazaars, Palay Markets, Nellaiappar temple bazaar).	5	4	3	2	1

Q17. How much do you agree or disagree that the following blue-green space can act as **landmark (point of reference)** for Tirunelveli? (Circle your answer).

Feature	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
a) Thamirabarani Town Bridge	5	4	3	2	1
b) Water bodies and Tankpits	5	4	3	2	1
c) District Science Centre	5	4	3	2	1
d) Open space in town (e.g. Palay Maithanam).	5	4	3	2	1
e) Streets and green spaces along shop houses (e.g. Bazaar and Agricultural Pocket Lands)).	5	4	3	2	1
f) Open spaces in your residential area and home gardens (e.g. playground and football field).	5	4	3	2	1
g) Pocket space of historical, institutional and government buildings (e.g. library, hospital, school).	5	4	3	2	1
h) Pocket space in town centre (e.g. Bazaar spaces like Palay Maerkets & Maidhan, Bazaar Around Nellaiappar temple, South Bazaar).	5	4	3	2	1

Others, please provide the name of the place, if any..... ....

Q18. How much do you agree or disagree with the following statement about properties and attributes of green infrastructure in Tirunelveli?

Properties and Attributes of Green Spaces	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Diversity					
a) Tirunelveli has a variety of blue and green …….spaces	5	4	3	2	1
b) Blue- Green infrastructure offers variety of activities.					
c) Blue- Green infrastructure rich in types of scenery.	5	4	3	2	1
d) Quantity of the blue- green infrastructures attracts me to engage in outdoor activities	5	4	3	2	1
e) Blue- Green infrastructure's conduciveness to a variety of activities induces residents to be outside home	5	4	3	2	1
Naturalness					
f) Blue- Green infrastructure in Tirunelveli is …….natural.	5	4	3	2	1
g) Rich in a variety of natural elements e.g. lake, river, trees, hills, scenery.	5	4	3	2	1
h) The naturalness of blue - green infrastructure environment attracts me to engage in outdoor activities	5	4	3	2	1

Coherence – legibility					
i) Blue -Green infrastructure offer landmarks for reference, thereby facilitating orientation and finding one's way.	5	4	3	2	1
j) It is a focal areas for activities (nodes).	5	4	3	2	1
Coherence –Accessibility (connectivity, proximity)					
k) There is a good connectivity among blue and green spaces in Tirunelveli	5	4	3	2	1
l) I can get access to any green space.	5	4	3	2	1
m) Believes Connectivity of Blue- green infrastructure allows me to move easily from one space to another.	5	4	3	2	1
n) Available Accessibility of Blue- green infrastructure to one another ease me in going to places.	5	4	3	2	1
o) The Blue- green spaces are in proximity with one another.	5	4	3	2	1

SECTION 4: WELL-BEING EFFECTS FROM GREEN INFRASTRUCTURE

Q19. Do you think that **exercising** (e.g. jogging and walking) in blue- green infrastructure as having beneficial effects to you?

□ Yes □ No

Q20. If yes, what are the benefits? (You may tick more than one choice).

□ I feel more active
□ My body feels healthier
□ I rarely fall sick
□ I feel happier and more cheerful
□ I feel free and energetic

Other, please name the benefits .....

Q21. Do you think that **strolling, sightseeing and relaxing** in the blue- green infrastructure as having beneficial effects to you?

□ Yes □ No

Q22. If yes, what are the benefits? (You may tick more than one choice).

□ Relief negative emotions and stress.
□ Forget worries and clear random thought
□ Solitude and contemplation

Other please specify .....

Q23. Do you think that **being and interacting with neighbours** in blue-green infrastructure as having beneficial effects to you?

□ Yes □ No

Q24. If yes, what are the benefits of interaction with neighbours? (You may tick more than one choice).

□ More bonding with them.
□ Happier to be with them.
□ More comfortable interacting with others
□ More willing and not hesitate to participate in community activity
□ Care more about them

Other please specify.....

Q25. How much do you agree or disagree with the statements about Blue- green infrastructure in Tirunelveli?

Green Spaces and Well-being of Residents	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Physical well-being					
a) Offer me place to exercise and be active (spot-exercising, jogging, walking, playing)	5	4	3	2	1
Cognitive well-being					
b) I can relief my emotion (e.g. forget worries, relief stress and clear random thoughts).	5	4	3	2	1
c) I can be comfortable, being relaxed and calm.	5	4	3	2	1
d) I can be alone and find privacy in green infrastructure.	5	4	3	2	1
e) I feel safe here.	5	4	3	2	1
f) I prefer the green infrastructure more than any other types of outdoor spaces.	5	4	3	2	1
g) I am satisfied with the green infrastructure because of their physical properties and attributes.	5	4	3	2	1
h) I am satisfied with the green infrastructure in Tirunelveli	5	4	3	2	1
i) I care and concern about the green infrastructure.	5	4	3	2	1
j) The Blue-green infrastructure should be protected and conserve.	5	4	3	2	1
k) Blue-Green spaces offers suitable activity for residents.	5	4	3	2	1
Attachment to Green Infrastructure					
l) It is a meaningful place for me - evoke personal meanings and personal place memory such as childhood memory, pleasant time with loved ones.	5	4	3	2	1
m) Blue- Green spaces is my favourite place.	5	4	3	2	1
Social well-being	5	4	3	2	1
n) Blue-Green infrastructure allows more interaction with other residents.	5	4	3	2	1
o) Blue- Green infrastructure allows more interaction with neighbours.	5	4	3	2	1
p) Blue- Green infrastructure allows participation with other residents (gotong royong and meeting).	5	4	3	2	1

Q26. How much do you agree or disagree that the following place affords **active living** such as **exercising (jogging, cycling, walking) and playing?**

Location	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
a) Around the Thamirabarani River.	5	4	3	2	1
b) VOC Ground and other parks	5	4	3	2	1
c) Open space in town (e.g. Maithanams, and grounds).	5	4	3	2	1
d) Streets and green infrastructure along shop houses (e.g. at Bazaars).	5	4	3	2	1
e) Open spaces in your neighbourhood area and home gardens (e.g. playground and football field).	5	4	3	2	1

f) Pocket space of historical, institutional and government buildings (e.g. in and around library, hospital, school).	5	4	3	2	1
g) Pocket space in town centre (e.g. Bazaar spaces like Palay Maerkets & Maidhan, Bazaar Around Nellaiappar temple, South Bazaar)	5	4	3	2	1
h) Infrastructure along river	5	4	3	2	1

Q27. Do you have favorite places?

□ Yes □ No

Q28. Where is the place? ……

Q29.Why it is your favorite? (You can choose more than one answer).

□ Place to relax, be alone and relief stress.

□ Place to do physical activity e.g. exercising and playing.

□ Place to interact with friends and family.

□ Place to interact with other residents.

□ It is safe and secure.

