Blue-Green Infrastructure Planning for a Sustainable Development: A Case of Tirunelveli

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Abstract

Globally, numerous urban centres are transitioning their planning methodologies towards nature-centric strategies as alternatives to conventional grey infrastructure solutions. This paradigm shift incorporates both green and blue elements which is driven by heightened environmental consciousness, particularly regarding climate change. This study investigates the emerging concept of “Blue-Green Infrastructure” (BGI), analysing the ongoing initiatives in India and internationally. Furthermore, it proposes prospective measures to foster sustainable urban development, mitigate urban river pollution, and enhance overall urban functionality, with a specific focus on Tirunelveli. Informed by global and domestic case studies, this paper aims to reconcile the divergence between traditional urban planning frameworks that are typically characterized by either Green Infrastructure or Water Sensitive Planning, by advocating for integration of BGI as an innovative urban strategy.

Keywords: Blue-Green Infrastructure (BGI), Water-sensitive Planning, Nature-based Solutions

Introduction

In the aftermath of the COVID-19 pandemic, numerous nations formulated economic recovery plans. However, there was also widespread recognition globally of the importance of sustainable resurgence, with focus on mitigating climate change impacts and undertaking long-term rehabilitation efforts in urban areas (Chandra, 2022). Due to urbanization, cities, the major contributors to climate change, are experiencing significant loss of green and blue elements across India.

For instance, studies have revealed alarming transformations in cities like Bengaluru, where urban areas have expanded by over 900 percent in just four decades, leading to depletion of green spaces and waterbodies (Ramachandra, 2017). Similarly, Mumbai has witnessed a decline of 60-65 percent in biodiversity and waterbodies due to urbanization (Fermades & Chatterjee, 2017). This has been the scenario of many metropolitan and large cities, thus making long-term sustainable development all but impossible.

This significant depletion in the environment has been unintentionally caused by incompetency to proficiently streamline, govern, and oversee the urban infrastructure and planning processes. Of the four threats that are anticipated to adversely affect countries due to climate change, only one pertains to governmental inadequacy in implementing sufficient measures to mitigate climate change. The remaining three threats are environmental in nature and largely stem from unplanned and negligent urban development practices (World Economic Forum, 2020).

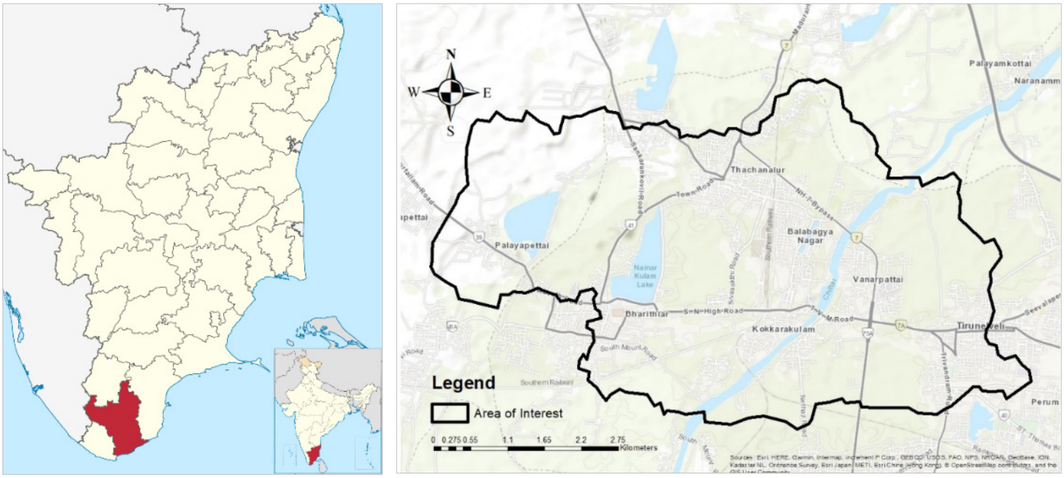
Hence, it is imperative for governments to prioritize their actions which are aimed at climate-proofing cities and promoting sustainable urban growth. But, previous attempts to address climate-related environmental problems by adapting conventional “grey infrastructures” have fallen short of providing long-term sustainable solutions, because they were temporary technological fixes. Instead, they should be more ecologically conscious by implementing and adhering to nature-driven approaches, a purpose purely offered by development of ‘Blue-Green Infrastructure’.

Study Area

Urbanization comes at the cost of diminishing greenery and waterbodies in cities, which result in significant environmental challenges. The city of Tirunelveli in Tamil Nadu, though still in its developmental phase, is not immune to this trend. Even though we have seen many cities reach a point of overcrowding and diminished resources, Tirunelveli is still in its developmental period. As such, it presents us with the opportunity to restore its balance with nature and prevent further loss of the blue-green elements.

Situated within the urban cluster of Tirunelveli District, the study area spans 29.18 square kilometres and is defined by contours and hydrological catchments. Central to this area is the Thamirabharani River, the only perennial river in Tamil Nadu, that flows from the Western Ghats to the Bay of Bengal, traversing Tirunelveli and Tuticorin districts.

Figure 1: Location of the Study Area: Tirunelveli



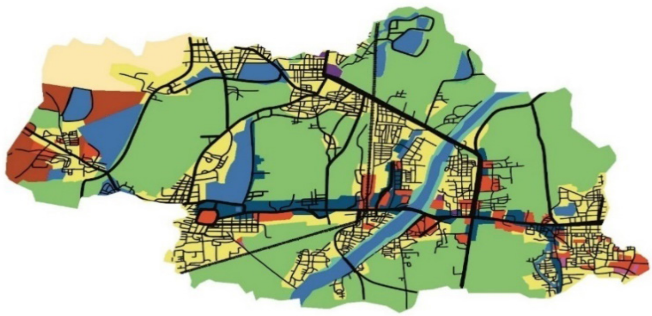
Source: Using base map sourced from ESRI

Figure 2: Water Network in Tirunelveli

Source: Using Secondary water resources data from Nellai Neervalam, on the base map sourced from ESRI

A comprehensive analysis of the study region reveals the presence of thirteen water tank pits that are interconnected by two channels. This interconnectedness presents the potential for establishing a network between the blue and green infrastructures which are crucial for sustainable urban development. The site area comprises 11% waterbodies and 52% green spaces. Over the years, the amount of blue and green components in the city has decreased drastically. Unfortunately, waterbodies which are a vital part of human settlements, have begun to lose their importance in the process of urbanization and there is an urgent need to address this issue via conscious urban planning.

Figure 3: Land Use Distribution in Tirunelveli



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

Source: Secondary Data from Tirunelveli Municipality

With an integrated network of blue-green spaces, it is possible to address the environmental issues that are present in the urban areas while also providing value and connection with society. This not only helps in reviving the environment but also enhances and protects the overall functioning of urban areas.

Objectives

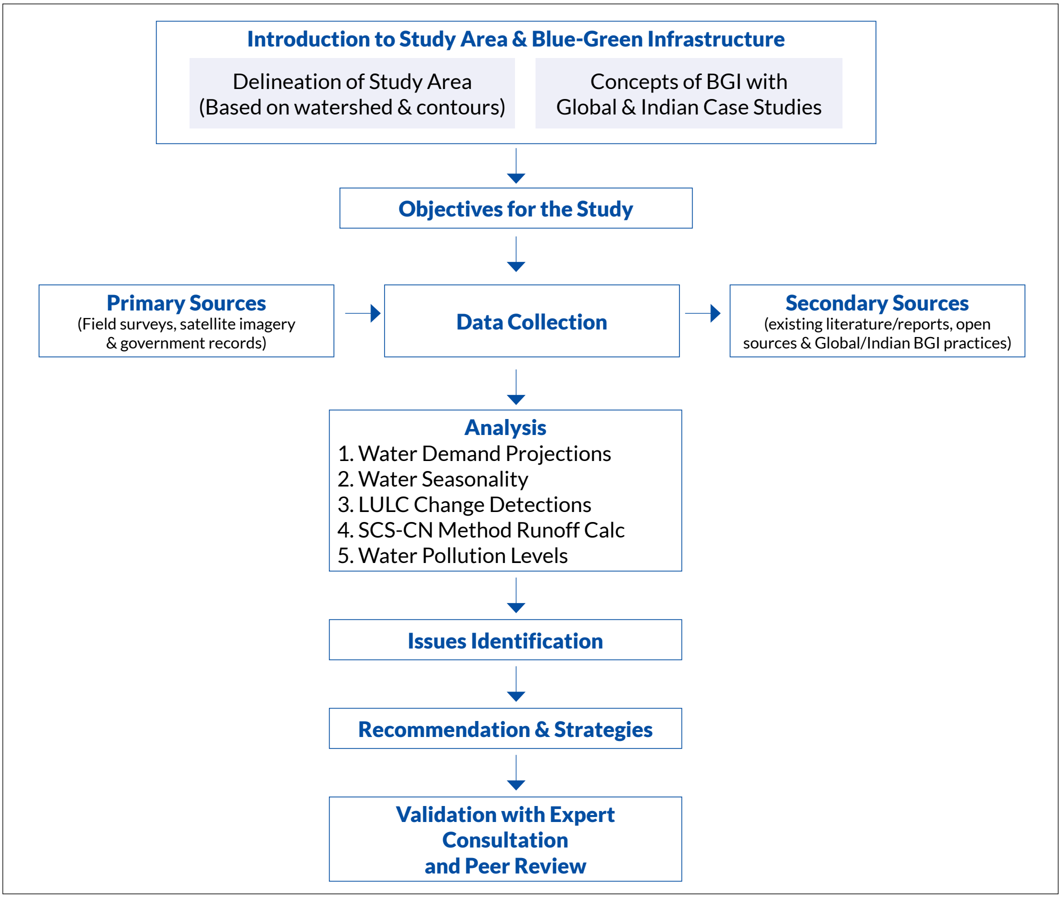
The objectives of this study are:

- To enhance the functionality of the city through blue and green networks.
- To future-proof and increase water availability of the city.
- To reduce water pollution and rejuvenate the waterbodies.
- To provide year-round recreation to strengthen the connections between society and nature as well as protect urban biodiversity.

