QATAR UNIVERSITY

COLLEGE OF ENGINEERING

URBAN AND LANDSCAPE DESIGN STRATEGIES FOR FLOOD RESILIENCE IN CHENNAI CITY

BY

ALIFA MUNEERUDEEN

A Thesis Submitted to

the Faculty of the College of

Engineering

in Partial Fulfillment

of the Requirements

for the Degree of

Masters of Science in Urban Planning and Design

June 2017

COMMITTEE PAGE

The members of the Committee approve the Thesis of Alifa Muneerudeen defended on 24/05/2017.

Dr. Anna Grichting Solder
Thesis Supervisor
Qatar University

Kwi-Gon Kim
Examining Committee Member
Seoul National University

Dr. M. Salim Ferwati
Examining Committee Member
Qatar University

Mohamed Arselene Ayari
Examining Committee Member
Qatar University

Approved:

Khalifa Al-Khalifa, Dean, College of Engineering

ABSTRACT

Muneerudeen, Alifa, Masters: June, 2017, Masters of Science in Urban Planning & Design

Title: Urban and Landscape Design Strategies for Flood Resilience in Chennai City

Supervisor of Thesis: Dr. Anna Grichting Solder.

Chennai, the capital city of Tamil Nadu is located in the South East of India and lies at a mere 6.7m above mean sea level. Chennai is in a vulnerable location due to storm surges as well as tropical cyclones that bring about heavy rains and yearly floods. The 2004 Tsunami greatly affected the coast, and rapid urbanization, accompanied by the reduction in the natural drain capacity of the ground caused by encroachments on marshes, wetlands and other ecologically sensitive and permeable areas has contributed to repeat flood events in the city. Channelized rivers and canals contaminated through the presence of informal settlements and garbage has exasperated the situation. Natural and man-made water infrastructures that include, monsoon water harvesting and storage systems such as the Temple tanks and reservoirs have been polluted, and have fallen into disuse.

The main aim of this research is to seek how urban and landscape design can contribute to the prevention and mitigation of flooding in Chennai city. How can Blue-Green Infrastructure and community involvement create more resilience? How can we enhance and remediate existing structures to mitigate flooding? For this, we will investigate: What types of flooding affect the City? What are the natural and constructed water systems affected by floods? What is the function of the historical water infrastructures today? How can we adapt to storm water flooding and storm surges from the sea? What urban and ecological infrastructures, strategies, and policies can be implemented to prevent and mitigate future flooding?

This thesis consolidates available literature and maps on Floods and after analysis of historic and contemporary maps and international case studies, suggests intervention measures at different urban scales, from micro to macro level to create resilience to floods in Chennai. Additionally, Urban Policy measures that can be implemented to support the proposed Urban and Landscape design intervention are recommended. It is anticipated that the lessons learnt from studying the city of Chennai will help other coastal cities develop resilience against floods.

Keywords: Urban Design, Flood resilience, Landscape Urbanism, Coastal cities, Floods, Climate change.

DEDICATION

For the pleasure of Allah,

Towards betterment of humanity, growth and prosperity

And for those who spent years hoping for change and consciousness.

ACKNOWLEDGMENTS

Praise is to Allah who has enabled me to progress and reach a successful completion of this thesis.

My greatest regard and thanks goes out to my supervisor, Dr Anna Grichting Solder for her dedication and valuable guidance without which this thesis was not possible. She has done much more than I could have expected in supporting me.

I would also like to thank Dr Hatem Galal Ibrahim for his inputs during the initial stages of my thesis. I express sincere gratitude to all the staff and co-students that I have had an opportunity to work with during the duration of the program.

Thank you Ihsaan for being the most understanding baby throughout the course of my master's program and my immense gratitude goes out to my dear aunt and family, here in Qatar for being my greatest support system. I am deeply indebted to my parents and brother, for their unending love and support and Thank you, Ershad, for the support you always offer by standing by me through the thick and thin of it all and being my strength when I felt I couldn't go on. Thank you Deena, Hisham and most of all, Heba.

Thank you all for the immense love, patience and understanding displayed when I couldn't be at my best towards you all.

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LIST OF ABBREVIATIONS

MSL –Mean Sea Level
SLR-Sea level rise
GIS- Geographic Information system
BGI –Blue green Infrastructure
SES-Socio-Ecological system for resilience
N –North
NW –North West
S -South
SW –South West
Chennai Metropolitan Area (CMA)
Urban heat islands (UHI)
(NIDM)
Sea surface temperature (SST)
hectares (ha)
GIS
CBD –Central Business District
CMWSSB – Chennai Metro Water Supply and Sewage Board
PWD – Public Works Department
CMA –Chennai Metropolitan Area
TNHB –Tamil Nadu Housing Board
TWAD - TAMILNADU WATER SUPPLY AND DRAINAGE BOARD
B.O.T –Build, Operate and Transfer
MRTS –Mass Rapid Transit/Transport system
CMRL –Chennai Metro Rail Limited.
STP- Sewage treatment plants
AP- Andhra Pradesh
TN- Tamil Nadu
C/s- cusecs per second
NGO-Non-Governmental Organization

From Tamil:
Pattinam-coastal area
Ur-city
Pakkam- fresh water source
Pet- Residential pockets
Padi – Agglomeration of population

CHAPTER 1: INTRODUCTION

1.1 Structure of the report

This chapter outlines the organization of the thesis by stating the problem, the aims and research questions. The scope and limitations are also specified. Chapter 2 provides an understanding of floods including their causes, impacts and factors that affect floods. It also and explains flooding in coastal cities as well as outlines the problems related to flooding faced by the city based on the existing research on Chennai city. The chapter further discusses the theoretical background on urban resilience measures for flooding, including vernacular and contemporary flood mitigation strategies and discusses areas in the selected case studies relevant to this thesis. Chapter 3 details the method for data collection, research approach explaining study tools, and survey and interview components of the study. This is followed by a detailed description of the study area (Chennai city) in Chapter 4, which is detailed and analyzed to understand the flow of water through the city so as to propose adequate resilience measures. Chapter 5 goes on to analyze the data to further understand the study area from the literature, maps as well as surveys and interviews. The following chapter 6 will discuss the results and propose a map of possible solutions along with stating the Limitations and scope for further research. Chapter 7 will mark the conclusion to the thesis

1.2 Problem statement

The city of Chennai (detailed in chapter 4) has witnessed a rapid urban development within the last few decades especially after the agglomeration of automobile industries in Chennai's suburbs. It is the fourth largest metropolitan area in India growing at an alarming rate due to the influx of people. The city has expanded immensely to cater to this growing demand. The city, being located along the Bay of Bengal, the equator and geographically being almost flat in terrain puts it in a vulnerable location to be exposed to Storm surges, cyclones and heavy monsoons which can lead to yearly floods as well as less common Tsunamis. The existing threat from sea level rise due to global warming makes it an inevitable reality that coastal cities like Chennai are going to be first ones to face the devastating consequences of a flood. The City suffered from the 2004 Tsunami which originated in the Bay of Bengal due to the impact of an underwater earthquake in Indonesia, which is quite frequent in the area.

Chennai is amongst the few cities in India to house ancient mangroves and marshes which are known to be nature's protective shield against floods. There are also 3 drain rivers that run through the city from the storage reservoirs which connect to the Buckingham canal - a salt water navigation canal running about 1km inland from the coastline. The canal was constructed during the British rule in India around the 1800's. This canal eventually drains the water from the rivers into the sea. Such systems also form a fragile ecosystem along the coast on which various migratory birds and other species depend on.

These protective systems against floods are being degraded with time due to unprecedented urban intensification. Urban structures being built on marshes and mangroves have clogged these natural drains causing widespread and sometimes irreversible damage to the water bodies and the biodiversity that it supports. Parts of the Buckingham canal running through the city are blocked due to heedless urban growth along its path.

The combination of sea level rise combined with inefficient drainage systems in the city and poor coastal protection from floods due to destruction of mangroves and construction activities are proving to be incurable and the city and its’ people are suffering consequences in the form of Increase in flooding and droughts.

The reduction in the natural drain facilities by encroaching on marshes, wetlands and other ecologically sensitive and permeable areas. Natural and man-made water infrastructures have also been affected by means of channelized rivers, and polluted canals through informal settlements. Historical monsoon water harvesting and storage systems such as the temple tanks and reservoirs have been polluted and contaminated, and have fallen into disuse.