Other please specify

……

Q30. How do you feel when you are in **THE THAMIRABARANI RIVER**? From each row, pick a number from a scale from a scale 5(positive scale) to 1(negative scale).

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	
Fond of it	5	4	3	2	1	Dislike it
Exciting	5	4	3	2	1	Boring
Calm/Serene	5	4	3	2	1	Chaos
Spacious	5	4	3	2	1	Crowded
Inspiring	5	4	3	2	1	Unimaginative
Familiar	5	4	3	2	1	Strange
Lively	5	4	3	2	1	Abandon/deserted/ empty
Clean	5	4	3	2	1	Dirty
Good facility	5	4	3	2	1	With vandalism/graffiti
Comfortable	5	4	3	2	1	Uncomfortable
Beautiful						Ugly
Safe and secure	5	4	3	2	1	Fear and anxiety

Q31. How do you feel when you are in the **PARKS & GARDENS IN TIRUNELVELI?**

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	
Fond of it	5	4	3	2	1	Dislike it
Exciting	5	4	3	2	1	Boring
Calm/Serene	5	4	3	2	1	Chaos
Spacious	5	4	3	2	1	Crowded
Inspiring	5	4	3	2	1	Unimaginative
Familiar	5	4	3	2	1	Strange

Lively	5	4	3	2	1	Abandon/deserted/ empty
Clean	5	4	3	2	1	Dirty
Good facility	5	4	3	2	1	With vandalism/graffiti
Comfortable	5	4	3	2	1	Uncomfortable
Beautiful						Ugly
Safe and secure	5	4	3	2	1	Fear and anxiety

Q32. How do you feel when you are in **POCKET SPACES in town centre such as Bazaars, maithanams?**

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	
Fond of it	5	4	3	2	1	Dislike it
Exciting	5	4	3	2	1	Boring
Calm/Serene	5	4	3	2	1	Chaos
Spacious	5	4	3	2	1	Crowded
Inspiring	5	4	3	2	1	Unimaginative
Familiar	5	4	3	2	1	Strange
Lively	5	4	3	2	1	Abandon/deserted/ empty
Clean	5	4	3	2	1	Dirty
Good facility	5	4	3	2	1	With vandalism/graffiti
Comfortable	5	4	3	2	1	Uncomfortable
Beautiful						Ugly
Safe and secure	5	4	3	2	1	Fear and anxiety

Q33. How do you feel when you are **NEIGHBOURHOOD GREEN SPACES, WATER BODIES & GARDENS IN YOUR PLACE?**

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	
Fond of it	5	4	3	2	1	Dislike it
Exciting	5	4	3	2	1	Boring
Calm/Serene	5	4	3	2	1	Chaos
Spacious	5	4	3	2	1	Crowded
Inspiring	5	4	3	2	1	Unimaginative
Familiar	5	4	3	2	1	Strange
Lively	5	4	3	2	1	Abandon/deserted/ empty
Clean	5	4	3	2	1	Dirty
Good facility	5	4	3	2	1	With vandalism/graffiti
Comfortable	5	4	3	2	1	Uncomfortable
Beautiful						Ugly
Safe and secure	5	4	3	2	1	Fear and anxiety

SECTION 5: FLOODING & SUSTAINABLE DEVICES

Q34. Does your town have flooding problems?

- ☐ Never
- ☐ Rarely (Once a year)
- ☐ Sometimes (Two or three times a year)
- ☐ Often (Four to six times a year)
- ☐ Frequently (More than six time per year)

Q35. Have you experienced flooding in **this house you live in NOW**? Choose **ONE** option to describe **the worse** flooding youexperienced:

- ☐ Yes – over 1m of flood water
- ☐ Yes – between 50cm and 1m of flood water
- ☐ Yes – between 10cm and 50cm of flood water
- ☐ Yes – but quite low levels, less than 10 cm
- ☐ No – never experienced flooding in my house

Q36. Have you experienced flooding in **your street**?
Choose **ANY** options that apply for **the worse** flooding you experienced:

- ☐ Yes – but I could still walk on the streets
- ☐ Yes – it was not possible to walk on the streets
- ☐ Yes – it was not possible to drive a car
- ☐ Yes – it was not possible to drive a motorcycle
- ☐ Yes – there was no public transport (buses)
- ☐ Yes – the only way to go around was by boat
- ☐ No – never experienced flooding in my street

Q37. What do you think is the cause of flooding in your area? _____

Q38 Who do you think is responsible for protecting you from flood? Choose **ANY** options that apply:

- ☐ the central government
- ☐ the provincial government
- ☐ the Mayor
- ☐ the Village Head
- ☐ the Public Works Service
- ☐ the Irrigation Service
- ☐ the village
- ☐ the citizens
- ☐ community groups
- ☐ myself
- ☐ other: _____
- ☐ I don't know

Q39. Have your house installed devices to capture the rain water (I.e, cisterns rain barrels, Rainwater recharge pits, Recharge bore wells?

- ☐ Yes
- ☐ No

If Yes, which device? ……..

What was the motivation to install these devices?

- ☐ Reduce Flooding
- ☐ Reduce Storm water runoff
- ☐ Reduce Nonpoint source pollution
- ☐ Conserve water
- ☐ Adapt to climate change
- ☐ Demonstration purposes
- ☐ Genral sustainability and environmental consciousness
- ☐ Compulsary by government
- ☐ I don't know

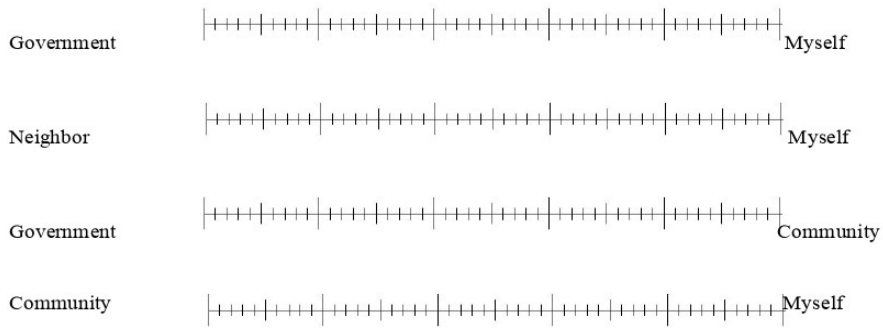
If any other, specify ……..

Q40. What blue-green infrastructure practices have already been installed in your neighborhoods?

- ☐ Rain Garden
- ☐ Permeable Pavement
- ☐ Rainwater harvesting
- ☐ Planter or tree boxes with storm water management purposes
- ☐ Vegetaed Bio swales
- ☐ Green roofs
- ☐ None of the above
- ☐ I don't know

If any other, specify ……

Could you indicate where the responsibility to deal with flooding should rest between these two ends:



END OF QUESTIONS

Thank you for your assistance!