Methodology of the Study

The methodology employed in this study involved a multi-faceted approach to assess the current state of the Blue-Green Infrastructure (BGI) and address the associated challenges in the study area. The following steps were undertaken:

Flow Chart 1: Methodology



- **Data Collection:** Comprehensive data collection was conducted to gather information on land use/land cover, surface temperatures, water demand, availability projections, sewage outfalls, and contamination levels. Primary data sources included field surveys, satellite imagery, and government records. Secondary data sources comprised of existing literature, reports, online open sources, and databases related to BGI global practices and in India.

- **Analysis:** By correlating the following analyses, the study attempted to provide a holistic understanding of the blue-green resource management in the study area, encompassing both quantitative assessments of water availability and qualitative evaluations of water quality and environmental health.

  - The **water demand and availability projections** data for the year 2040 were analyzed to gain insights into the future water requirements and potential challenges that are associated in meeting them.

- The **seasonal patterns and trends of water availability** were analyzed to understand the fluctuations that take place throughout the year, and which are crucial for effective water resource management.
- The **detection of land use/land cover changes** were performed and correlated with the surface temperature data to identify the relationships between land use changes, availability of green areas, and temperature variations within the urban clusters.
- **The SCS-CN method** was then employed to assess the impact of land use changes on **water runoff**, aiding in the evaluation of the effects of urbanization and land development on hydrological processes.
- Evaluation of **water pollution in the river** including sewage outfalls and contamination levels, was conducted to assess the water quality and environmental impact which helped in guiding strategies for improvement of water quality and leading to environmental protection.

- **Issues Identification:** Following the analysis, the issues of the study area were identified, which encompassed land use conversions, urban heat islands, water network system challenges, poor drainage systems, sewage contaminations, and encroachments on waterbodies.

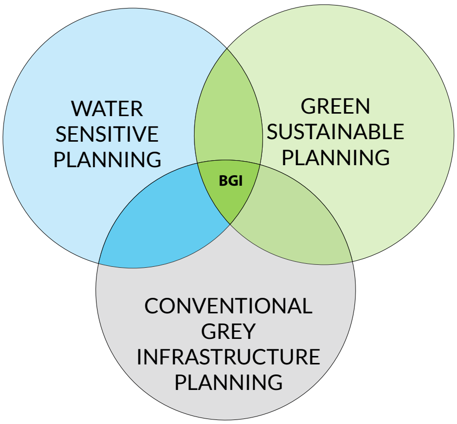
- **Recommendations and strategies** were developed to address these issues.

Methodology and findings were then validated through peer reviews, expert consultations, and comparison with existing studies and best practices in Blue-Green Infrastructure (BGI).

Blue-Green Infrastructure (BGI): An Urban Solution

Blue-Green Infrastructure (BGI) is a holistic urban planning approach that is aimed at creating interconnected networks of green and blue spaces within urban areas. These spaces are strategically planned and managed which provide a range of ecosystem services and other benefits to the environment, economy, and society.

Figure 4: Concept of Blue-Green Infrastructure (BGI)



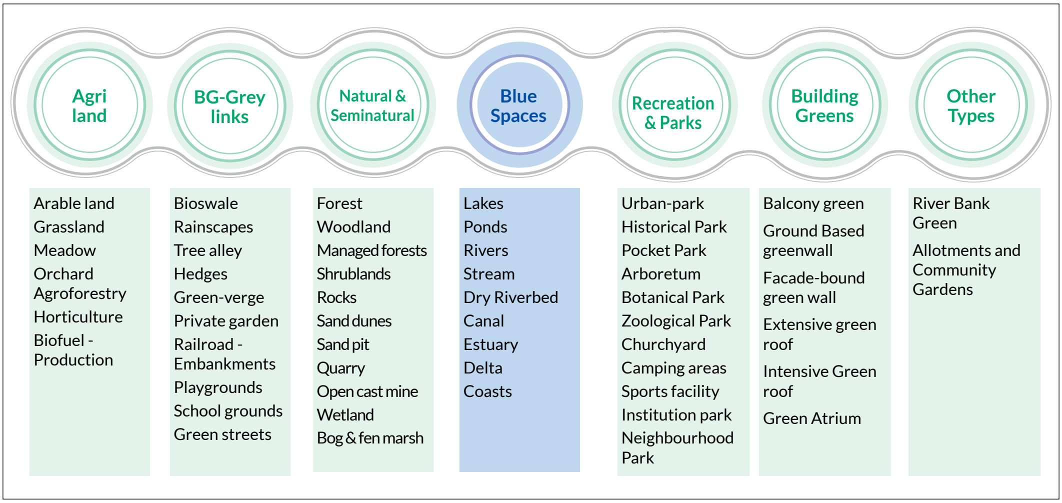
While there is no universally accepted definition of BGI, it is used interchangeably with Green Infrastructure. However, it is important to acknowledge that Green Infrastructure includes blue components as well. Thus, BGI emphasizes the integration of both green (land) and blue (water) spaces to improve environmental conditions and enhance the well-being of citizens.

"Green Infrastructure is a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services such as water purification, air quality, space for recreation, and climate mitigation and adaptation. This network of green (land) and blue (water) spaces can improve environmental conditions and therefore citizens' health and quality of life. It also supports a green economy, creates job opportunities, and enhances biodiversity", as defined by the European Commission (2013).

Addressing the Gap Between Blue and Green Initiatives

Despite the recognition of the importance of BGI, there exists a gap in its implementation at the administrative level. Initiatives focus on single objectives that are related to either green or blue components of the environment, such as water-sensitive planning, green infrastructure, stormwater management, flood management etc. (E2Designlab, 2017). BGI aims to bridge this gap by coordinating with the greening and water management efforts to achieve complementary results.

Figure 5: List of Blue and Green Spaces in the Paradigm

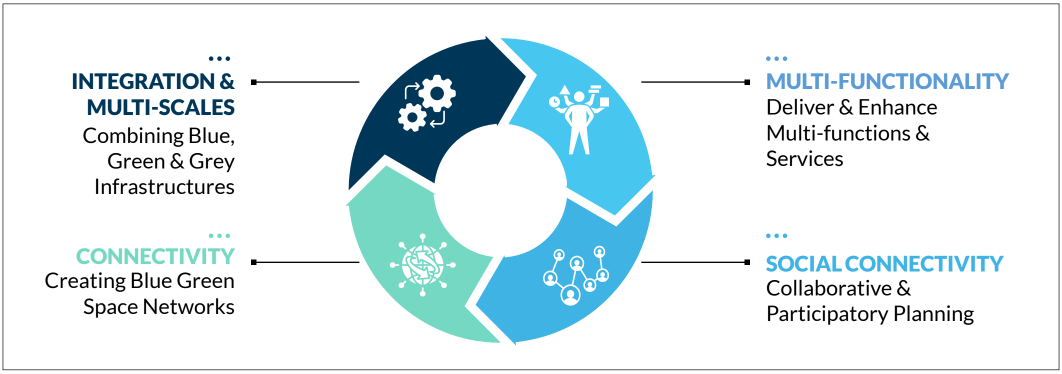


Core Principles of BGI

Effective planning of BGI requires the consideration of various operational scales, from local to city-wide or watershed levels, as well as their long-term effects. The four core principles of Blue-Green infrastructure were identified after a thorough understanding of its functions and benefits. These principles emphasize the importance of coordinating urban blue and green areas, establishing interconnected networks, maximizing benefits, and engaging diverse stakeholders in the planning process. The core principles of BGI are:

- **Integration of infrastructures at different scales**: To integrate and coordinate urban blue and green areas at multiple scales ranging from meso, through nano, micro, and macro scales of perspectives.
- **Connectivity of spaces:** To establish a blue-green network that helps to enhance and safeguard the multi-functions of the network components which an isolated space cannot deliver on its own.
- **Multi-functionality:** To consolidate the various initiatives and enhance the potential of urban blue-green spaces, thereby enabling them to offer numerous advantages and benefits.
- **Social connectivity:** To ensure implementations and solutions that actively involve participation from a diverse range of stakeholders which foster social inclusivity.