The city ideally should therefore have its own protective mechanisms and systems that provide a significant measure of resilience and mitigate the effects of a possible flood or similar disasters. There should be factors to slow down and absorb the entry of excess water at a high speed into the city during a possible flood arising from the sea. There should also be mechanisms to drain excess water from the city due to cyclonic rains to avoid floods from water logging.

1.3 Research Aim and Research Questions

The main aim of this research is to seek how urban and landscape design can contribute to the prevention and mitigation of flooding in the city of Chennai and how to create more resilient urban infrastructures and communities.

How can we enhance the cities natural features, remediate existing structures, or create new ecological infrastructures to mitigate flooding? What ways can we use or enhance the cities' natural features in building resilience against floods in the future.

To answer this, we will investigate the following:

What are the types of flooding that affect the city of Chennai? What are the natural and constructed water systems in Chennai that are affected flooding? What are the historical water infrastructures and what is there role in the city today? What is the interrelation between storm water flooding and storm surges coming from the sea? What are the urban and ecological infrastructures, strategies, and policies that can be implemented to prevent and mitigate future flooding?

1.4 Research Objective

- To understand the present condition of lakes, rivers, marshes and tanks and canal in Chennai city. -historic and contemporary infrastructure and what new systems are needed.
- To understand the natural drainage systems in Chennai and evaluate their current and past effectiveness in protecting the city against floods
- To suggest recommendations for their improvement in functioning and maintenance through maps as well as social, economic and legal proceedings as well as community participation.

1.5 Project Goal tree

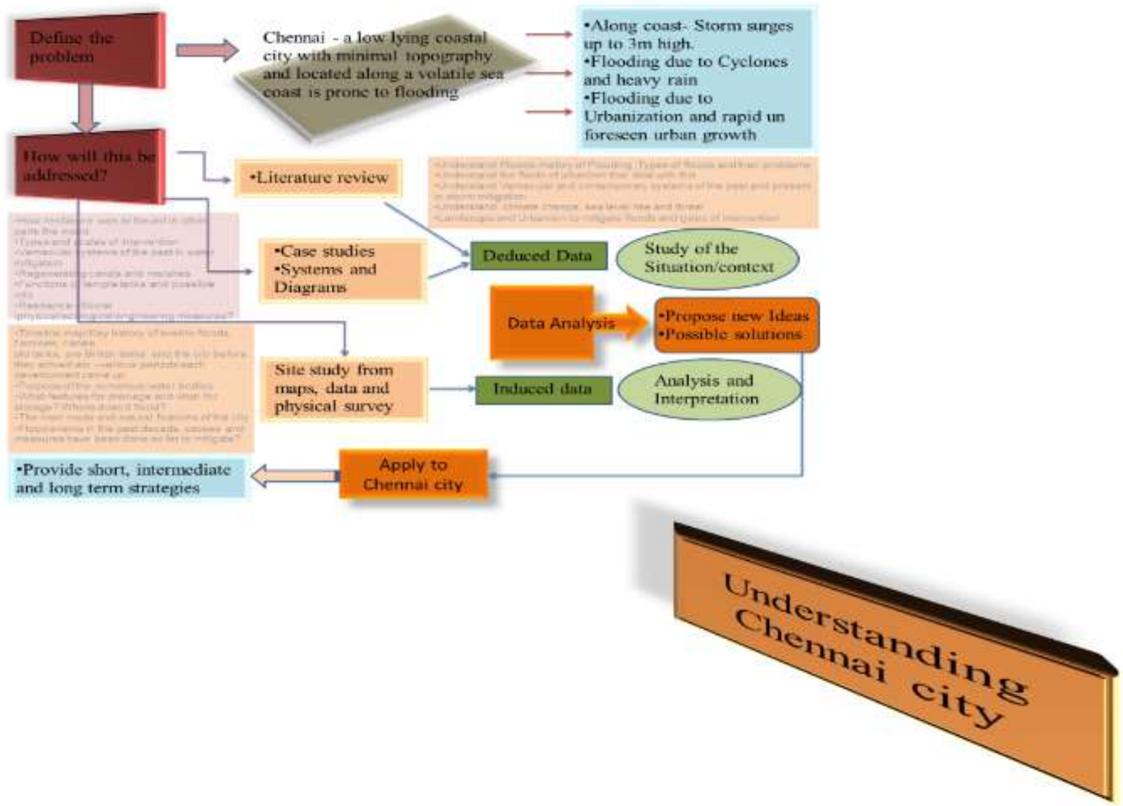


Figure 1: Project Goal Tree.

1.6 Limitation of the study

The thesis will not focus on utilizing GIS for mapping and will only provide a broad suggestion framework in the form of diagrams for the maps at a micro as well as macro level. Producing detailed strategy maps are beyond the time scope of this study and can be carried out for further studies. Detailed limitations are mentioned towards the end of the study after Recommendations and Discussion.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction to floods –Understanding the Problem of Floods

Earliest recordings of floods in cities were in the form of Sumerian cuneiform tablets. One such interpreted tablet is said to be from Nineveh (modern Iraq and dates back to the 7th century BC.) It talks about a flood similar to the story of the Noah's ark, only that it preceded it in time frame – where a man is asked by his God to make a boat and load it with pairs of humans and animals as he would wipe out all creations except those from the face of the Earth.

The word "flood" originates from 'Flod' as used in old English. Floods are the most widely recognized regular catastrophes; their recurrence, extent and the expense of harm are on way up everywhere in the world. Floods cause around 33% of all deaths, 33% of all injuries and 33% of all damage from regular calamities (Askew, 1999). During a United Nations Natural Disaster Reduction World Conference held in Yokohama in May 1994, one of the 10 "principles" of the Yokohama Strategy discussed was that "hazard appraisal is a required stride for the reception of satisfactory and fruitful calamity diminishment approaches and measures". "Flooding is a general interim state of incomplete or complete immersion of ordinarily dry territories from flood of inland or tidal waters or from abnormal and quick gathering or runoff overflow" (Jeb and Aggarwal, 2008). According to the European Commission (2007), "a natural phenomenon that results in the ephemeral submerging with water of a land that does not occur under mundane conditions". They are the naturally occurring events and hence cannot be obviated, and they can have earnest consequences such as displacement of people and damage to the environment, for example, uprooting of individuals and harm to the earth (IFRC,2001; Adeoye et al., 2009; Nmeribeh, 2011). Floods can likewise be brought on by anthropogenic exercises and human intercessions in the characteristic procedures, for example, increment in settlement ranges, populace development and monetary resources over low lying fields inclining to flood prompting alterations in the natural drainage and river basin patterns such as deforestation and environmental change (EC, 2007; Balabanova, 2008; Kwak, 2008; Kondoh, 2008; and Vassilev, 2010). The Center for Research on the Epidemiology of Disasters (CRED) describe flooding as "a significant rise of water level in a stream, lake, reservoir or coastal region" Jonkman SN & Kelman (2005) express flooding as the presence of water in normally dry areas. There is an increased risk of extreme losses owing to decrease in forest cover and people in urban areas moving more proximal to the coasts, rivers and lakes. Drowning is the primary cause of mortality due to flood. (Jonkman SN & Kelman,2005). Additionally, floods caused over 6.8 million deaths in the 20th century and almost half of all flood related fatalities of the last quarter of the 20th century occurred in Asia making it most vulnerable to floods (Jonkman SN & Kelman,2005; Noji E, 2000).

Floods as a Natural Disaster. The expressions "floods", "flood danger," and "flood hazard" cover an expansive scope of topics. Flood hazard is the negative outcome of natural events on social and financial misfortunes. Simonovic (2009), highlights the probability that flood dangers may increase because of human actions and may diminish by proper flood administration and planning.

Natural Events are not considered disasters until human lives are influenced, either by death and harm, or loss of property and things valued by individuals. Any large-scale disaster whether it is the 2005 Hurricane Katrina in the US, the 2015 Nepal seismic tremor or the 2004 Indian Ocean tidal wave Tsunami point toward the poor comprehension of how nature functions and an over confidence in the human and innovative technological abilities. More than one third of deaths caused by natural disasters are from serious cases of flooding. Some areas are more prone to flooding than others. For example, melt waters that originate in the mountainous regions of its neighbors India and Nepal regularly inundate the relatively low-lying nation of Bangladesh. Of all the natural disasters, floods are most frequent and are by far the worst in terms of total amount of lives they claim, injuries they cause, and also the high amount of property damage. Global warming is leading to a steady rise in Global mean temperature. This leads to erratic weather and unexpected damage to life and property. The impact the disaster leaves depends on the density of population and concentration of activity in the potential area which increases vulnerability when compared to a place similarly exposed to the hazard but less populated.