12.2 Annexure 2: Expert Opinion Survey –Interview Questionnaires:

1. Are your aware of Blue-green infrastructure concept?
2. Rate the quality and cleanliness of water bodies in the town.
3. What are the issues related to the Thamirabarani River?
4. Do you think Thamirabarani will perish and die soon like Cavery river? If yes, how many years would it take?
5. What are the measures that government could take to revitalize the river?
6. What are the measures the community could take to revitalize the river and water bodies?
7. Do you think thamirabarani is highly polluted?
   If yes, Due to what reason, is it so polluted?
8. Do you think, it is possible to eliminate the pollutants through biological methods using wetland sedimentation tanks, before discharged into the river?
9. Recommended methods or ways to reduce the pollution in the river and water bodies?
10. Do you feel that a network between the blue and green elements can serve better for the environment, than when alone?
11. What are the current issues related to the environment in Tirunelveli?
12. Do you feel that Tirunelveli has very few public green spaces? What could we do to improve the condition of it?

12.3 Annexure 4: Ranking of Ecosystem Services of all Waterbodies:

	Ecosystem Services	Kandiaperi Lake	Seeniappanthirukulam	Ilandakulam	Theneerkulam	Krishnaperi Kulam	Nainar Lake	Udayarpatti kualm	Sendimangalam	Pirayankulam	Alanganeri	Sambankulam	Arugankulam	Mullikulam
Provisioning Services	Fish - Food Provision	1	1	1	1	1	1	0	1	1	1	0	1	0
	Vegetables, Fruits & Grains - Food Provision	0	0	0	0	0	1	0	0	0	0	0	0	0
	Water storage - Fresh Water Provision	1	1	1	1	1	1	1	1	1	1	1	1	1
	Irrigation Purposes - Fresh Water Provision	1	1	1	1	1	1	0	1	1	1	1	1	0
	Drinking Water Purpose -Fresh Water Provision	0	0	0	0	0	1	0	1	1	1	0	1	0
	Fuelwood -Fiber & Fuel Provision	0	0	0	1	0	1	0	1	1	1	1	1	0
	Timber - Fiber & Fuel Provisions	0	0	0	0	0	0	0	0	0	0	0	0	0
	Foddler - Fiber & Fuel Provisions	0	0	0	0	0	0	0	1	1	1	1	1	0
	Peat - Fiber & Fuel Provisions	1	0	0	0	1	1	1	1	1	1	0	1	0
	Livestock Rearing - Fiber & Fuel Provisions	1	0	0	0	1	1	0	1	1	1	0	1	0
	Extraction of materials from Biota (Biochemical Fuel) - Fiber & Fuel Provisions	0	0	0	0	0	0	0	0	0	0	0	0	0
	Medicinal Values -- Fiber & Fuel Provisions	0	0	0	0	0	1	0	1	1	1	1	1	0
	Ornamental Species - Fiber & Fuel Provisions	0	0	0	0	0	0	0	0	0	0	0	0	0
	Genes for resistance to plant pathogen - Fiber & Fuel Provisions	0	0	0	0	0	0	0	0	0	0	0	0	0
Regulating Services	Regulation of Greenhouse gases -Climate Regulation	1	0	1	1	1	1	0	1	1	1	0	1	0
	Regulation of temperature/ micro-climate -Climate Regulation	1	1	1	1	1	1	1	1	1	1	1	1	1
	Groundwater recharge and Discharge - Hydrological Regime Regulation	1	0	1	1	1	1	0	1	1	1	1	1	0
	Storage of water for agriculture -Hydrological Regime Regulation	1	1	1	1	1	1	0	1	1	1	0	1	1
	Storage of water for industry -Hydrological Regime Regulation	0	0	0	1	0	1	0	1	1	1	1	1	0
	Nutrient Retention -Pollution Control Regulation	1	0	0	0	1	1	0	0	0	0	0	0	0
	Removal of excess nutrients -Pollution Control Regulation	0	0	0	0	0	1	0	0	0	0	0	0	0
	Removal of pollutants -Pollution Control Regulation	1	1	1	1	1	1	0	0	0	0	0	0	1
	Flood Control -Natural Hazard Mitigation	1	1	1	1	1	1	1	1	1	1	1	1	1
	Strom Protection -Natural Hazard Mitigation	1	1	1	1	1	1	1	1	1	1	1	1	1

	Ecosystem Services	Kandiaperi Lake	Seeniappanthirukulam	Ilandakulam	Theneerkulam	Krishnaperi Kulam	Nainar Lake	Udayarpatti kualm	Sendimangalam	Pirayankulam	Alanganeri	Sambankulam	Arugankulam	Mullikulam
Cultural Services	Personal feelings and well-being -Spiritual & Inspiration	0	0	0	0	0	1	1	0	0	0	0	0	0
	Religious Significance -Spiritual & Inspiration	0	1	0	0	0	1	0	0	0	0	0	0	0
	Opportunities for tourism -Recreational Services	1	0	1	1	1	1	1	0	0	0	0	0	0
	Opportunities for recreational activities -Recreational Services	1	1	1	1	1	1	1	0	0	0	0	0	1
	Opportunities for formal and informal education and training -Educational Services	1	0	1	1	1	1	1	0	0	0	0	0	0
	Appreciation of natural features- Aesthetics	1	1	1	1	1	1	0	1	1	1	1	1	0
Suppoorting Services	Habitats for residents or transient species -Biodiversity	1	0	1	1	1	1	1	1	1	1	1	1	1
	Storage, recycling, processing and acquisition of nutrients -Nutrient Cycle support	1	1	0	0	1	1	0	0	0	1	0	0	0
	Sediment Retention -Soil Formation Support	1	0	0	0	1	1	0	0	0	1	1	0	0
	Accumulation of organic matter -Soil Formation Support	1	1	0	0	1	1	0	1	1	1	1	1	0
	Support for pollinators	0	1	1	1	0	1	0	1	1	1	0	1	0
	Total Rank out of 36	21	14	16	18	21	30	10	20	20	22	14	20	8