Figure 6: Core Principles of BGI



Global Blue-Green Infrastructure Practices

Blue-green initiatives, also known as nature-driven solutions, have been implemented globally over the past two decades to address a range of urban challenges. While these initiatives differ in characteristics and objectives depending on the specific issues they aim to tackle, the knowledge gained from these actions informs the development of Blue-Green Infrastructure methodologies for urban problem-solving. Table 1 provides an overview of these measures:

Table 1: Learnings from Global Blue-Green Strategies

Location	Strategy	Motivation for BGI	Intent/Outcome
Singapore	Active, Beautiful, Clean (ABC) Water Program	Adaptation to climate change	To fully harness the potential of the extensive network of drains, canals, and rivers, the development of 17 reservoirs, and other drainage systems over time has been planned to boost tourism and improve water quality. (Dreiseitl, 2016)
		Flood prevention, groundwater level	
		Water pollution, water Recycling	
		Increasing biodiversity	
		Increasing permeability	

Location	Strategy	Motivation for BGI	Intent/Outcome
Gorla Magiore Waterpark, Milano	Wetland Constructed System	Decrease in floods Decrease in river pollution Ecosystem services Increase in Biodiversity Carbon sequestration Sustainable urbanisation	Constructed wetlands outperform the grey infrastructure treatment plants for water treatment and flood mitigation. Despite having comparable expenses, constructed wetlands offer additional benefits such as wildlife support and recreation, which are highly valued by neighbouring communities.
Wuhan, China	Sponge City Program	Lake rejuvenations Stormwater management Water sensitive planning Flood management Reduced water pollution	The city has set annual stormwater retention goals by zoning certain land areas and ensuring that urban infrastructure can absorb the run-off. This is achieved by allocating 20% of the land to absorbent blue-green elements. (Jing, 2019)
Hannover, Germany	Sustainable Housing Community	Rainwater management Increasing permeability Renaturation Natural Recreation in Dense Settlements	With the concept of "every single drop matters" in mind, rainwater harvesting has been prioritized, along with a semi-natural run-off strategy. There is also emphasis on maintaining a constant status of the aquifer in the local area. (Dreiseitl, 2016)
Philadelphia	Green City Clean Water Plan	Stormwater management Flood management Sustainable urbanisation Groundwater recharge Decrease in pollution Permeability Carbon sequestration	Embracing the five paradigms of infrastructure systems, the city successfully renovated its century-old drainage system. It implemented rainwater harvesting management throughout the city by incorporating bioswales, retention tanks, and drainage channels to enhance water resilience.

Indian Practices of Blue-Green Infrastructure

Indian cities like Delhi, Bhopal, Madurai, and Bengaluru are increasingly incorporating the Blue-Green Infrastructure into their development plans to enhance environmental resilience of urban areas, despite the concept being relatively new to the Indian context. The primary aim of these plans is to enhance the city's natural blue network system and adjacent public spaces through strategic and intentional interventions.

However, implementing such approaches in Indian cities presents significant challenges. These cities are already densely inhabited and are facing multiple development issues such as mixed land use, imbricating responsibilities of different institutions, distorted urban growth, technological challenges etc. With limited space for blue-green facilities within these densely built environments, any new Blue-Green Infrastructure initiative must demonstrate high efficiency and adaptability to ensure sustainable development outcomes.

Table 2: Learnings from Blue-Green Initiatives in India

Location	Strategy	Motivation for BGI	Intent/Outcome
Delhi	Blue-Green Master Plan of Delhi 2040	Flood Prevention	For preservation of the environment and enhancement of urban development, an integrated network of BGI has been envisaged to be provided throughout the city to ensure the city's resilience against major future shocks and calamities. A "Blue-Green Policy" has been drafted and introduced for the country. (DDA, 2021)
		Decrease in pollution	
		Aquifer Recharge	
		Rising permeability	
		Increase in Biodiversity	
		Green corridors	
		Afforestation	
		Natural recreation space and values	
Bhopal	Blue-Green Master Plan of Bhopal 2021	Lake rejuvenation	To enhance, preserve, and develop the green elements and build a sustainable urban environment. (NIUA, 2016)
		Sustainable Urbanisation	
		Water management	
		Water recycling	
		Waste management	
		To increase green spaces	

Analyses

Water Demand & Availability Projection for 2040

As per data from the Public Works Department (PWD), the overall quantity of water obtainable in the Thamirabarani River basin including surface water, groundwater, recycled, and de-silted water is estimated to be 1740 MCM (Million Cubic Meters). The projected data shows that in 2040, the amount of water available for urban sectors is only 135 MCM, which means that by then the water demand will be equal to or higher than the current availability which demonstrates the need to increase the amount of water available.

Seasonality Occurrence Analysis

The JRC (Joint Research Centre) Global Water Data has been utilized to assess the seasonal occurrence of waterbodies. The results of the study demonstrate that the majority of waterbodies in the area retain water for only 4-6 months, while a few can last the year. This indicates that there is an imperative need to boost the availability of water throughout the year.

Figure 7: Seasonal Water Occurrence of Waterbodies in Tirunelveli

Figure 7 (a): Water Availability in the Waterbodies from January-February (Winter)

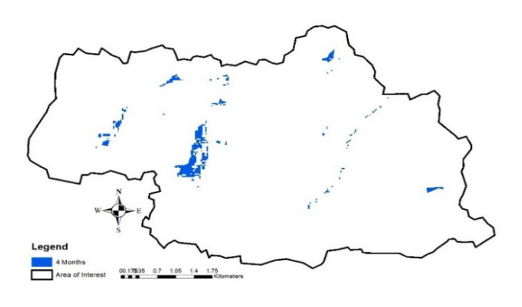


Figure 7 (b): Water Availability in the Waterbodies from March-May (Summer)

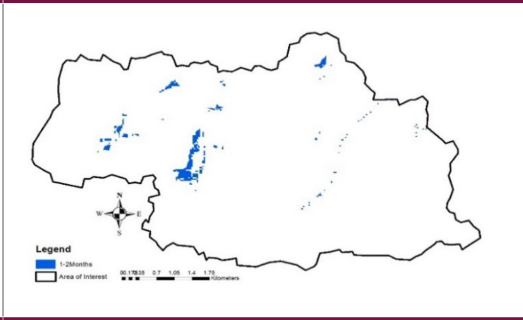


Figure 7 (c): Water Availability in the Waterbodies from June-October (Pre-Monsoon)

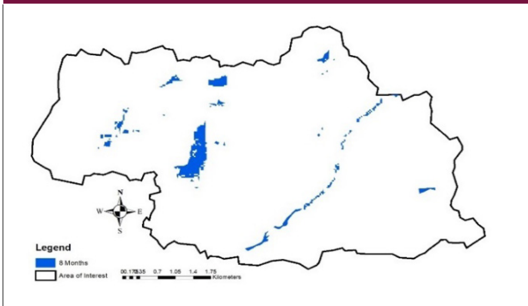
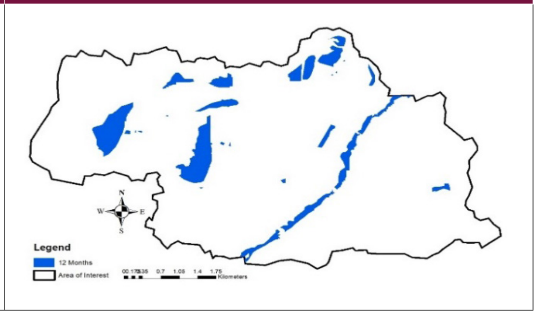


Figure 7 (d): Water Availability in the Waterbodies from October to January (Post-Monsoon)

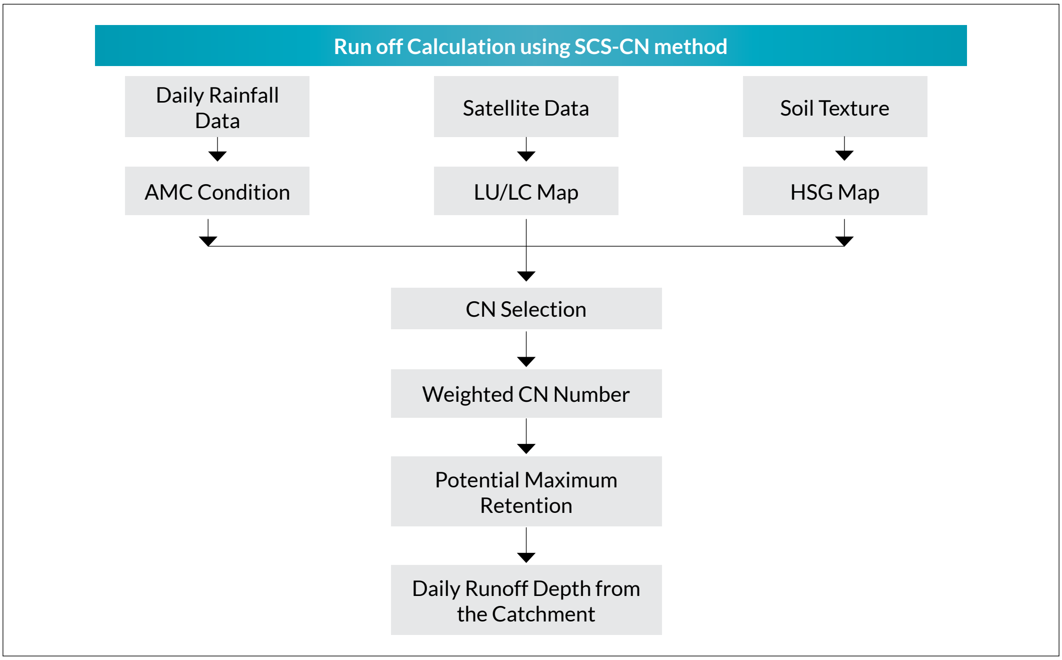


Source: Analysis using secondary resources from JRC Global Water Data Archive

Run-Off Calculation Using SCS-CN Method

The annual run off from the catchment area was calculated using the Soil Conservation Service – Curve Number (SCS-CN) method as demonstrated in Figure 8 to better understand its potentiality.