2.1.1 Causes of Floods.

Floods happen when prolonged rain, intense storms, or melting snow release more water than rivers or land can contain without causing damage, as a result they over-flow their banks usually into low lying surrounding areas. There can be different types of floods, which begin in different ways and will be discussed in due course.

There are diverse factors that cause or lead to floods and they are multifaceted and often unrelated. They can broadly be classified as Ecological/Natural causes and Anthropogenic/Manmade causes.

1. Ecological (Natural) Causes:

These causes are beyond human control and can be further divided as Hydro-Meteorological factors and Geomorphologic factors. Natural hazards, include volcanos, seismic events, earthquakes, cyclones, typhoons, hurricane, tropical storms, floods, mudslides, tsunamis, and tidal waves or storm surges.

Hydro- Meteorological factors. Factors related to weather such as prolonged and intense rainfall, cyclones, typhoons, storms and tidal surges, precipitation, wind, sea level rise, tide levels, wave action etc. form the core of these factors, greatly affecting flooding. Hydrological factors include; but are not limited to ice and snow melt, impermeable surfaces, saturated land, etc.

Hydro-Meteorological hazards result from atmospheric or hydrological processes; they are caused by the movement of water in some shape or form, and by weather patterns. Examples can include floods, droughts, hurricanes, tornadoes, storms, blizzards among others. On a global scale, the role of land use is generally unresolved, but on a watershed scale, land-use effects can be as important as changes in the meteorological processes.

Geomorphologic factors. Topography and terrain, soil type, poor infiltration rates, land erosion etc. or of a geological nature (earthquakes, volcanic activity including associated flooding, tidal waves or tsunamis but also soil movements, landslides, subsidence or the expansion and retraction of clay soils). The knowledge, perception and impact of natural hazards and associated disasters vary according to the continent, soil, sub-soil, relief and climate.

2. Anthropogenic (Manmade) Causes

The Anthropogenic causes include population growth and rapid urbanization, land use change, deforestation, intensive agriculture, unplanned flood control measures, poor drainage and storm water management, clogging of river channels, socio-economic and development activities, etc., destruction of natural ecology –Marshes and Wetlands, technological hazards, climate change, global warming.

Technological hazards are either constant or accidental hazards directly linked to human activities. Humans can make them worse by a shortsighted attitude or, on the contrary, mitigate their impact by prior security measures. These hazards can have serious consequences on human health, property and the environment.

2.1.2 Types of Floods.

A. Urban Flooding. This is a growing concern in developed as well as developing countries contributing to losses and interruption of transport services. There is a complex combination of reasons that cause increased damage which is directly proportional to the urban settlements in the area. Urban areas have limited open soil, drains are clogged and lack the capacity to cope with sudden floods due to overpopulation and the strain on the city's resources. In parts of Europe, water enters sewage systems in one place and re surfaces at another. In Mexico, constant urban expansion has reduced permeability of the soil for ground water recharge. Additionally, overexploitation of ground water in the last century has compounded the risk of flooding.

Urban floods are also caused by improper land use planning. Increased urbanisation and populations cause a rising demand for land thus, encroaching upon areas. Economic and Political factors often override laws and regulations for construction of new infrastructure. Capacity and resource constraint obstruct plans for improving the natural flow paths for this water.

B. Riverine floods. This happens due to heavy downpours or obstruction in the natural flow path of the rivers *but* the effects are slow. In southern China, reclamation of flood plains along the Yangtze river for agriculture has increased the frequency of floods leading to more erosion. The flood plains could retain flood water normally and release it back slowly avoiding flooding. The government has decided to restore 14000 sq.km of natural wetlands by 2030 to mitigate future risks.

C. Pluvial or overland floods. This is caused by rainfall not being absorbed into the land and flowing overland through non-permeable urban areas. Localised flooding clogs the drainage system and flows into urban areas which is a regular occurrence in tropical urban areas.

D. Coastal Flooding. This is caused by incursion of sea by storms, tsunamis etc. and in recent times due to rising sea levels. Flooding due to tsunamis is less common than storm surges.

E. Ground water floods. When ground water level of the water table of underlying aquifer reaches surface level or if the ground water is rendered unusable due to pollution, the water level could rise and exceed the combined water and sewage volume.

F. Failure of Artificial systems. Bursts in water mains, drainage systems, failure of pumping systems, failed flood defences and dams or failure of embankments and levees cause such flooding. The areas adjoining these areas and low lying areas are affected. Many levees along rivers to protect agricultural and residential land failed, thus flooding areas around the Mississippi and Missouri Rivers (Larson 1993).

G. Flash Floods. They are caused by local convective thunderstorms and occurs within six hours of torrential rain as defined by National Oceanic and Atmospheric Administration (NOAA). Surface conditions and topography exasperate the problem. Impervious roofs, streets, car parks that encourage run off also lead to dire situations.

H. Semi-permanent Flooding. Urban areas lying below sea level or with water table close to the surface will flood even due to slight rains. Usually, settlements that emerge in these areas are informal and unplanned with poverty ridden inhabitants moving here due to rapid urbanization and the inability to afford land. Sea level rise and land subsidies can create many more such areas in the future.

Even if historical data is available, it is difficult to estimate the probability of pluvial, ground water, flash as well as semi-permanent flooding as they are caused by multiple variables. It is impossible to know or estimate when and where a future flood will occur as they are dependent on the weather which is transient.

2.1.3 Impacts of flooding

Primary effects: The primary effects of flooding include loss of life, damage to buildings and other structures, including bridges, sewerage systems, roadways, and canals. Floods also frequently damage power transmission and sometimes power generation which then has knock-on effects caused by the loss of power. This includes loss of drinking water treatment and water supply which may result in loss of drinking water or severe water contamination. It may also cause the loss of sewage disposal facilities. Lack of clean water combined with human sewage in the flood waters raises the risk of waterborne diseases which can include typhoid, cholera and many other diseases depending upon the location of the flood.

Damage to roads and transport infrastructure may make it difficult to mobilize aid to those affected or to provide emergency health treatment. Flood waters typically inundate farm land making the land unworkable and preventing crops from being planted or harvested which can lead to shortages of food both for humans and farm animals. Entire harvests for a country can be lost in extreme flood circumstances. Some tree species may not survive prolonged flooding of their root systems.

Secondary and long-term effects. Economic hardship due to a temporary decline in tourism, rebuilding costs, or food shortages leading to price increases is a common after-effect of severe flooding. The impact on those affected may cause psychological damage to those affected in particular where deaths, serious injuries and loss of property occur.

Urban flooding can lead to chronically wet houses which is linked to an increase in respiratory problems and other illnesses. Urban flooding also has significant economic implications for affected neighborhoods.

Socio-economic impacts. Floods have taken a significant toll on a sizeable population of human beings when compared to any other natural disaster. Population growth, urbanization, land use change and climatological factors such as increased events of extreme rainfall, storms and cyclones etc. have compounded human vulnerability and losses that would be incurred due to lack of preparedness as well as overlooking the situation. Frequency and impact of flooding are expected to increase across the world, more so in developing countries which is where majority floods already occur. However, Sea level Rise (SLR) due to global warming increases the risk to developed nations alike. Preparation and mitigation can help reduce the loss of lives as well as damage caused due to future floods.

Environmental impacts. Degradation of marshes and wetlands for urbanization, along with destruction of sand dunes, tidal flats, mangroves and estuaries along coasts which help attenuate strong cyclone winds as well as absorb strong waves and surges from the sea. Disregard for tanks, ponds and lakes with the city leads to inadequate water storage and discharge options.

The natural shock absorbers during extreme events mentioned above have been ignored. Marshlands, tanks and ponds which are large water bodies, accrue rainwater and prevent a heavy downpour from leading to a flood as well as recharge ground water.