12.4 Riparian Native Species Inventory for Thamirabarani River:

Botanical name	Family	H	S
Abelmoschus angulosus Steud.ex.Mast.	Malvaceae	S	C
Abrus precatorius L.	Fabaceae	C	E
Abutilon indicum (L.)Sweet .	Malvaceae	S	C
Acacia auriculiformis Benth.	Fabaceae	T	Ex
Acacia mangium Willd.	Fabaceae	T	Ex
Acacia nilotica (Benth.)Brenan.	Fabaceae	T	C
Acacia pennata (L.) Willd.	Fabaceae	T	C
Acalypha indica L.	Euphorbiaceae	H	C
Acalypha lanceolata Willd.	Euphorbiaceae	H	C
Acanthospermum hispidum DC.	Asclepiadaceae	H	C
Achyranthes aspera L.	Amaranthaceae	H	E
Achyranthes bidentata Blume	Amaranthaceae	H	C
Acmella radicans (Jacq.)R.K.Jansen	Asteraceae	H	C
Acorus calamus L.	Araceae	H	C
Actinodaphne wightiana (Kuntze.)Noltie	Lauraceae	T	C
Adenanthera pavonina L.	Fabaceae	T	C
Adenium obesum Roem. & Schult.	Apocyanaceae	S	C
Adhatoda vasica Nees-Pl.Asiat.Rar.(Wallich)	Acanthaceae	S	C
Adhatoda zeylanica Mediqus.	Acanthaceae	S	C
Aegle marmelos (L.)	Rutaceae	T	E
Aerva lanata (L.)Juss.ex Schult.	Amaranthaceae	H	C
Aeschynomene aspera L.	Fabaceae	S	C
Aganosma cymosum (Roxb.)G.Don.	Apocyanaceae	C	C
Agave cantula Roxb.	Agavaceae	H	C
Ageratum conyzoides L.	Asteraceae	H	Ex
Ailanthus excelsa Roxb.	Simoroubaceae	T	C
Alangium salvifolium (L.f.)Wangerin.	Cornaceae	T	C
Albizia chinensis (Osbeck .)Merr.	Fabaceae	T	C
Albizia lebbeck (L.)Benth.	Mimosaceae	T	C
Albizia saman (Jacq.)F.Muell.	Fabaceae	T	C
Alloteropsis cimicina (L.)Stapf.	Poaceae	H	C
Aloe vera (L.)Burm.f.	Liliaceae	H	Ex
Alpinia galanga (L.)Willd.	Zingiberaceae	H	C
Alstonia scholaris (L.)W.T.Aiton.	Apocynaceae	T	C
Alstonia venanata R.Br.	Apocyanaceae	T	E
Alternanthera paronychioides A.St.Hil.	Amaranthaceae	H	Ex
Alternanthera pungens Kunth	Amaranthaceae	H	Ex
Alternanthera sessilis (L.)R.Br.ex D.C.	Amaranthaceae	H	C
Amaranthes spinosus L.	Amaranthaceae	H	Ex
Amaranthes viridi L.	Amaranthaceae	H	C
Ampelocissus indica (L.)Planch.	Vitaceae	C	R
Ampelocissus latifolia (Roxb.)Planch.	Vitaceae	C	C
Anabaena azolla Strasb.	Azollaceae	H	C
Anacardium occidentals L.	Anacardiaceae	T	Ex

Anamirta cocculus (L.)Wight & Arn.	Menispermaceae	C	C
Ananas comosus (L.)Merr.	Bromeliaceae	H	Ex
Andrographis alata (Burm.f.)Wall.ex Nees	Acanthaceae	H	C
Andrographis paniculata (Burm.f.)Nees.	Acanthaceae	H	E
Andrographis serpyllifolia (Vahl)Wight	Acanthaceae	H	E
Anisomeles indica (L.)Kuntze.	Lamiaceae	H	C
Anisomeles malabarica (L.)R.Br.	Lamiaceae	S	C
Annona squamosa L.	Annonaceae	T	Ex
Anogeissus latifolia (Roxb.ex.DC.)Wall.ex.Guill. &Perr.	Combretaceae	T	C
Antidesma acidum Retz.	Euphorbiaceae	S	C
Antidesma ghaesembilla Gaertn.	Euphorbiaceae	S	C
Antidesma montanum Blume.	Phyllanthaceae	T	C
Antigonon leptopus Hook.& Arn.	Polygonaceae	C	Ex
Aponogeton appendiculatus H.Bruggen.	Aponogetonaceae	H	C
Aponogeton natans (L.)Engler & Krause	Aponogetonaceae	H	C
Archidendron bigeminum (L.) I.C.Nielsen.	Fabaceae	T	C
Areca catechu L.	Arecaceae	T	Ex
Arenga wightii Griff.	Arecaceae	T	E
Argemone Mexicana L.var.	Pappavaraceae	H	Ex
Argyreia boseana Santapau & V.Patel	Convolvulaceae	L	C
Argyreia elliptica (Roth)Choisy.	Convolvulaceae	C	C
Argyreia sericea Dalzell.	Convolvulaceae	C	E
Arisaema leschenaultii Blume.	Araceae	H	C
Aristida setacea Retz.	Poaceae	H	C
Aristolochia gigas var S.watson	Aristolochiaceae	H	R
Bacopa monnieri (L.)Pennell	Scropulariaceae	H	C
Balbostylis barbata (Rottb.) C.B.Clarke	Cyperaceae	H	C
Bambusa bambos (L.) Voss.	Poaceae	T	C
Bambusa tulda Roxb.	Poaceae	T	R
Bambusa vulgaris Schrad.	Poaceae	T	Ex
Barleria buxifolia L.	Acanthaceae	S	C
Barleria cuspidata Heyne ex Nees	Acanthaceae	S	E
Barleria mysorensis Heyne er Roth	Acanthaceae	H	C
Barleria nitida Nees	Acanthaceae	S	C
Barleria prionitis L.	Acanthaceae	H	C
Basillicum polystachion Moench.	Poaceae	H	C
Bauhinia malabarica Lam.	Fabaceae	T	C
Bauhinia phoenicea Wight & Arn.	Fabaceae	C	E
Bauhinia racemosa Lam.	Caesalpiniaceae	T	C
Biophytum reinwardtii (Zucc.)Klotzsch	Oxalidaceae	H	C
Borassus flabellifer L.	Arecaeae	T	C
Bougainvillea spectabilis Willd.	Nyctaginaceae	C	Ex
Brachiaria ramosa (L.)Stapf.	Poaceae	H	C
Brassica campestris L.	Capparidaceae	H	C