Figure 8: Method Used to Calculate the Annual Run off Using SCS-CN Method



Source: Dhawale, A.W. (2013)

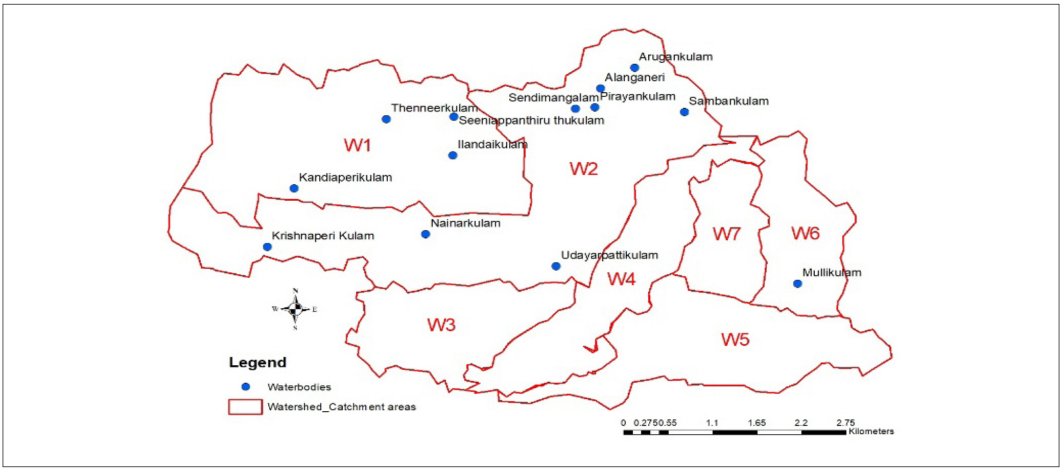
Table 3: Findings of Run Off Calculation for the Whole Watershed

Total Rainfall in the Year	1555.56 mm	**Total Run Off in the Year**	526.78 mm
Total Rainfall Volume in the Year	46.14 MCM	**Total Run Off Volume in the Year**	15.63 MCM
Percentage of Run Off from Rainwater		34%	

According to the analysis, 46.14 MCM of rainfall was recorded in the entire study area, out of which 34% was in the form of run off (15.63 MCM). This run off either drains into the rivers or gets wasted along with sewers.

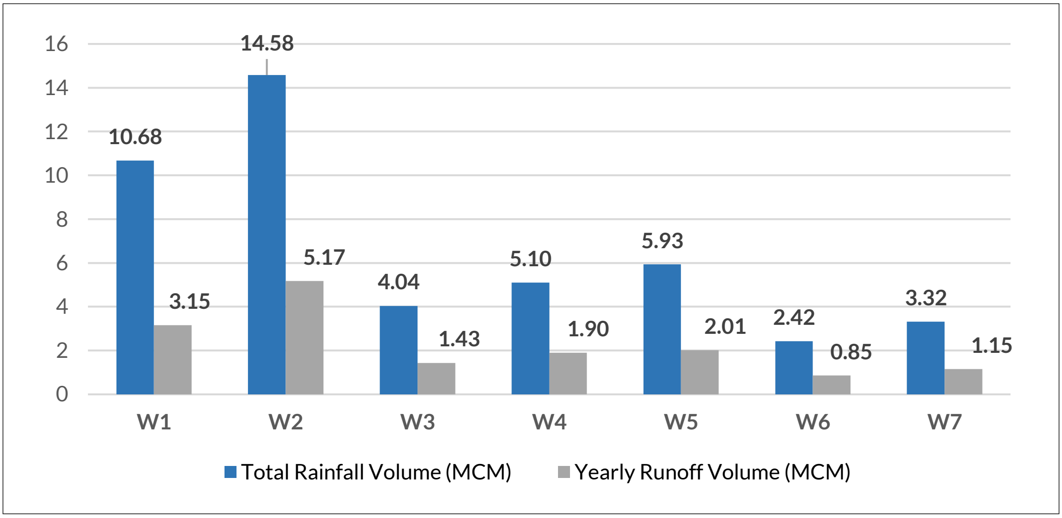
In addition, the entire watershed has been divided into seven distinct catchment zones as shown in Figure 9. With similar methodology, their individual run off volume and depth have been computed as well. Consequently, the run off percentages for smaller catchments/watersheds range from 30-35% which presents great opportunities to improve the water supply through storage or infiltration systems in the areas.

Figure 9: Smaller Catchment Areas Inside the Watershed Along with Placement of Waterbodies in Tirunelveli



Source: Delineation using Digital Elevation Model (DEM) in GIS

Figure 10: Comparison of Total Rainfall Volume and Run Off Volume in Tirunelveli



Potential to Increase Water Availability

After considering the run off depth and the storage capacity of the existing waterbodies in watersheds, it was calculated that 11.89 MCM of water can be augmented for the study zone, apart from the watershed with a river. Despite that the Watershed W2 has several waterbodies, it is still capable of storing an additional 4.34 MCM of water.

Table 4: Potential of Increased Water Availability from Run Off Volume in Tirunelveli

	Name of Tank	Tankpit Area/ Ayacut in Ha	Water Capacity of Tankpits in MCM	(Existing) Watershed's Total Water Storage Capacity in MCM	Watershed ID	Run Off Volume in that Watershed area (MCM)	Potential to Increase Water Availability = Run Off Capacity (MCM)
1	Kandiaperikulam	161.81	0.947	1.0426	W1	3.15	2.1100
2	Seeniappanthiru thukulam	30.4	0.0125				
3	Ilandaikulam	30.42	0.0782				
4	Thenneerkulam	10.715	0.0049				
5	Krishnaperikulam	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 waterbodies in these catchment areas (W3, W5, W7) 0.00 0.00		0.00	0.00	0.00	W3	1.43	1.43
		0.00	0.00	W5	2.01	2.01	
		0.00	0.00	W7	1.15	1.15	
Total Capacity of all Waterbodies = MCM			1.8848 MCM	Potential to Increase Water Availability			11.89

Source: Analysis using secondary water resources data from Nellai Neervalam

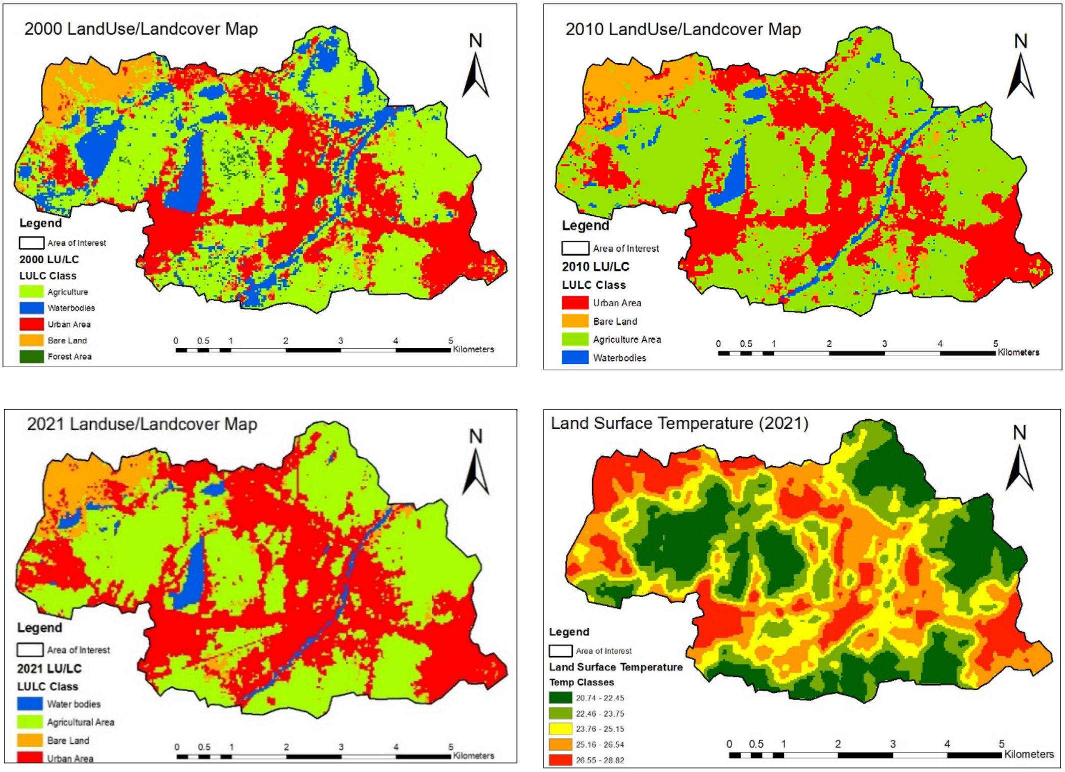
LU/LC Change Detection and Comparison with Surface Temperature

Land use/Land cover analysis was conducted for the years 2000, 2010, and 2021 which revealed that there is a gradual decline of waterbodies and forest areas over this period. The study area experienced rapid urbanisation which resulted in the transformation of small ponds and creeks into other land uses such as barren land and urban areas.