2.2 Why is flooding of a coastal city such a problem?

Coasts are dynamic systems undergoing adjustments of form and process (termed morphodynamics) at different time and space scales in response to geo-morphological and oceanographical factors (Cowell et al. 2003 a,b) (Balica et al,2012). A senior economist with world bank, Stephane Hallegate quotes,

" Coastal defenses reduce the risk of floods today, but they also attract population and assets in protected areas and thus put them at risk in case of the defense fails, or if an event overwhelms it. " (year)

Flood exposure is increasing in coastal cities (Hanson, S. et al (2011) and De Sherbinin, A., Schiller, A. & Pulsipher, A (2007). Increase in population and asset concentration on water front's along with reasons such as climate change (Nicholls, R. J. et al.,2011) and subsidence (Nicholls, R. J(1995)., Dixon, T. H. et al.(2005) and (The

World Bank, 2010). Flooding of coastal cities are considered the most dangerous and harmful of natural disasters (Douben 2006). Large chunks of populations live along coastal cities. A study confirmed that 21% of the world's population lives in coastal cities. (du Gommes et al. 1997; Brooks et al. 2006). There is also a net coastward migration of populations worldwide (Bijlsma et al. 1995).

It is estimated that the number of people flooded in a year by storm surges would increase 6 times and 14 times given a 0.5- and 1.0-m rise in global sea levels, respectively (Nicholls 2004)(Balica et al,2012). Thus, any disaster secondary to flooding would have a major potential impact on wider ecosystems.

Coastal cities are at an increased risk from flooding as well as storm surges, coupled with increase in rainfall due to anthropogenic activities and a modified Hydro-meteorological cycle.

A research published in *Nature Climate Change* by Hallegatte, S., Green, C., Nicholls, R. J., & Corfee-Morlot, J. (2013) reported a study which compared 136 cities with population greater than 1 million to determine the most flood prone coastal cities in the world. This was done by comparing data on population distribution and the flood protection systems they had. This was used in combination with projections of SLR, sinking of ground due to subsidence and ground water depletion as well as forecasted projections of population growth, GDP etc. Cost of damage was calculated by measuring the depth of water flooding a city. Losses of up to 1 trillion would be incurred in the best as well as worst case scenario of SLR. Almost all cities at high risk from coastal flooding are in Asia and North Africa.

Climate change and land subsidence lead to major losses and even if the probability of flood is not increased, SLR and subsidence will increase global flood losses to tune of about 60 billion US dollars by 2050 (Hallegatte, S., Green, C., Nicholls, R. J., & Corfee-Morlot, J.,2013). Adaptation will be the only measure that will reduce the probability of a flood event below present values. We also need to prepare for larger disasters than those experienced today as there is an upward trend in flood events which make a once in hundred years flood a yearly event.

The top 20 most vulnerable cities as per the study where largest losses can be expected are:

1) Guangzhou, China
2) Mumbai, India
3) Kolkata, India
4) Guayaquil, Ecuador
5) Shenzen, China
6) Miami, Florida, USA
7) Tianjin, China
8) New York, New York — Newark, New Jersey, USA
9) Ho Chi Minh City, Vietnam
10) New Orleans, Louisiana
11) Jakarta, Indonesia
12) Abidjan, Ivory Coast
13) ***Chennai, India***
14) Surat, India

15) Zhanjiang, China

16) Tampa—St. Petersburg, Florida, USA

17) Boston, Massachusetts, USA

18) Bangkok, Thailand

19) Xiamen, China

20) Nagoya, Japan

Nicholls highlights that cities should take steps for prevention and mitigation which include barriers for storm surges and levees with increased heights, flood resistant buildings, and even converting low lying areas into parks and football fields as flood risk is on the rise and cities need to be prepared before storm surges such as ‘Katrina’ become the norm (2015). Additionally, losses from floods can also be brought down to an average of $50 billion annually as compared to trillions that would be lost without preparation.

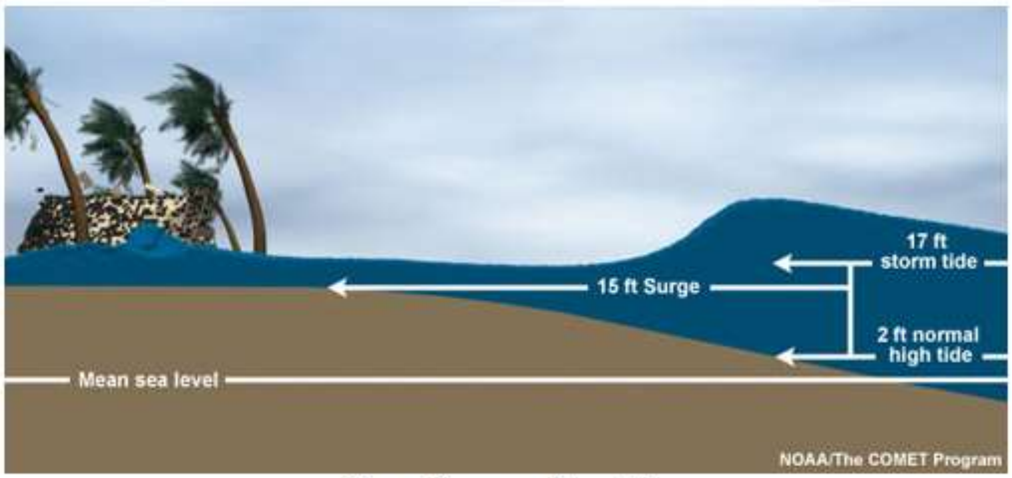
2.2.1 Causes of Coastal Floods.

Coastal floods have many contributing factors:

- Tropical cyclones and other weather events which cause strong wind and rain can raise the water level and cause a ‘storm surge’.
- Wind driven waves from storms as well as strong local winds can lead to huge waves hitting the coast.
- High tides can increase flood risk during a storm.
- Storm surge related floods can be joined in by rain upstream in the watershed flooding rivers which will lead to a dual problem at the coast with water trying to

discharge and at the same time, water from the storm surge trying to enter the city.

- Overall, Sea level rise and ocean temperature variations can also cause high water level.



Storm Surge vs. Storm Tide

Total Water Level = Storm Surge + Tide + Waves + Rivers + Other Additional Factors

Figure 2: Storm surge vs. storm tide. Source: http://www.stormsurge.noaa.gov/overview_formation.html

The combination of storm surge, tides, waves river discharge, and other additional factors at the coast makes coastal flooding more dangerous than others causing significant damage.

2.2.2 Anthropogenic Impact on coastal systems.

Land subsidence is a big problem in many Asian cities, contributing further to the growing risk of coastal flooding. Many coastal cities are built on deltas where significant sinking is occurring due to soil impaction and transfer of ground water to sea which further aggravates the problem of sea level rise. In some cities, land subsidence is a bigger problem than sea level rise. For example, in Bangkok, Gulf of Thailand is rising at a rate of 0.25 cm per year, but the city is sinking faster at a rate of 4 cm per year. In north Jakarta, surface is sinking at 6 cm per year and surface bridges are under water thereby obstructing water routes of exit.

Urbanization increases vulnerability, and thereby the risk of flood due to population, infrastructure and wealth being concentrated over a smaller area (Taisuke et al., 2009). Risk of flooding in cities is further amplified as urbanization modifies local hydrological and hydro-meteorological systems increasing 'Flood Hazards'. Urban densification which is more in developing than developed countries increases 'Vulnerability'. On a larger scale, global climate change compounds the 'risk' (Huong and Pathirana, 2013). Rural to Urban migration as well as interstate and inter country migration also burdens the infrastructure. Sprawls are thus created by human settlements, growth of industry and infrastructure (UN, 2006). Urban runoff and poor infiltration due to increase in impervious surfaces also increases flooding.

Significant research in the last two decades shows the ability of urban areas to modify local microclimate. It also establishes that the hydro-meteorological changes driven by urbanization of a settlement have an impact on extreme rainfall. Urban areas are known to have higher temperatures than surroundings. These Urban Heat Islands (UHI) are known to increase rainfall in the area around the cities. This increase can be as high as 25% in some cases (Shepherd et al., 2002; Mote et al., 2007).

Aikawa highlights that human activities also increase unwanted heat due to excessive energy consumption (Aikawa et al.,2008). This anthropogenic effect increases temperature and causes other environmental problems as well significantly affecting the local circulation, absence of trees due to deforestation as well as for expansion of city facilities also increases evaporo-transpiration.