Breynia retusa (Dennst.)Alston.	Euphorbiaceae	S	C
Bryophyllum pinnatum (Lam.)Oken.	Crassulaceae	H	Ex
Buchanania lanzan Spreng.	Anacardiaceae	T	C
Burea monnosperma (Lam.) Taub.	Fabaceae	T	E
Burmannia pusilla (Miers.)Thwaites.	Burmanniaceae	H	C
Caesalpinia bonduc (L.)Roxb.	Fabaceae	C	C
Cajanus albicans (Wight&Arn.)Maesen	Fabaceae	C	C
Cajanus lineatus (Wight & Arn.)Maesen.	Fabaceae	S	E
Caladium bicolor Wightii (Lem.)Engl.	Araceae	H	Ex
Calamus rotang L.	Araceae	C	E
Calamus travancoricus Bedd.ex Becc.	Arecaceae	C	E
Calophyllum inophyllum L.	Calophyllaceae	T	C
Calotropis gigantea (L.) R.Br.W.T.Aiton.	Apocyanaceae	S	C
Calycopteris floribunda (Roxb.) Poir.	Combretaceae	S	C
Camellia sinensis (*L.*)Kuntze var.	Camelliaceae	S	Ex
Caralluma umbellata Haw.	Asclepiadaceae	H	C
Cardiospermum halicacabum L.	Sapindaceae	C	C
Careya arborea Roxb.	Barringtoniaceae	T	C
Carica papaya L.	Caricaceae	T	Ex
Carissa carandas L.	Apocyanaceae	S	C
Carissa inermis Vahl.	Apocyanaceae	S	E
Carissa spinarum L.	Apocyanaceae	S	C
Carmona retusa (Vahl.)Masamune.	Boraginaceae	S	C
Caryota urens L.	Arecaceae	T	C
Cassia alata L.	Caesalpiniaceae	S	Ex
Cassia auriculata L.	Fabaceae	S	C
Cassia fistula L.	Caesalpiniaceae	T	C
Cassia hirsuta L.	Caesalpiniaceae	S	Ex
Cassia mimosoides L.	Caesalpiniaceae	H	C
Cassia occidentalis L.	Caesalpiniaceae	S	Ex
Cassia pumila Lam.	Fabaceae	H	C
Cassia siamea Lam.	Caesalpiniaceae	T	C
Cassia tora L.	Caesalpiniaceae	H	C
Casuarina litorea L.	Casurinaceae	T	Ex
Catharanthus roseus L.	Apocyanaceae	H	Ex
Cayratia japonica (Thunb.)Gagnep.	Menispermaceae	S	C
Cayratia pedata (Lam.)Gagnep.	Menispermaceae	C	R
Cayratia trifolia (L.) Domin	Menispermaceae	H	C
Ceiba pentandra (L.)Gaertn.	Bombacaceae	T	Ex
Celastrus paniculatus Willd.	Celastraceae	C	C
Celosia argentea L.	Amaranthaceae	H	Ex
Celosia cristata L.	Amaranthaceae	H	C
Centella asiatica (L.) Urban	Apiaceae	H	C
Centrosema pubescens Benth.	Fabaceae	C	Ex
Ceropegia candelabrum L.	Asclepiadaceae	C	E

Chassalia ophiosyloides (Wallich) Craiv	Rubiaceae	S	C
Chloris barbata SW.	Poaceae	H	C
Chromolaena oderata (L.)King & Robinson	Asteraceae	H	Ex
Chrysophyllum roxburghii G.Don.	Sapotaceae	T	C
Chrysopogon aciculatus (Retz.)Trin.	Poaceae	H	C
Cinnamomum camphora (L.)J.Presl	Lauraceae	T	Ex
Cinnamomum macrocarpum Hook.f.	Lauraceae	T	E
Cinnamomum malabatrum (Burm.f.)J.Presl.	Lauraceae	T	E
Cinnamomum verum J.Presl.	Lauraceae	T	C
Cissampelos pareira L.	Menispermaceae	C	C
Cissus quadrangularis L.	Menispermaceae	C	C
Cissus vitignea L.	Menispermaceae	C	C
Citrus aurantium L.	Rutaceae	T	Ex
Citrus medica L.var.liman L.	Rutaceae	T	C
Clematis gouriana Roxb .ex.DC.	Ranunculaceae	C	C
Cleome aspera Koen.ex.DC.	Capparidaceae	H	C
Cleome rutidosperma DC.	Capparidaceae	H	C
Cleome viscosa L.	Capparidaceae	H	C
Clerodendrum indicum (L.)Kuntze	Lamiaceae	S	C
Clerodendrum infortunatum L .	Verbenaceae	S	C
Clerodendrum paniculatum L.	Verbenaceae	S	Ex
Clitoria ternatea L.	Fabaceae	C	Ex
Coccinia grandis (L.) Voilgt.	Cucurbitaceae	C	C
Cocculus hirsutus L.	Menispermaceae	C	C
Cocos nucifera L.	Arecaceae	T	C
Coffea arabica L.	Rubiaceae	S	Ex
Cyrtococcum trigonum (Retz.)A.Camus	Poaceae	H	C
Dactyloctenium aegyptium (L.) Willd.	Poaceae	H	C
Datura metel L.	Solanaceae	S	C
Datura stramonium L.var.innermis(Juss.)	Solanaceae	S	Ex
Debregeasia longifolia (Burm.f.)Wedd.	Urticaceae	T	C
Decalepis arayalpathra Joseph & Chandrasekaran	Apocynaceae	S	E
Dendrocalamus strictus (Roxb.)Nees.	Poaceae	T	C
Dentrophthoe falcata (L.f.)Ettingsh.	Loranthaceae	S	E
Derris benthamii (Thwaites.)	Fabaceae	C	C
Derris scandens (Roxb.)Benth.	Fabaceae	C	C
Derris trifoliata (Lour.)	Fabaceae	C	C
Desmodium gangeticum (L.)DC.	Fabaceae	S	C
Desmodium heterophyllum (Willd.)DC.	Fabaceae	H	C
Desmodium motorium (Houtt.) Nerr.	Fabaceae	S	C
Desmodium triflorum (L.)D.C.	Fabaceae	H	C
Dictyospermum montanum Wight.	Commelinaceae	H	C
Digitaria longiflora (Retz.)Pers	Poaceae	H	C
Digitaria marginata Link	Poaceae	H	C

Dillenia pentagyna Roxb.	Dilleniaceae	T	C
Dioscorea alata L.	Dioscoreaceae	C	C
Dioscorea bulbifera L.	Dioscoreaceae	C	C
Dioscorea oppositifolia L.	Dioscoreaceae	C	C
Dioscorea pentaphylla L.	Dioscoreaceae	C	C
Diospyros buxifolia (Blume.)Hiern	Ebenaceae	T	C
Diospyros malabarica (Desr.)Kostel.	Ebenaceae	T	E
Diospyros paniculata Dalzell.	Ebenaceae	T	C
Dipteracanthus prostratus (Poir.)Nees.	Acanthaceae	H	C
Dolichandrone atrovirens (Heyne.ex.Roth.)Sprague.	Bignoniaceae	T	E
Dolichandrone falcata (Wall.ex.DC.)Seem.	Bignoniaceae	T	R
Drosera burmannii DC.	Droceraceae	H	E
Drymaria cordata (L.)Willd.ex Roem. & Schult.subsp.diandra (Blume)Duke.	Caryophyllaceae	H	C
Dyschoriste madurensis (Burm.f.) Kuntze	Acanthaceae	S	C
Echinochloa colona (L.)	Poaceae	H	C
Eclipta alba (L.) Hassk.	Asteraceae	H	C
Eclipta prostrata Var. dixitii.	Asteraceae	H	E
Eichhornia crassipes (Mart.)	Pontederiaceae	H	Ex
Elaeocarpus serratus L.	Elaeocarpaceae	T	C
Elaeocarpus tuberculatus Roxb.	Elaeocarpaceae	T	C
Elatostema acuminatum (Poir.)Brongn.	Urticaceae	H	C
Elephantopus scaber L.	Asteraceae	H	C
Elettaria cardamomum (L.)Maton	Zingiberaceae	H	C
Eluesine indica (L.) Gaertner	Poaceae	H	C
Emilia sonchifolia (L.)DC.	Asteraceae	H	C
Emilia zeylanica Clarke.	Asteraceae	H	C
Entada rheedei (Spreng.)	Fabaceae	C	C
Eragrostis riparia (Willd.)Nees	Poaceae	H	C
Eragrostis unioloides (Retz.)Nees ex Steud	Poaceae	H	C
Eragrostis viscosa (Rtez.)Trin.	Poaceae	H	C
Ergos hertacce	Poaceae	H	C
Eriocaulon eurypeplon Kom.	Eriocaulaceae	H	R
Eriochloa procera (Retz.) C.E.Hubb.	Poaceae	H	C
Fimbristylis argentea (Rottb.)Vahl.	Cyperaceae	H	C
Fimbristylis dichotoma (L.)Vahl.ssp.	Cyperaceae	H	C
Fimbristylis miliaccea (L.) Vahl.	Cyperaceae	H	C
Fimbristylis tenera Rome.& Schult.	Cyperaceae	H	C
Fimbrystis ovata (Burm .f.) Kern	Poaceae	H	C
Flacourtia indica (Burm.f.)Merr.	Flacoutiaceae	C	C
Flueggea leucopyrus Willd.	Phyllanthaceae	S	C
Garcinia mangostana L.	Clusiaceae	T	Ex
Gardenia angusta (L.) Merr.	Rubiaceae	S	Ex
Gliricidia sepium (Jacq.)Walp.	Fabaceae	T	Ex