The development was along one of the major transit lines that connects the CBD (Central Business District) to the suburbs. Between the city and the suburbs, there is a significant difference in surface temperature. The urban heat effect is seen in highly populated areas such as the city centre near the temple, or the older settlements close to the river. Areas with large waterbodies and vegetation typically remain relatively cooler.

Since 2010, there has been an increase of more than two degrees in the temperature of urban zones which suggests the formation of a heat island. To counter this effect, green policies must be implemented and embraced for better results.

Figure 11: LU/LC Classification of 2000, 2010, and 2021 and LST Map of 2021, Tirunelveli



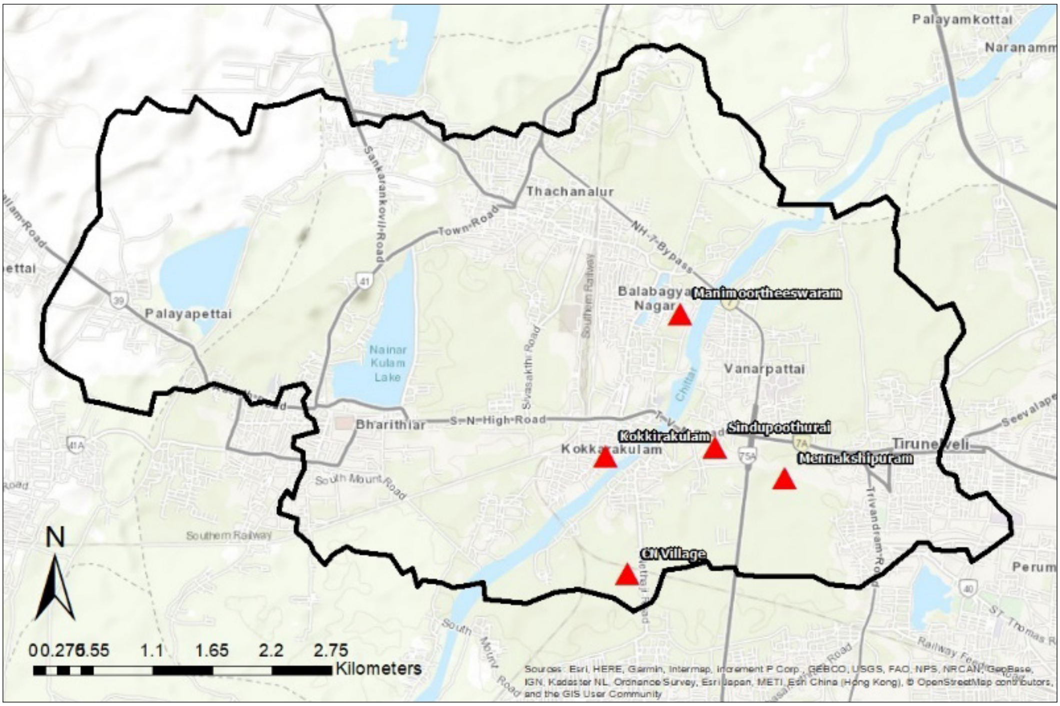
Note: Methodology for LST adopted based on Ugur & Gordana, 2016.

Source: Author using GIS Software

Sewage Outfall and Contamination Level Analysis

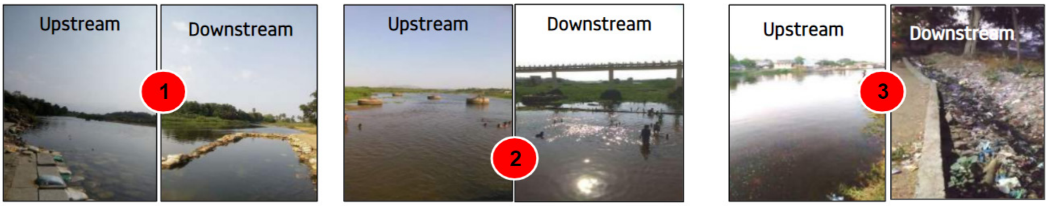
There are five sewage outfall points in the study area. As per CPCB (Central Pollution Control Board) Tirunelveli, the quality of water at these outfall spots satisfies both class-B and Class-C standards. There is a 7.77 MLD gap between the water generated and the sewage water that gets treated. This is discharged directly into the river through these outfall intrusion points. This gap needs to be addressed and using Nature-based Solutions could provide more benefits to the environment than any conventional treatment plant.

Figure 12: Sewage Outfall Spots in Tirunelveli



Source: Secondary Data from CPCB, Tirunelveli

Figure 13: Reconnaissance Survey Pictures Showing Condition of Sewage Outfall Spots along the Thamirabarani River



Source: Pictures taken by Author on 12.01.2022

Table 5: Showing Sewage Treatment Gaps in the Municipal Corporation, Tirunelveli

Urban Area	Total Amount of Sewage Produced	Total Amount of Sewage Fed into the Treatment Plant
Tirunelveli M. Corp	31.97 MLD	24.2 MLD

Source: Secondary Data from CPCB, Tirunelveli

Issues Identified

The following issues were identified from the comprehensive analysis conducted in the study area:

- Conversions of land use from blue to green to urban areas.
- Rapid urbanization led to the emergence of Urban Heat Islands in densely populated settlements.
- There is potential for improving the existing water network system.
- Many areas suffer from poor drainage systems and impermeability.
- Most tank pits have surface water availability for only 4-6 months per year.
- In two decades, water availability balances out with demand, leaving little surplus for use.
- Approximately 34% of rainwater is converted into run off, resulting in wastage.
- There is potential to increase water availability in the watershed by 11.89 MCM through various means.
- Quality of discharge water into the river requires improvement.
- It is necessary to address the 7.77 MLD gap between sewage generated and treated in the city.
- Lack of recreational spaces and encroachments in floodplains is evident from people's perceptions and expert opinions.
- Dumping of waste/construction materials into waterbodies is a significant concern.
- Inadequate leisure facilities around waterbodies hinder the social connectivity with nature.

Recommendations and Strategies

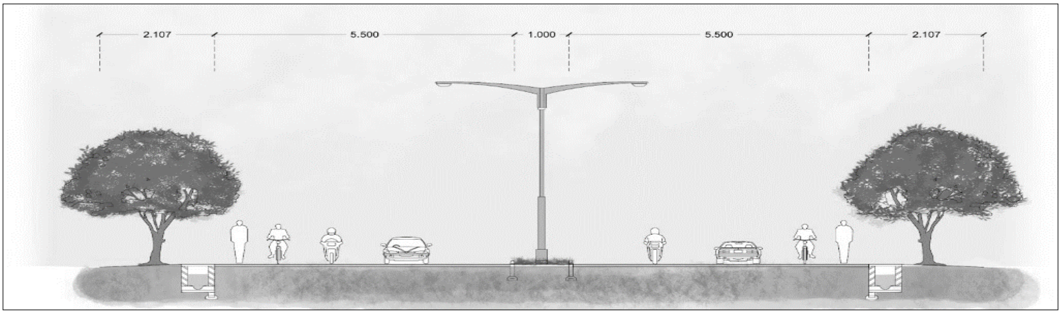
This section outlines the proactive measures that are aimed at addressing the identified issues and promoting sustainable management of water resources and environmental conservation in the study area. With focus on improvising and integrating Blue-Green infrastructure, the proposals include:

- Improvisation and integration of Blue-Green infrastructure, such as roads and water channels, is proposed with the main aim of managing stormwater at its source and redirecting it to the available water resources and to the ground.
- It is recommended to construct two retention basins, with a total volume of approximately 11,500 cubic meters, on the same land where two waterbodies were converted into green spaces, as per the land use/land cover analysis. This is correlated with the potential to hold more water based on the SCS-CN method that was used to calculate the watershed run off.
- To mitigate the existing sewage treatment gap, constructed wetlands with vertical subsurface systems have been suggested to treat the quantity of discharge water that is effectively flowing into the river.
- Riparian region regulations and development initiatives are advocated to prevent encroachments, foster social connectivity with nature, establish green corridors, and promote river-centric planning, thus ensuring sustainable management of river ecosystems.