From an Urban perspective, quantification of increase in flood hazard is imperative. We are aware that urban factors such as impervious surfaces increase floods but this is of little help to adaptation planning as they don't represent the future scenario appropriately. Effective mitigation and adaptation can be made only when the whole system is understood. The combined impact of many important challenging parameters often lead to uncertainty and errors, and should only be used as indicators of a wide variety of parameters to plan for but is still required for a realistic long term strategy plan. (Huong and Pathirana, 2013).

2.2.3 Climate change and other natural impacts.

Climate change is a long haul shift in weather conditions recognized by changes in temperature, precipitation, winds, and other different markers. Changes in the climate can be induced by any deviation in normal environmental conditions as well as by sudden variables such as extreme events. Events such as sudden shifts in weather, rainfall, etc as well as storms, cyclones, hurricanes and their increased force and frequencies are all common place today than in the last decade.

The growing physical risks to coastal cities result from a combination of factors related to climate change including sea level rise and increase in intensity of cyclones bringing stronger winds and heavier precipitation along with more powerful storm surges. Rising sea levels secondary to thermal expansion of sea water and melting glaciers add to the damage caused by already increasing storm surges.

Future warming will be accompanied by other changes, including the amount and distribution of rain, snow, and ice and the risk of extreme weather events such as heat waves, heavy rain falls and related flooding, dry spells and/or droughts, and forest fires. Impacts of climate change and associated sea level rise are seen all across the world – in countries from the Northern to southern hemisphere, the equator as well as the tropics, but coastal cities are at high risk.

Climate change bears a direct consequence on increasing flood hazards globally. (Milly et al., 2008). (IPCC, 2002, 2007) also attributes climate change driven increased precipitation to be a major cause in increasing flood occurrence, frequency and intensity globally. This combined with global warming is also leading to acceleration in SLR resulting in an increased magnitude of flooding. ActionAid indicates that weather is less predictable with increase in heavy thunderstorms, rains and storm surges (2006). IPCC highlights that there is less quantitative research available on climate change impacts on small areas but changes in SLR are well established (2007). Flood incidents have increased in cities along river deltas and coasts which can be traced back to climate change led to SLR. Large surface runoffs affect the levels in rivers while tides at sea also seem to be higher leading to storm surges. UNFCCC warns that sea levels globally would rise by 9-88cm over the next 100 years (2005). Between 1993 and 2008, Sea levels around Vietnam rose at the rate of 3mm per year (MONRE, 2009a).

Warming of the environment and release of gases that cause the planet to be hotter have also started to gradually increase sea levels.

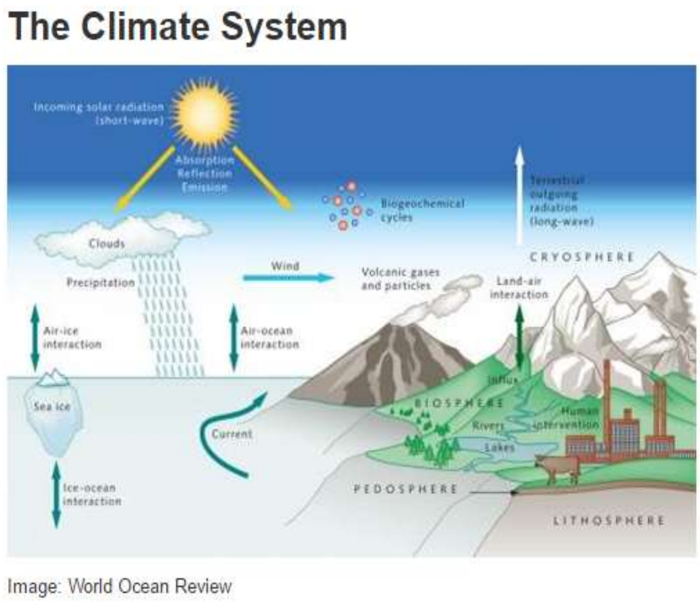


Figure 3: The climate system. Adapted from World Ocean Review.

Natural and Anthropogenic causes of climate change. Even though the climate on earth varies considerably all the time based on the geographic location, natural features and across time scales, the earth's energy balance and thus, its long term weather state is maintained by a balance between the incoming and outgoing energy. Any factor that causes a considerable imbalance between these energy states over a period of time contribute to climate change. These are termed 'Climate Forcers' as the name implies, they create a new ' long term state ' for climate leading the weather to be more warm or cool ,depending on the cause of change.

Across time, various factors have contributed to climate change some of which may now be non- existent or have been replaced by other newer more significant threats. Factors contributing to shift in climatic conditions (climate change) can be divided as - Natural Factors and Anthropogenic (Manmade) factors. Variations in ocean currents or atmospheric circulation can also influence the climate for short periods of time but can help estimate long-term forced climate change that can be anticipated.

Natural causes. Climate on earth can be affected by various natural phenomena that are beyond human control. These can be changes due to volcanic activity, solar output, and the earth's orbit around the Sun. Volcanic activity and changes in solar radiation contribute the most to contemporary climate change and have been the most significant across all time scales- the past, present and future. These factors primarily influence the amount of incoming energy in the earth's energy balance. Volcanic eruptions are episodic and have relatively short-term effects on climate. However, solar irradiance has contributed the most to climate trends over the past century. Environment and climate change, Canada has stated that Industrial Revolution and the effect of greenhouse gas addition to the atmosphere has been over 50 times that of changes in the Sun's output.

Anthropogenic (Manmade) causes. Human activities have long contributed to climate change and continue to do so till this day. Burning of fossil fuels and destruction of forest land for agriculture and other human benefits such as real estate has furthered the problem. These activities affect not just the environment but also change surface temperatures on land and add to emittance of substances such as Greenhouse Gases (GHG). Human influences on climatic systems have increased substantially since the industrial revolution.

The planet has been warming ever since the industrial revolution and continues to do so. Emissions from greenhouse gases have the potential to warm the planet to levels that have never been experienced in the history of human civilization and could have far-reaching and/or unpredictable environmental, social, and economic consequences.

On the one hand, some coastal cities have structural and non-structural strategies to protect them from floods. On the other hand, many have minimal defenses to flooding exposing them to disruption, economic loss and loss of life. Vulnerability is considered as the extent of harm which can be expected under certain conditions of exposure, susceptibility and resilience (Balica et al,2012), (Balica et al. 2009; Hufschmidt 2011; Scheuer et al. 2010; Willroth et al. 2010; Fuchs et al. 2011). Baarse (1995), (Balica et al,2012) suggests that some 189 million people live in areas below one in a hundred-year storm surge level. Therefore, there is a need for assessing flood vulnerability in susceptible areas. These assessment methods should be easily understood and readily calculated. Hoozemans et al. (1996) did a vulnerability survey and found that an average of 46 million people every year experience storm-surge flooding.(Balica et al,2012)

Vulnerability indices have been developed as a rapid and consistent method to characterize coastal cities according to their relative vulnerability to floods. There are various ways of assessing vulnerability. The simplest way is assessing the physical vulnerability. More complicated methods assess economic and social vulnerability.

There are three components of coastal flood vulnerability. Van Beek (2006) identifies three interdependent subsystems in the coastal vulnerability system (Balica et al,2012):

1. The natural river subsystem in which the physical, chemical and biological processes take place.
2. Socioeconomic subsystem which is related to the human activities involving the water bodies. Socio-economic systems are made up of rules and institutions that describe human use of resources as well as systems of knowledge and ethics that interpret natural systems from a human point of view. (Balica et al,2012)

3. Administrative and institutive subsystem is the component that describes legislative and administrative policies related to flooding.

Regions are vulnerable to floods due to three main factors: exposure, susceptibility and resilience (Balica et al. 2009),(Balica et al,2012). The vulnerability of any system (at any scale) is reflective of (or a function of) the exposure and susceptibility of that system to hazardous conditions and the resilience of the system to adapt and/or recover from the effects of those conditions (Smit and Wandel 2006).