Gloriosa superba L.	Colchicaceae	C	C
Glycyrrhiza glabra Torr.	Fabaceae	T	C
Gomphrena globosa L.	Amaranthaceae	H	Ex
Gomphrena serrata L.	Amaranthaceae	H	Ex
Goniothalamus cardiopetalus Dalzell-Hookers J.Bot.	Annonaceae	T	E
Gossypium arboreum L.	Malvaceae	S	R
Grewia bracteata B.Heyne ex Benth.	Tiliaceae	T	C
Grewia emarginata Buch.Ham.ex DC.	Tiliaceae	T	C
Grewia tilifolia Vahl.	Tiliaceae	T	C
Gymnema sylvestre (Retz.)Schult.	Menispermaceae	C	C
Gynura nitida DC.	Asteraceae	H	E
Hedyotis albo-nervia Bedd.	Rubiaceae	S	E
Hedyotis Brevicalyx Sivarajan,Biju&B. Mathew	Rubiaceae	H	C
Hedyotis corymbosa (L.) Lam.	Rubiaceae	H	C
Hedyotis herbace (L.)Roxb.	Rubiaceae	H	C
Hedyotis membranacea Thwaites.	Rubiaceae	S	R
Hedyotis trinervia (Retz.) Roemer&Schultes	Rubiaceae	H	C
Helianthus annus L.	Asteraceae	H	C
Helicteres isora L.	Malvaceae	S	C
Heliotropium indicum L.	Boraginaceae	H	C
Heliotropium marifolium Retz.	Boraginaceae	H	C
Heliotropium supinum L.	Boraginaceae	H	C
Hemidesmus indicus (L.)R.Br.ex Schult.	Apocynaceae	C	E
Heteropogon controtus (L.)P.Beaiv.ex.Roem. & Schultes.	Poaceae	H	C
Hibiscus cannabinus L.	Malvaceae	H	C
Hibiscus hispidissimus Griff.	Malvaceae	C	C
Hibiscus rosa-sinensis L.	Malvaceae	S	Ex
Hibiscus tiliaceus L.	Malvaceae	T	C
Holigarana aronottiana Hook.f.	Anacardiaceae	T	E
Holigarana grahamii (Wight.)Kurz.	Anacardiaceae	T	R
Hopea parviflora Bedd.	Dipterocarpaceae	T	E
Hopea ponga (Dennst.)Mabb.	Dipterocarpaceae	T	E
Hyptis suaveolens (L.)Poit.	Lamiaceae	H	Ex
Ichnocarpus frutescens (L.)R.Br. W.T.Ation.	Apocyanaceae	C	C
Impatiens acaulis. Arn.	Balsaminaceae	H	C
Impatiens verticillata Wight.	Balsaminaceae	H	E
Indigofera tinctoria L.	Fabaceae	S	C
Indoneesiella echioides (L.) Sreem.	Fabaceae	H	C
Indoneesiella eshioides (L.) Sreem	Acanthaceae	H	C
Ipomea alba L.	Convolvulaceae	C	Ex
Isachne miliacea Roth.	Poaceae	H	C
Ixora brachiata Roxb.	Rubiaceae	T	E
Ixora coccinea L.	Rubiaceae	S	C

Ixora johnsonii Hook.f.	Rubiaceae	S	E
Ixora nigricans R.Br.ex Wight & Arn.	Rubiaceae	S	C
Jasminum angustifolia (L.)Willd.	Oleaceae	C	R
Jasminum azoricum L.	Oleaceae	C	C
Jasminum malabaricum Wight.	Oleaceae	C	E
Jasminum multiflorum (Burm.f.)Andrews	Oleaceae	C	C
Jatropha curcas L.	Euphorbiaceae	S	Ex
Jatropha gossyphifolia L.	Euphorbiaceae	S	Ex
Justicia diffusa Willd.	Acanthaceae	H	C
Justicia gendarussa Burm.f.	Acanthaceae	S	C
Lagenendra toxicaria Dalzell.	Araceae	H	C
Lagerstroemia speciosa (L.)Pers.	Lythraceae	T	C
Laggera alata (D.Don.)Oliv.	Asteraceae	H	C
Lannea coromandelica (Houtt.)Merr.	Anacardiaceae	T	C
Lantana camara L.	Verbanaceae	S	Ex
Lawsonia inermis L.	Lythraceae	S	C
Leea guineense G.Don.	Vitaceae	S	C
Leea indica (Burm.f.)Merr.	Vitaceae	S	E
Leerisia hexandra Sw.	Poaceae	H	C
Leptochloa chinensis (L.) Nees.	Poaceae	H	C
Leucas aspera (Willd.)Link.	Lamiaceae	H	C
Leucas biflora (Vahl.)R.Br.	Lamiaceae	H	C
Leucas zeylanica (L.)W.T.Aiton.	Lamiaceae	H	C
Limnophila indica (L.)Druce	Plantaginaceae	H	C
Limonia acidissima L.	Rutaceae	T	C
Mariscus dubius (Rottb.) Kük. ex G.E.C.Fischer	Cyperaceae	H	C
Mariscus javanicus (Houtt.) Merr. & F.P	Cyperaceae	H	C
Maytenus emarginata (Willd.)Ding Hou.C	Celastraceae	S	C
Melanocenchris jacquemontii Jaub. & Spach.	Poaceae	H	R
Melastoma malabathricum L.	Melastomaceae	S	R
Melochia corchorifolia L.	Sterculiaceae	H	C
Memecylcon duck Retz.	Melastomaceae	T	R
Memecylon angustifolium Wight.	Melastomaceae	S	C
Memecylon umbellatum Burm.f.	Melastomaceae	S	C
Memeyclon talbotianum Brandis	Melastomaceae	T	E
Merremia emarginata (Burm.Hallier.f.	Convolvulaceae	C	C
Merremia hederacea (Burm.f.)Hallier f.	Convolvulaceae	C	C
Merremia tridentata (L.) Hallier f.	Convolvulaceae	H	C
Merremia vitifolia (Burm.f.)Hallier.f.	Convolvulaceae	H	C
Mesua ferrea L.	Calophyllaceae	T	C
Michelia champaca L.	Magnoliaceae	T	C
Millettia rubiginosa Wight and Arn.	Fabaceae	C	E
Millingtonia hortensis L.f.	Bignoniaceae	T	Ex
Mimosa diplotricha C.Wright ex. Sauvalle.	Fabaceae	S	Ex
Mimosa diplotricha var.*inermis*.	Mimosaceae	S	Ex