Road Improvisation with Blue and Green Elements

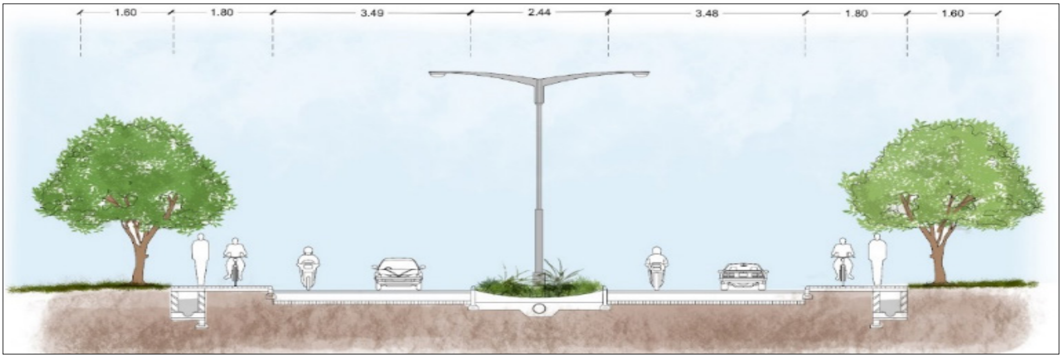
Retention boulevards include a green, slightly sunken median that transports and slowly absorbs rainwater through infiltration while still enabling ordinary vehicles to use the street. They involve reducing the capacity of existing highways; therefore, this kind of initiatives can be highly useful along major, underused metropolitan networks. *Example: S.A. Plads, Copenhagen.*

Figure 14: Existing Road Section of Arterial Roads



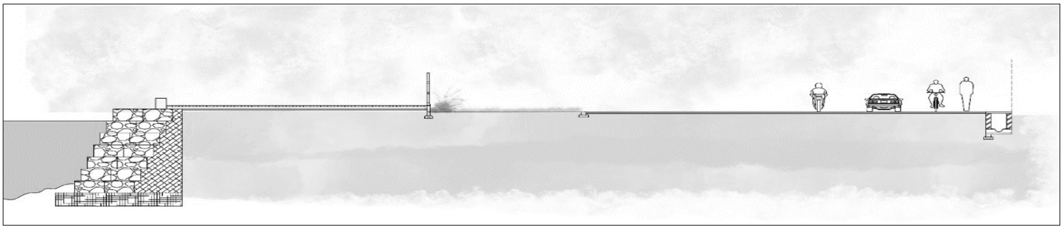
Source: Author

Figure 15: Proposal of Retention Boulevards - Roads Section



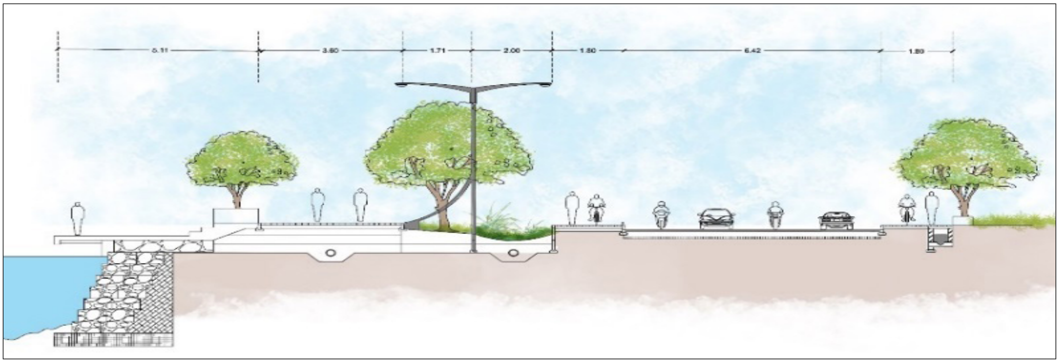
Source: Author

Figure 16: Existing Road Section of Collector Roads



Source: Author

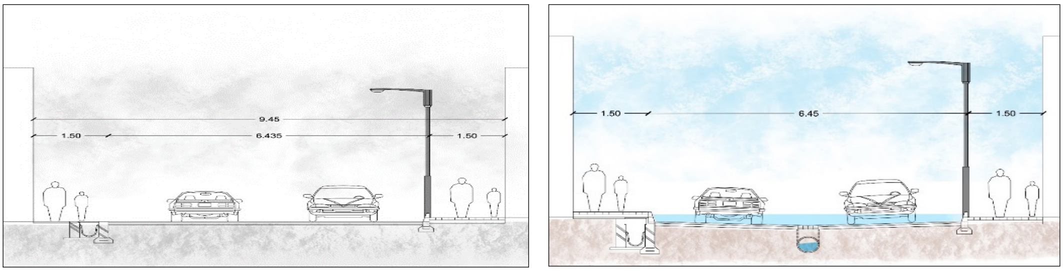
Figure 17: Proposal of Green Streets - Road Section



Source: Author

Green streets are recommended to have linkages with cloudburst roads. The infiltration planters and porous surfaces should be used in conjunction with the nearby waterways to create green streets. *Eg: Watts Branch, DC.*

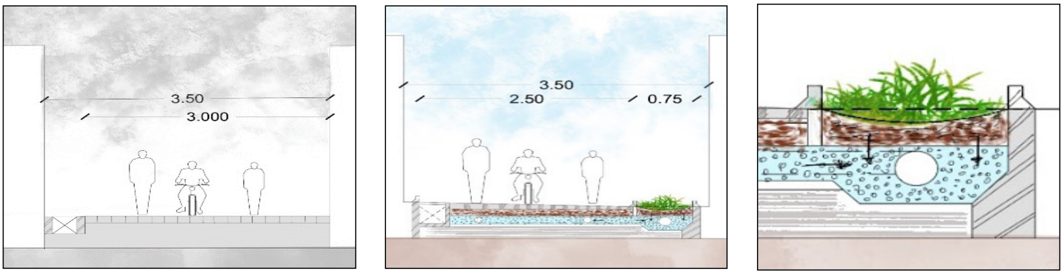
Figure 18: Existing Road Section of Sub-Arterial Roads (Left Image) & Proposed Road Sections for Burst Pipe Road (Right Image)



Source: Author

To ensure connectivity and not hinder the busy traffic on the road, pipes are positioned just under street level to collect and convey water to the nearby waterways. The cases where there is not enough room for above-ground transportation, burst pipe road proposals are recommended and built with a V-shaped profile. *For example: Cloud Burst pipe roads in the Pladds area, Copenhagen.*

Figure 19: Existing Road Section of Local Roads (Left Image), Proposed Road Sections for Retention Alley (Middle Image), and Bioswale Detail Section (Right Image)



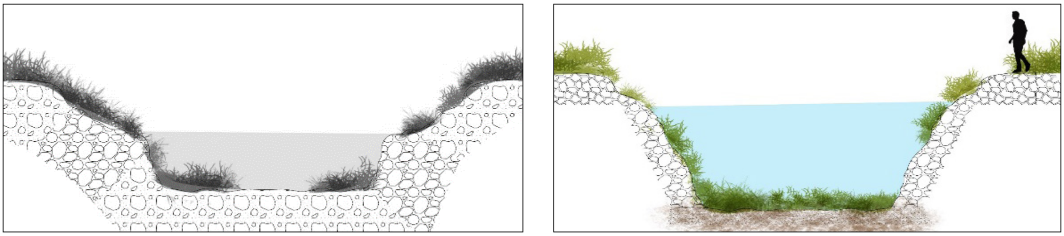
Source: Author

Normally, retention alleys are in areas which lead to vulnerable low-lying regions. Through sponge planters, bioswales, and filtrating surfaces, retention alleys provide delayed transit of stormwater and potential detention of the same. *For example: Hans Tavsens Park, Copenhagen.*

Water Channel Improvisation with Blue and Green Elements

Urban creeks involve old streams that serve as transportation links between other waterbodies. Urban streams, which are smaller in size, can restore or build stronger neighbourhood character and social areas. *For instance: Creeks or streams in Arkadien Asperg, Stuttgart, Germany, etc.*

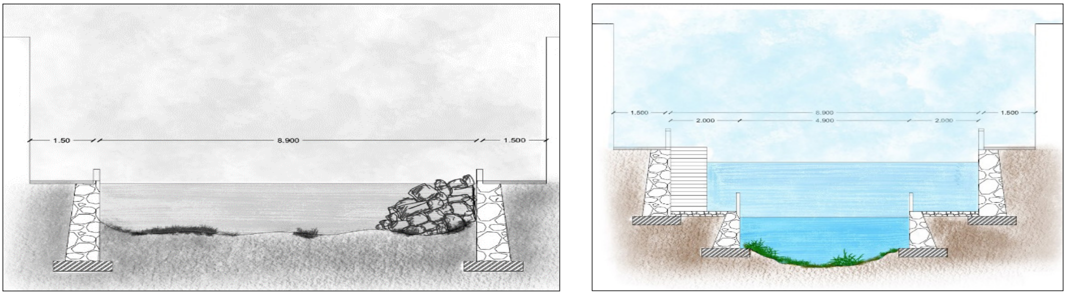
Figure 20: Existing Road Section of Urban Creeks (Left Image), Proposed Road Sections for Urban Creeks (Right Image)