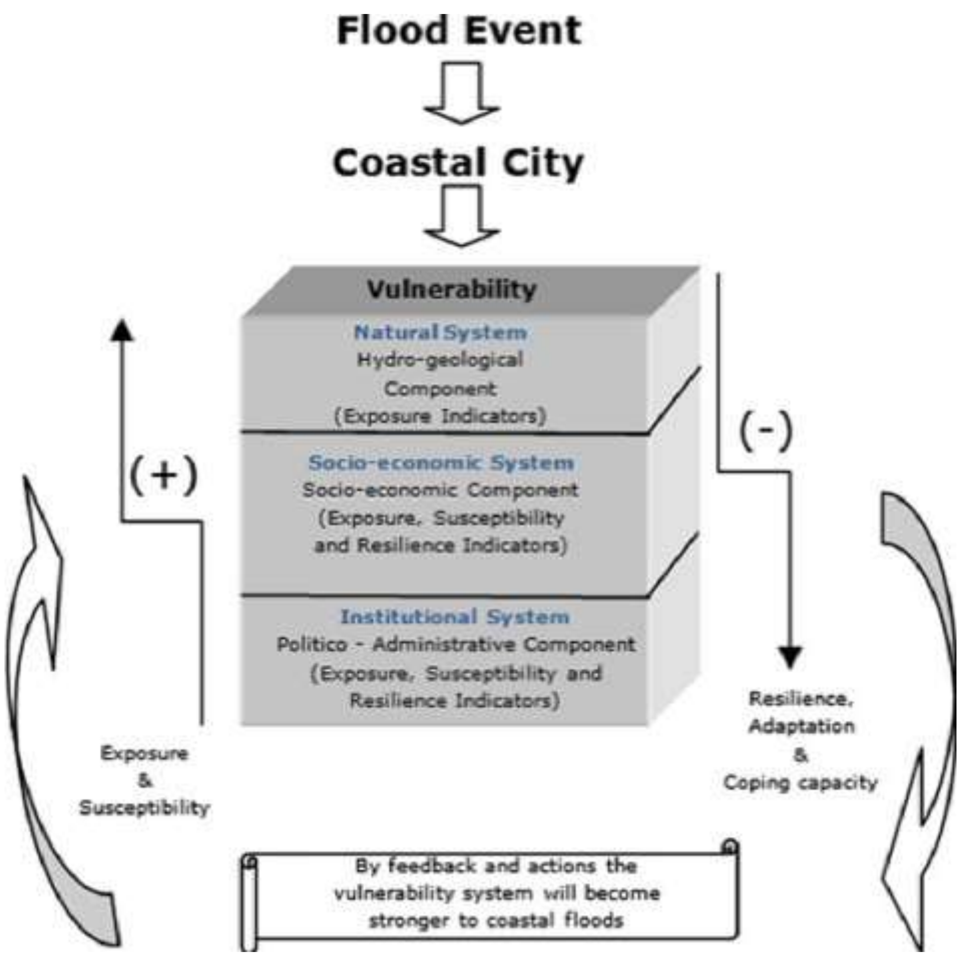


Figure 4: Vulnerability system diagram. Adapted from Balica et al. 2009

Asia experiences a considerable share of extreme events in the world. Rapid urbanization is adding to the vulnerability. Major floods endanger cities while droughts are also common in rural areas. A suitable approach to address risks of natural disasters should include human resources such as capacity building, governance and economic resources to reduce disparities and inequalities within society as well as infrastructure and technology resources to improve and utilize environmental infrastructure such as waste water treatment, industrial waste management and the reuse of natural resources.

Rising population and development has been burgeoning Indian mega cities for a long time rendering the existing infrastructure incapable of providing even basic necessities to all citizens (Nair,2009). Water and Electricity supplies are unreliable and expensive. Adding to this, climate change has been causing health issues and uncertainty in weather patterns. Rising sea levels and increasing occurrence and intensity of tropical storms threaten the existence of Indian coastal cities such as Chennai; Mumbai and Calcutta (Nair, 2009). Current policies have proven incapable to deal with the challenges presented to the cities. Environmental degradation is rampant and drainage systems are inefficient (Nair, 2009).

2.2.3 Coastlines as a line of Defense against Storm surges and SLR.

Possible effects of storm surges and SLR are not considered by investors, real estate marketers or even the government. Even though sea levels have been rising gradually throughout history, in this age, SLR is accelerated as ice caps are melting and seas are warmer. SLR could possibly rise by 1-2 feet by 2050 according to scientists who studied the last glacial melt between Greenland and West Antarctic ice sheet where SLR rose between 13-19 feet. Architects, planners and engineers do not seem to design with SLR in mind. Cities on the coast are already at risk due to storm surges even if SLR were to be ignored. Areas such as New York, New Orleans and many others are prone to normal storm surges up to 12 feet high. The need to strengthen coasts to prevent future flooding is a much needed intervention to prevent loss of life as well as damage to property and infrastructure.

Netherlands has land below sea level and having faced storm surges over centuries have come up with solutions to adapt. London and Thames barrier is another flood protection mechanism that has worked well. But, countries in South East Asia, such as Bangladesh where much land is at sea level as well as areas that are not much higher than mean sea level (MSL) are also vulnerable. SLR has gradually increased from 1.8mm/year between 1961-2003 to a sudden 3.8mm/year in the decade between 1993-2003 (IPCC, 2007). Impact of SLR on developing countries, as recorded by the World Bank, predicts a minimum of 1m rise in SLR by 2050 or by the end of the century. They also estimate an accelerated estimate of 3m by 2100 (Susmita, Benoit et al, 2007). Continental subsidence such as in Boston is also expected to add 6 inches to SLR during this century (Boston globe,2007). The melting of ice caps are also decided by various internal and external influences and could rapidly increase at any point. Coastal marshes that support fishes and other near shore aquatic environments are disappearing at 20,000 acres per year (Pews Ocean Commission,2003).

2.3 The Case of Chennai City

In the recent decade, floods have been reported in most major cities and towns in India. Tsunami (2004), Mumbai (2005), followed by other major South Asian cities like Dhaka, Islamabad and Rawalpindi suffer urban flooding regularly(Saravanan and

Chander ,2015). At the core of disaster risk reduction lies the fact that flood resistance in cities must integrate and address three contributory aspects, viz. flood avoidance, flood tolerance and flood resilience.This in turn builds resilience to climatic changes in cities (Gupta and Nair,2010).

Chennai Metropolitan Area (CMA) is 1189 sq kms comprising of 8 districts including the Chennai District. The population of Chennai increased from 5.8 to 8.9 million in the decade between 2001 to 2011(Krishnekumaar and Meenakshisundaram, 2016). Chennai is affected by the lack of adequate drainage facility that is contributed in part by uncontrolled impervious built area , encroachment of drain channels and shrinkage of marshes (Saravanan and Chander, 2015). Unrestraint urbanization in combination with ecological and climatic variation makes Chennai vulnerable to repeat flood events(Saravanan and Chander ,2015). Chennai has significant urban heat islands (UHI) (Swamy and Nagendra, 2016) and UHI related extremes can also add to unpredictability in precipitation.

Globally, SLR has risen by 3 inches in the past 2 decades alone, and is expected to rise by about 1/8 inch each year and it is predicted that sea level rise can be up to or 2 meters by the end of this century (Fowler, 2017). Many coastal communities would see about one foot of SLR by 2045 (ucsusa.org, 2014). Given that the elevation of Chennai city above Sea level (MSL) is only about 6.7 meters and several neighborhoods lay at sea level means drainage of water is a challenge within the given topography. The city has 2847 km of urban roads but only 855 km of storm drains as per NIDM reports (CPREEC, 2008). Improper and inefficient storm water drains have increased the flood situation in the city along with loss of green cover and ecologically sensitive areas to construction (Gupta and Nair, 2010).

An increase in tropical cyclones in the recent past (Emanuel, 1987; Knutson and Tuleya, 2004) have been noted and even though the number of cyclones may not suggest an increasetheir intensities have risen and along with the potential to cause destruction (Emanuel, 2005)which is mainly associated with the warming of sea surface temperature (SST) (Knutson et al., 2010). The SST of the Bay of Bengal has been increasing quite rapidly (Narasimhan et al 2016) as in the figure below.