Mimosa pudica L.	Fabaceae	H	Ex
Mimusops elengi L.	Sapotaceae	T	C
Mollugo nudicaulis Lam.	Aizoaceae	H	C
Mollugo pentaphylla L.	Aizoaceae	H	C
Momordica charantia L.	Cucurbitaceae	C	C
Monochoria vaginalis (Burm.f.)C.Presl.	Pontederiaceae	H	C
Morinda pubexans Smith.	Rubiaceae	T	C
Moringa oleifera Lam.	Moringaceae	T	E
Morus alba L.	Moraceae	T	Ex
Mukia maderaspatana (L.)M.Roem.	Cucurbitaceae	C	C
Muntiniga calabura L.	Elaeocarpaceae	T	Ex
Murraya koenigii (L.)Spreng.	Rutaceae	T	C
Murraya paniculata (L.)Jack.	Rutaceae	S	C
Musa paradisiaca L.	Musaceae	H	C
Mussaenda frondosa L.	Rubiaceae	S	C
Ocimum muricata L.	Lamiaceae	H	R
Ocimum scantum L.	Lamiaceae	H	C
Ocimum tenuiflorum L.	Lamiaceae	H	C
Olax scandens Roxb.	Olacaceae	S	R
Olea dioica Roxb.	Oleaceae	T	C
Ophiorrhiza mungos L.	Rubiaceae	H	E
Oplimenus composites (L.)P.Beauv.	Poaceae	H	C
Oplismenus burmannii	Poaceae	H	C
Orthosiphon thymiflorus (Roth)Sleesan	Lamiaceae	H	C
Oryza rufipogon Griff	Poaceae	H	C
Oryza sativa L.	Poaceae	H	C
Osbeckia aspera (L.) Bl.	Melastomaceae	S	C
Osbeckia virgata D.Don.ex Wight & Arn.	Melastomaceae	S	C
Pandanus fascicularis Lam.	Pandanaceae	T	C
Pandanus odorifer (Forssk.)Kuntze. Tectorius	Pandanaceae	T	C
Pandanus thwaitesii Martelli	Pandanaceae	S	C
Pandanus unipapillatus Dennst.	Pandanaceae	T	E
Pycreus polystachyos (Rottb.)	Cyperaceae	H	C
Pycreus punctialatus (Vahl.)Nees.	Cyperaceae	H	C
Pyrus communis L.var.pyraster L.	Rosaceae	T	Ex
Quisqualis indica L.	Combretaceae	T	C
Rauvolfia serpentina (L.)Benth ex Kurz	Apocyanaceae	H	E
Rhynchosia minima (L.) DC	Fabaceae	C	C
Rhynchospora corymbosa (L.) Britton.	Cyperaceae	H	C
Ricinus commiunis L.	Euphorbiaceae	S	Ex
Rivina humilis L.	Phytolochiaceae	S	Ex
Ruellia rivularis (Benoist)Bovin ex Benoist.	Acanthaceae	H	C
Ruellia tuberosa L.	Acanthaceae	H	Ex
Salacia fruticosa Heyne ex Lawson.	Celastraceae	C	E
Sansevieria roxburghiana Schult.&Schult.f.	Agavaceae	H	C

Santalum album L.	Fabaceae	T	V
Saraca asoca Rox.	Caesalpiniaceae	T	E
Sarcostemma viminale (L.)R.Br.	Asclepiadaceae	C	C
Schefflera stellata (Gaertn.)Hams	Araliaceae	S	C
Schefflera wallichiana (Wight & Arn.)Hams	Araliaceae	T	E
Tinospora cordifolia (Willd.)Miers.	Menispermaceae	C	C
Toddalia asiatica (L.)Lam.	Rutaceae	S	C
Tragia hispida Willd.	Euphorbiaceae	H	C
Trianthema portulacastrum L.	Aizoaceae	H	C
Trichomanes plicatum (Bosch) Bedd.	Hymenophyllacea e	H	R
Tridax procumbens L.	Asteraceae	H	Ex
Tylophora fasciculata Buch.-Ham.ex Wight & Arn.	Asclepiadaceae	S	C
Tylophora indica (Burm.f.)Merr.	Asclepiadaceae	S	C
Tylophora marcantha Hook.f.	Asclepiadaceae	S	C
Tylophora tetrapetala (Dennst.)Suresh.	Asclepiadaceae	S	C
Utricularia caerulea L.	Lentibulariaceae	H	C
Uvaria naruram (Dunal)Blume.	Annonaceae	C	C
Vateria indica L.	Dipterocarpaceae	T	E
Vernonia anthelmintica (L.)Willd.	Asteraceae	H	C
Vernonia cinerea (L.)Less.	Asteraceae	H	C
Vicoa indica (L.)DC.	Asteraceae	H	C
Vitex altissima L.f.	Verbanaceae	T	C
Vitex negundo (L.)L.	Verbanaceae	T	C
Vitex trifoliata Merr.	Verbenaceae	S	C
Waltheria indica L.	Sterculiaceae	H	C
Wattakaka volubilis (L.f.)Stapf.	Asclepiadaceae	S	C
Wedelia chinensis (Osbeck.)Merr.	Verbanaceae	H	C
Wedelia trilobata L.	Asteraceae	H	Ex
Wrightia tinctoria R.Br.	Apocyanaceae	T	C
Xanthium indicum Koen.	Asteraceae	H	C
Zea mays L.Sp.	Poaceae	H	Ex
Zingiber neesanum (J.Graham.)	Zingiberaceae	H	R
Ziziphus mauritiana Mill.Gard.Dict.	Rhamnaceae	T	C
Ziziphus oenopllia (L.)Mill.	Rhamnaceae	C	C
Ziziphus rugosa Lam.	Rhamnaceae	C	C
Zornia diphylla (L.) Pers.	Fabaceae	H	C