Source: Author

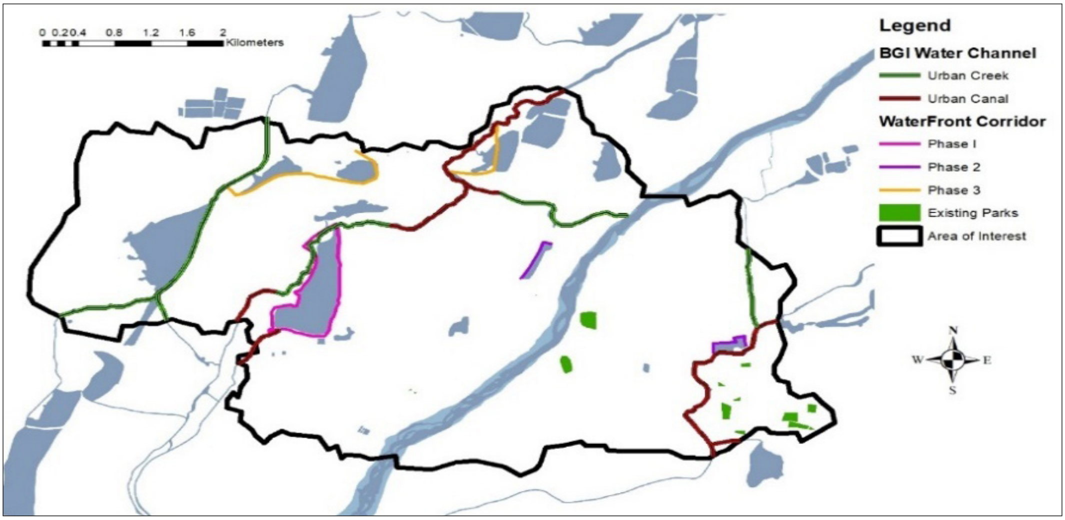
Urban canals entail water channels within a congested urban environment. They can be created to add fresh, healthy respite to the city while boosting biodiversity and the potential for stormwater run off. *For example: Cheonggyecheon Canal in South Korea.*

Figure 21: Existing Road Section of Urban Canals (Left Image), Proposed Road Sections for Urban Canals (Right Image)



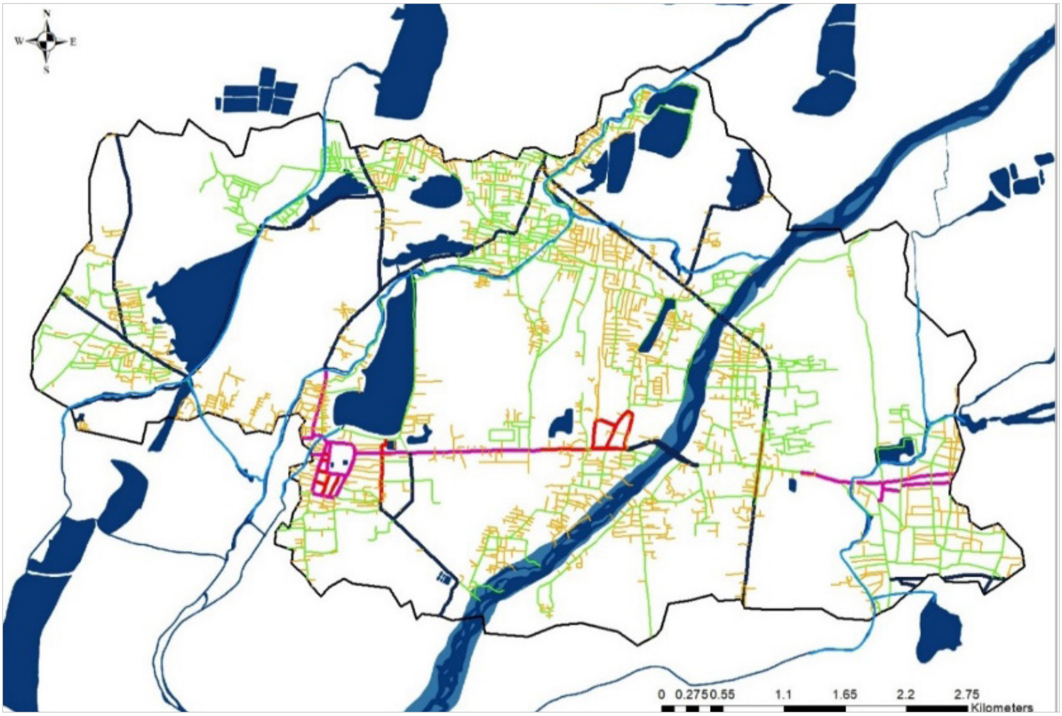
Source: Author

Figure 22: Proposed Urban Creeks and Urban Canals with Waterfront Corridors, Tirunelveli



Source: Author

Figure 23: Proposed Roads Connected with nearby Waterbody for Drainage of Stormwater, Tirunelveli



Source: Author

Table 6: Length of the Proposed Roads and Water Channels

Road/Street Type	Length (km)	Water Channel Type	Length (km)
Cloudburst Roads	4.30	Urban Canals	8.350
Cloudburst Pipe Roads	6.73	Urban Creeks	9.146
Retention Boulevards	22.3		
Green Streets	105.72		
Retention Alleys	112.90		

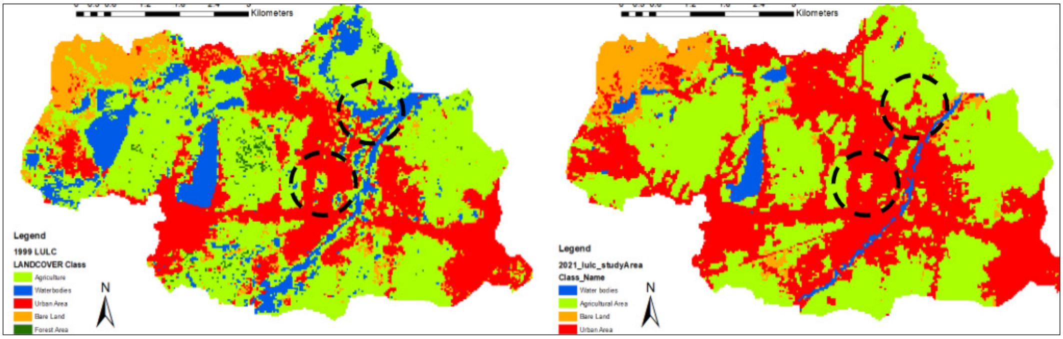
Source: Author

The BGI Road Typologies are put forward in the area under consideration following alignment with the contour. Furthermore, they are proposed as per the inclination so that stormwater can be effectively guided towards any nearby waterbodies and channels. It is recommended to designate waterfront corridors to facilitate the connection between people and waterbodies, thus helping in cultivating a bond with the natural surroundings.

Retention Basins

With 11.89 MCM of run off available from rainwater, so to increase the water availability, two retention basins have been proposed in the low-lying elevations in the middle of urban settlement. The area is in catchment W2. In comparison to LULC of the years 2000 and 2020, two waterbodies have disappeared over this time period due to the effects of urbanization.

Figure 24: LULC Maps of 2000 and 2020 Showing the Disappearance of Two Waterbodies in Tirunelveli



Source: Author

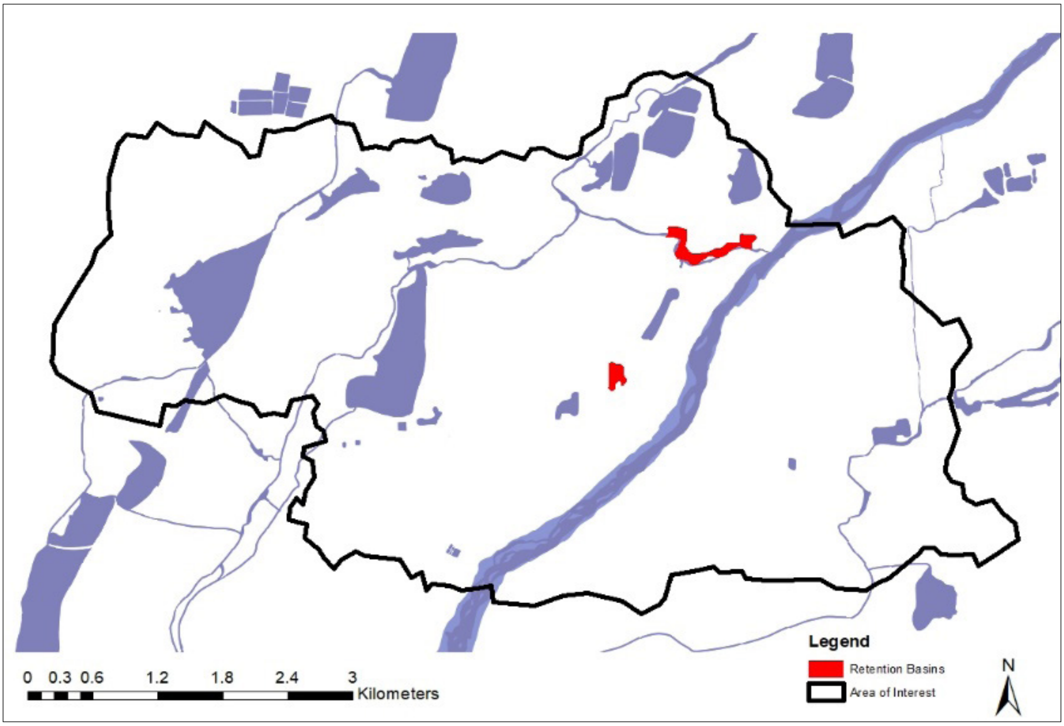
These retention basins were aligned with the contours to find that they were in the low-lying areas of the elevation in the study area, therefore feasibility of accumulating stormwater was possible, thus making it suitable for the proposal.