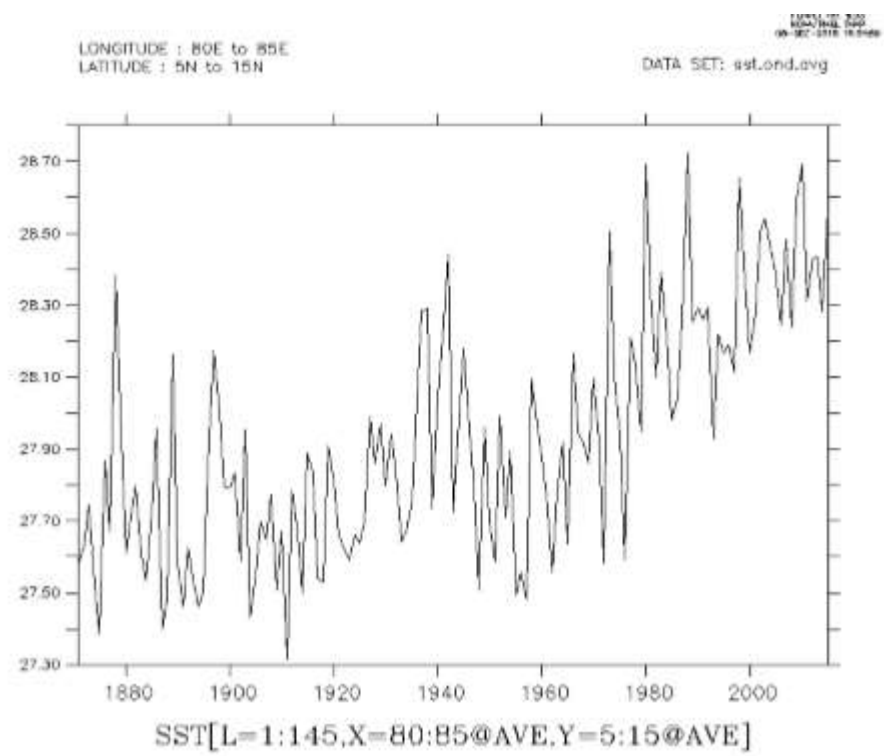


Figure 5 - The SST of the Bay of Bengal (in Celsius) Source: Narasimhan et al 2016

As of November, the highest recorded rain in history was 108.8cm (1918). The new record stands at 119.8 (2015). The December rain was 3 times higher than average. It was also the highest recorded in the last decade (Saravanan and Chander ,2015). There hasn't has not been a significant rise or drop in rainfall in the past 200 years but there has been a comparative decrease in the past two decades, and increased floods (Gupta and Nair, 2010) (Glaser et al., 2008).

Chennai has been frequented by disastrous floods in 1943,1976 and 1985 due to heavy rains caused by depressions in Bay of Bengal as well as cyclonic systems. Major rivers flooded and drainage systems failed (Gupta and Nair,2010). Additionally, floods have been regular from 2002 onward. In 2002, residential areas resembled islands and all communication, transport and trade links were cut off (Gupta and Nair,2010). This was followed by the 2004 Indian Ocean Tsunami where Chennai was severely hit, leading to loss of life at the beaches as well as flooding and water logging in residential areas due to heavy rainfall (6 cm within 24 h or less). Most slums were inundated and people had to be evacuated. Kumar et alproduced an inundation map of the Tsunami that revealed the suffering endured by the coast (2008). The North zone along the coast was relatively protected due to the presence of shoreline erosion protection features. Some areas along the coast suffered heavy erosion due to the pounding ocean waves. Coastal environment and livelihood was severely hit (Sundar and Sundaravadivelu 2005). The southern reaches that are almost flat led to high run ups along river mouths and carried the waters up to 4 km inland.

The year 2005 saw a deep depression over Bay of Bengal that brought up to 42 cm rainfall in around 40 h during North-east monsoon of 2005. This was followed by repeated events of flooding in 2006, 2007 and 2008 (Gupta and Nair,2010). The years that followed saw similar flooding during the same period of winter (North East monsoons). In recent memory, the floods of 2014, 2015 and 2016 have been catastrophic as well. The 2015 flooding was caused by a combination of factors including ElNino. ElNinos are known to impact and intensify NE monsoons (Zubair and Ropelewski, 2006). However,his is not an isolated event as intense flood events preceded 2015 and also continued in 2016. The trend is expected to continue with sea level rise and global climatic changes expected to affect coastal cities more than others.

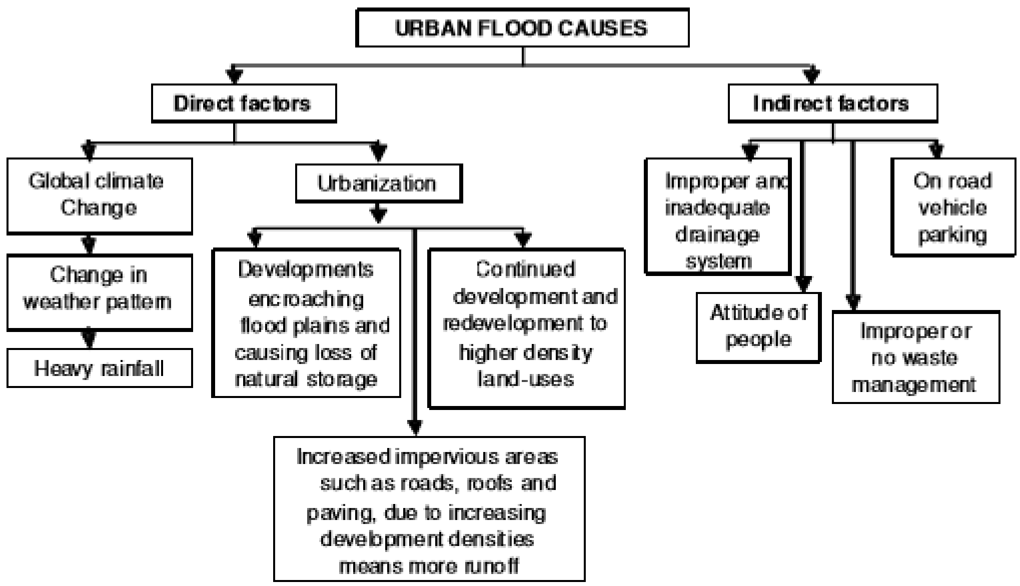


Figure 6: Causes of floods in urban areas. Source: Gupta and Nair,2010.

Chennai originally had an excess of about 650 water bodies that are now destroyed, built upon or shrunk due to non-maintenance and have dwindled to just 27. Major lakes (19originally) in the city have halved in capacity from 1130 hectares (ha) to 645 ha. NIDM report also highlights that some areas have replaced green cover by up to 99% by changing land use and that increase in impermeable surfaces and constructed buildings have increased peak flow (maximum discharge of water instantaneously) by up to 89% in the 4 years from 1997 to2001 further reducing the ability of the city to absorb water into the ground (CPREEC, 2008). The rivers, Cooum and Adyar, remain stagnant and carry water only during floods. The river Cooum drains off excess water from 75 tanks within its catchment and Adyar drains 450 tanks (Gupta and Nair,2010). The navigation canal built in 1800's by the British also served to mitigate dangers from the sea. Now the canal only acts as a drainage area. Slum settlements along the banks of the Cooum and Adyar were recorded to be 30,922, and lack basic amenities and are increasingly vulnerable during floods. They also pollute the water courses and lead to spread of diseases (CPREEC, 2008).

Pallikarnai marsh drained about 250 sq.km of the city through its network of satellite marshes around the main one and covered an area of 5,000 ha around the mid-20th century. By 2011, this was reduced to about almost 600 ha due to urbanization (Saravanan and Chander ,2015). Marshlands and ecologically sensitive infrastructures were used as dump yards. Anand (1999) noted that very few people are aware of where their household and commercial waste ends up. Reluctance was also noted in civic partnership to help reduce waste landing up in ecologically sensitive areas unless personal benefits were offered. Effective disposal of waste will also reduce harm to the coastal ecosystem (Appasamy and Lundqvist, 1993). Madras (2011) recommends that sanitation be given the highest priority by the municipal agencies as many slums lack basic sanitation as well.

The fragmentation of the marsh was attributed to mushrooming of housing and commercial activities, industries as well as governmental and public buildings permitted by change in land use. In addition, transport infrastructure was also laid over all water sensitive natural infrastructures. Originally Madras (Chennai) was formed as a set of settlements far apart but each with a temple as the nucleus (Gupta and Nair,2010). Since the early 20th century, there has been considerable decrease in green cover in the city due to influx of population from within Tamil Nadu as well as from other states (Gupta and Nair,2010). Urbanization has cut through many of these important features reducing capacity and causing blockage and shrinkage, sometimes completely replacing these networks.