12.5 River Bank design checklist:

Project Location		
Project Location	_____	
Type of Project (land use)		
Size of Project		
Is this a river dependent or critical service use?	□ Yes	□ No
30 ft. river setback (as verified by plat of survey)	□ Yes	□ No
Public Access	□ Yes	□ No
3.2 Multi-Use Path		
3.2.1 Design Criteria	□ Yes	□ No
3.2.2 Public Access	□ Yes □ N/A, please describe	□ No
3.2.3 Minimum Path Width, select all thatapply	□ Separated 12' bicycle, 8' pedestrian □ Combined, 16'	□ Combined, 10' □ Combined, 10' with 2' paved, gravel, or mowed shoulders □ Other, please describe below
3.2.4 Paving and Materials, select all thatapply	□ Granite □ Architectural Granite □ Poured-in-Place Concrete □ Concrete Pavers □ Unit Pavers	□ Permeable Pavers □ Asphalt □ Decomposed Aggregate □ Other, please describe below
Comments, please not which section from the list above (e.g. 3.2.3) you're describing		
3.3 Furnishings		
3.3.1 Site Furnishing Guidelines		
Materials, select all the apply	□ Stainless Steel □ Galvanized Steel □ Powder Coated Steel	□ Hardwoods, describe below □ Recycled Plastic Lumber, describe below □ Other, please describe below
Benches & Tables, on per 250 linear feet (LF) of river frontage.	LF of river frontage Total Benches Total Tables	_____ _____ _____
Trash and Recycling Receptacles, onemetal trash and one metal recycling receptacles per 250 linear feet (LF) of river frontage	LF of river frontage Total Trash Receptacles Total Recycling Receptacles	_____ _____ _____
Railings	□ Yes	□ No

Comments, please note which section from the list above you're describing	

3.4 Seating and Gathering Areas

3.4.1 Seating Area Guidelines

Location, one per 500 linear feet (LF) of river frontage.	LF of river frontage Total Seating Areas	_____ _____
Furnishings, Each seating area shouldprovide a minimum of two benches andone trash receptacle.	Total Benches Total Trash Receptacles	_____ _____

3.5 Lighting

3.5.1 Lighting Guidelines, see follow pages for an example of an acceptable product data sheet.

Fixture Height, recommended between14-30 feet tall	□ Yes, between 14-30'	□ Other, please describe below
Color Temperature, LED bulbs that provide white light with a color temperature of 3000K or below.	□ 3000K or below	□ Other, please describe below
Light Pollution	□ Dark Sky Compliant	□ N/A
Additional Features	□ Yes, please describe below	□ No
Security Lighting	□ Yes	□ No

Comments, please note which section from the list above you're describing	

3.6 Wayfinding and Signage

3.5.1 Lighting Guidelines

Brand and Identity	□ Yes □ N/A	□ No
Signage, indicate total signs	□ Yes □ N/A	□ No
Mile Marker, locate every quarter mile	□ Yes □ N/A	□ No
Regulatory Signage, indicate total	□ Yes	□ No

signs	□ N/A	
Identity Signage, indicate total signs	□ Yes □ N/A	□ No
Comments, please note which section from the list above you're describing		

3.7 Landscaping

3.7.1 Preservation and Restoration Guidelines

Preservation, preserve existing habitat and plantings	□ Yes □ N/A	□ No
Disturbance, minimize disturb	□ Yes □ N/A	□ No
Protection, protect existing vegetation during construction by installing tree protection fence	□ Yes □ N/A	□ No
Tree Preservation and Removal, preserve mature, healthy, native shade and evergreen trees	□ Yes □ N/A	□ No

3.7.2 Plant Selection Guidelines

Plant Selection, Identify total number of plants selected	Submergent Emergent Riparian Upland	_____ _____ _____ _____
Fencing, 4-6' ornamental metal fence for vehicular use areas, 4' ornamental metal fence for non-vehicular use areas	□ Yes , height _____ □ N/A	□ No
Trees, 2 per 25 LF of river frontage for vehicular use areas, 1 per 25 LF for non-vehicular use areas	LF of river frontage Total Vehicular Area Trees Total Non-Vehicular Area Trees	_____ _____ _____
Hedges, continuous hedge on the river side of fence is required for vehicular use areas	□ Yes □ N/A	□ No
Foundation Plantings, required for non-vehicular use areas	□ Yes □ N/A	□ No
Comments, please note which section from the list above you're describing		

3.8 Riverbank Treatments

3.8.1 Riverbank Guidelines		
Existing sloped riverbank is to beretained and improved	□ Yes	□ No

3.9 River Edge Treatments

3.9.1 River Edge Guidelines

Describe the proposed river edge stabilization and enhancement treatments.	

3.10 Sloped Bank Treatments

3.10.1 Sloped Bank Guidelines

Describe the proposed sloped banktreatments.	

3.11 Vertical Bulkhead or Seawall Treatments

3.11.1 Vertical Bulkhead or Seawall Guidelines

Describe the proposed vertical bulkhead and seawall guidelinestreatments.	

3.12 Guidelines for Improvements Outside of the Required Setback

3.12.1 Design, Orientation, and Massing of New Structures and Buildings

Placement, locate buildings and vehicular areas outside of the riversetback	□ Yes , height _____ □ N/A	□ No
River-facing façade, river-facing facadeshould be designed as a principal or major façade	□ Yes , height _____ □ N/A	□ No
Massing and Articulation, locate lower buildings with active frontage adjacent to river setback area. Step back massing along river. Locate taller buildings behind low buildings	□ Yes □ N/A	□ No

Neighborhood Transitions, step down height of buildings to transition to the scale of adjacent neighborhoods	□ Yes □ N/A	□ No
First Floor, activate first floors of buildings with direct access to river and multi-use path	□ Yes □ N/A	□ No
Wildlife, incorporate bird-friendly design standards into building designs	□ Yes □ N/A	□ No
Sunlight, river corridor should have sunlight for approximately six (6) hours per day	□ Yes □ N/A	□ No

3.12.2 Screening Guidelines

Outdoor Storage, if necessary, storageareas should be locatede beyond the minimum 30' setback area	□ Yes , height _____ □ N/A	□ No
Materials, select all that apply	□ Poured-in-Place Concrete □ Split Face Concrete Masonry Units □ Ground Face Concrete Masonry Units	□ Heavy Wood □ Other, please describe below
Walls and Fences, screening walls andfences should be planted with vines at the base	□ Yes □ N/A	□ No
Access, fencing that separates theriverfront from the outside of the setback area should be avoided	□ Yes □ N/A	□ No

CERTIFICATE OF COMPLETION

This is to certify that this thesis project titled "**Blue-Green Infrastructure Planning for a Sustainable Development - Tirunelveli**" was carried out by Smt. **Karpagavalli S**, a student of **Master of City Planning**, at the **Indian Institute of Technology, Kharagpur**. The research for this project was undertaken under the guidance of the afore-mentioned institute and completed during the period of **2.8.2021** to **19.04.2022**.

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This report has been submitted by the student as a final deliverable under the competition. All parts of this research can used by any of the undersigning parties.

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