Table 7: Volume, Area, Depth, and Cost Estimate of the Retention Basin

Retention Basin	Volume (cu.m)	Area (sq.m)	Depth (m)	Approximate Cost Estimated for the River Basin (Rs crore)
1	191436	31906	~6.00	10.6
2	143577	93508	~4.50	9
Total	335013			20

Source: Author

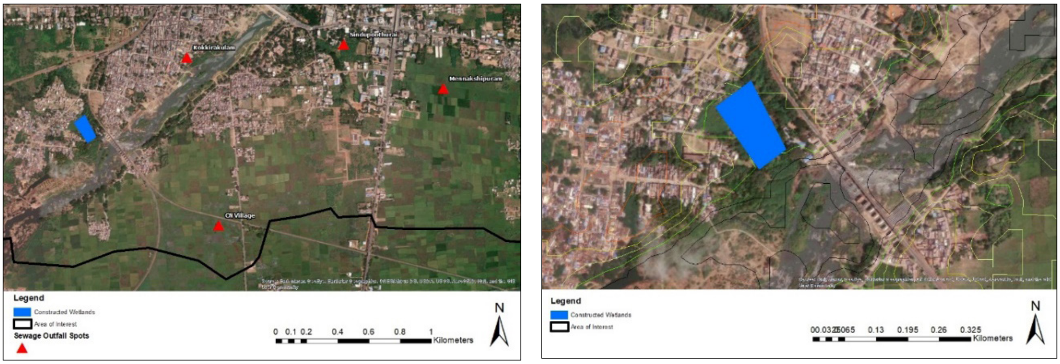
Figure 25: Placement of the Retention Basin in Tirunelveli



Source: Author

Constructed Wetlands with Vertical Subsurface Flow

Figure 26: Satellite Image of Placement of Constructed Wetlands Adjacent to Thamirabharani River in the Study Area



Source: Author

By implementing the method recommended in the UN-Habitat manual for calculation of areas in the Constructed Wetlands (CW), we get an area of 95444.18 sqm for the vertical flow bed.

A single CW with 600 KLD capacity is recommended, therefore we need a set of 6 units of VF-CW each with 7320 sqm area. Implementation can be done in two phases with units of two CWs in phase 1 and units of four CWs in phase 2.

Table 8: Area Requirement of All Units in Constructed Wetland

Area of VF Bed	~95,500 sqm
Settler/Primary Anaerobic Settling Tank	~3,850 sqm
Polishing Pond	~7,770 sqm
Total Area Needed	~111000 sqm

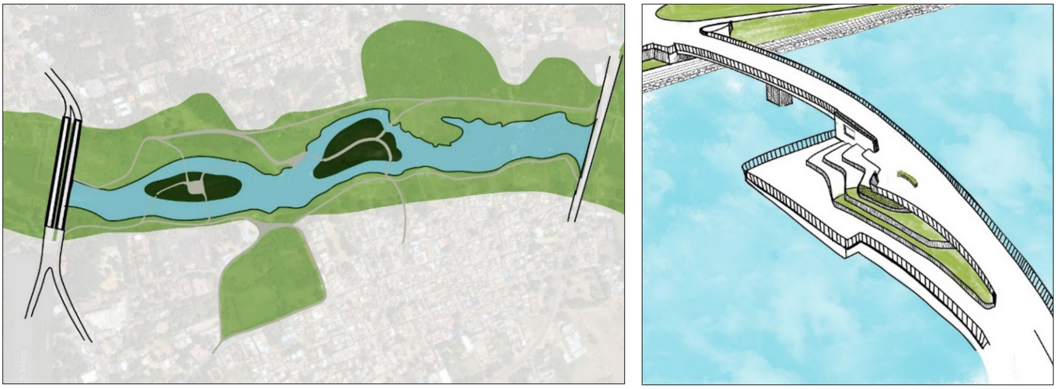
Source: Author

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 growing in Tirunelveli, Tamil Nadu.

Riparian Region Regulation & Development

The Riparian Region can align with the “Blue-Green Policy of Delhi Master Plan 2041” with focus on the following regarding the river and waterbodies:

Figure 27: Provision of Nature Trails in the Riparian Region and 300m Green Buffer Around the Flood Plains and Provision of Recreational Spaces



Source: Author

Recommendations to Enhance the Value of Rivers

- Species that degrade the riparian region are recommended to be restored with native flora and fauna
- Tree Planting and Reforestation along the banks of the river are recommended to enhance the rich biodiversity of the environments

- Through the Constructed Wetland (VSSF – Vertical Sub-Surface Flow) management, sewage outflows into rivers were carefully scrutinized and biological purification of rainwater from the storms through CW is ensured

Recommendations to Strengthen the Bond Between Society and Nature

- Nature Trails during low river water level are provided in places with Nature-based Solutions to enhance the relationship between the 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 nature trips, wildlife tours, camping, etc., 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 parks near the river to be a part of the recreation program to increase footfalls and generate more revenue.

Interventions for Green Elements

- A 300m buffer to be provided and greened to preserve the river.
- To strengthen the bond between people and the river, a green corridor of two hundred meters is to be provided.
- Proper re-stilting of the "wetland" to be done and planting of trees to ensure the debris from being fed into the river and to control contamination; ultimately "restoring the ecosystem".
- Green roofing of government buildings and temples.

Recommendations of River Bank Design Checklist for Riverfront Projects

A river bank design checklist is advised to ensure consistency across all riverfront projects by minimising encroachment, fostering social connectivity with rivers, and improving biodiversity along the river bank. It is also recommended to include: A multi-use pedestrian pathway with a minimum width of 10 feet, 12 feet for segregated cycling and pedestrian lanes, and a combined Bicycle-pedestrian pathway of 16 feet are advised. Additionally, it is suggested to provide seating with tree covers and permeable pavers (as permitted materials). For a secure urban facility, proper lighting and signage guidelines for the riverfront projects are also necessary.

Recommendations for an Exhaustive List of Riparian Vegetation

It is important to promote landscaping initiatives that include bioswales, stormwater planters, and green standards. It is advised to compile a comprehensive inventory of all the benefits of riparian plants and those that are suitable to the Tirunelveli climate and region.

Policy Recommendations for Tirunelveli

- **Infrastructure-related policies**
  - Zero Tolerance Policy for Combined Sewer Overflows (CSOs)
  - Water quality milestones of river discharges

- **Planning related policies**
    - River Bank Protection Policies on:
        - Encroachment
        - Foreign species
        - Non-naturalised shorelines
        - Direct waste discharge
        - Dumping of wastes
    - Preservation of wetlands under the National River Conservation Plan
    - Alignment with "Blue-Green Policy of Delhi Master Plan 2041"
    - Permeable Streets Policy
- **Green norms**
    - Promotion of Green Norms in Building Construction through FSI incentives
    - Tax Exemptions for Green Roofing (70% or 500 sqm) of buildings
    - Special tax incentives for solar proofing rooftops
    - Compulsory Green/Solar Proofing of every government building and temple structures
    - Mandatory/Strict Regulations for Rainwater Harvesting
- **Citizen engagement norms**
    - River Protection Community under the Nellai Neervalam Plan
    - Zero Plastic Pollution norms
    - Overflow Action Days Ordinance

Suggestions, Conclusion, and Way Forward

In conclusion, this paper addresses a range of critical issues that concern urban rivers and waterbodies, particularly in the context of Tirunelveli, by advocating for interventions that integrate both blue and green elements of cities. It tackles challenges such as water pollution, flood risks, water availability, urban biodiversity degradation, neglect of the importance of waterbodies, and lack of citizen engagement with urban rivers, along with floodplain encroachments.

The proposed strategies rejuvenate the entire water network system through an integrated Blue-Green network and aims to protect and enhance the hydrological and ecological values, future-proof the environment for climate change adaptation, and prevent further loss of waterbodies and vegetation. They enable long-term environmental sustainability by strengthening the green elements and help them to flourish.

Moving forward, it is imperative for the government and the stakeholders to take decisive steps towards implementing these recommendations, thereby ensuring the protection and revitalization of waterbodies and urban ecosystems for the benefit of current and future generations.

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Conflicts of Interest

The authors declare no conflict of interest.

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