High density impervious developments in the city combined with high motor vehicle use necessitate spaces for parking and roads(Gupta and Nair, 2009). Unplanned urbanization makes the city prone to repeat flooding as well as decreases ground water due to more impervious surfaces (Krishnekumaar and Meenakshisundaram,2016). Impervious structures and built infrastructure have increased surface runoff and the capacity of ground water to retain water. The capacity was lost to such a point that there was almost a complete stop in ground water recharging processes in the city and the level of ground water came down to 10 m from the year 1997 to 2001 (CMWSSB, year). Up to 33% loss of ground water was seen in some parts of the city during the same period. Ground water quality also significantly deteriorated (The Hindu, 2004). 36 localities are identified as flood risk hotspots by Chennai Municipal Corporation (Gupta and Nair,2010).

There is a steady increase in built impervious area and a subsequent decrease in agricultural lands, forest and barren land (Illayaraja and Lamin, 2011). Examination of land use maps by GIS –Land Use Land Cover (LULC) study by Illayaraja and Lamin, (2011) revealed that the built-up area which was 22.2% (1970) increased to 58.05% (2006), area of forest cover decreased from 17.36% (1970) to 4.48% (2006), water bodies decreased from 10%(1970) to 3.74%(1991) and increased to 8.51% (2006). Agricultural land decreased from 33.34 %(1970) to 2.75%(2006) and land demarcated for waste decreased from 38.39%(1970) to 20.27%(2006).

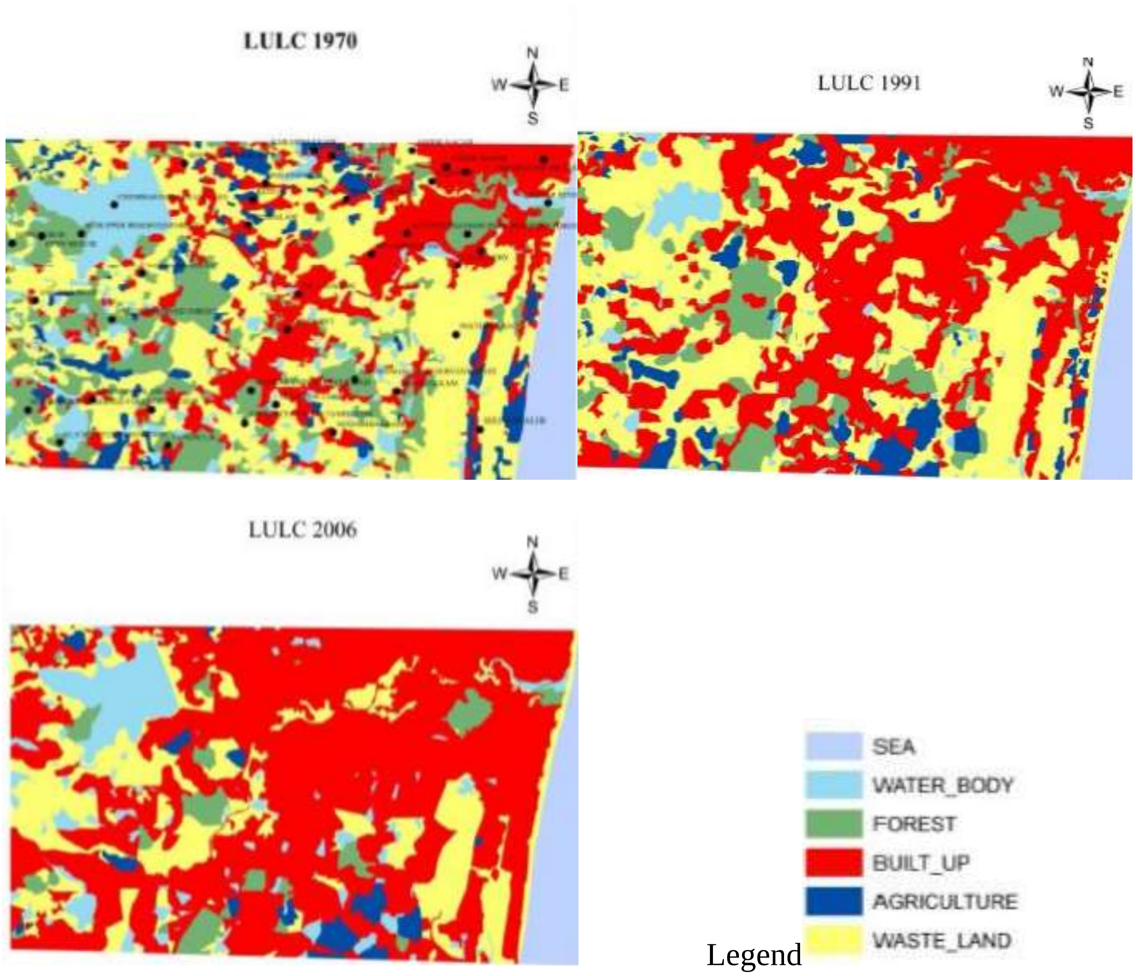


Figure 7: LULC Changes-1970,1991 and 2006 . Source: Illayaraja and Lamin, 2011.

Wetlands act as natural flood water storage that can safely be discharged by the system slowly(Melesse et al,2006). It is estimated that urban wetlands have reduced by 30% (Gupta and Nair, 2009). Wetlands, lakes and even manmade water bodies, have disappeared or shrunk drastically over the years in Chennai due to anthropogenic activities of slum dwellers and the elite class alike. Dumping waste in non-designated areas have also contributed to this (Sundersingh, 1990). Degradation of natural tanks and river banks, and their use as waste dumping sites followed by encroachment by slum dwellers and then being designated as land for housing complexes, garden/parks significantly contribute to progressive loss of natural flood control. Chennai had an extensive network of temple tanks (as seen in picture below). These are in disuse due to non-maintenance and have become inefficient in controlling floods or storing water.

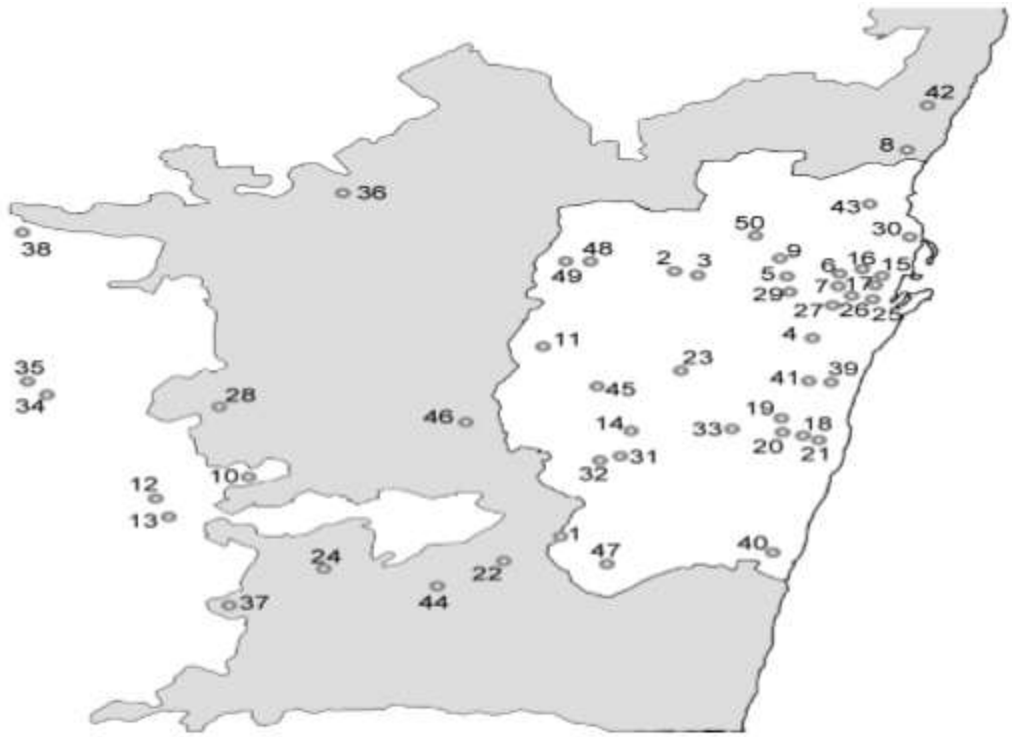
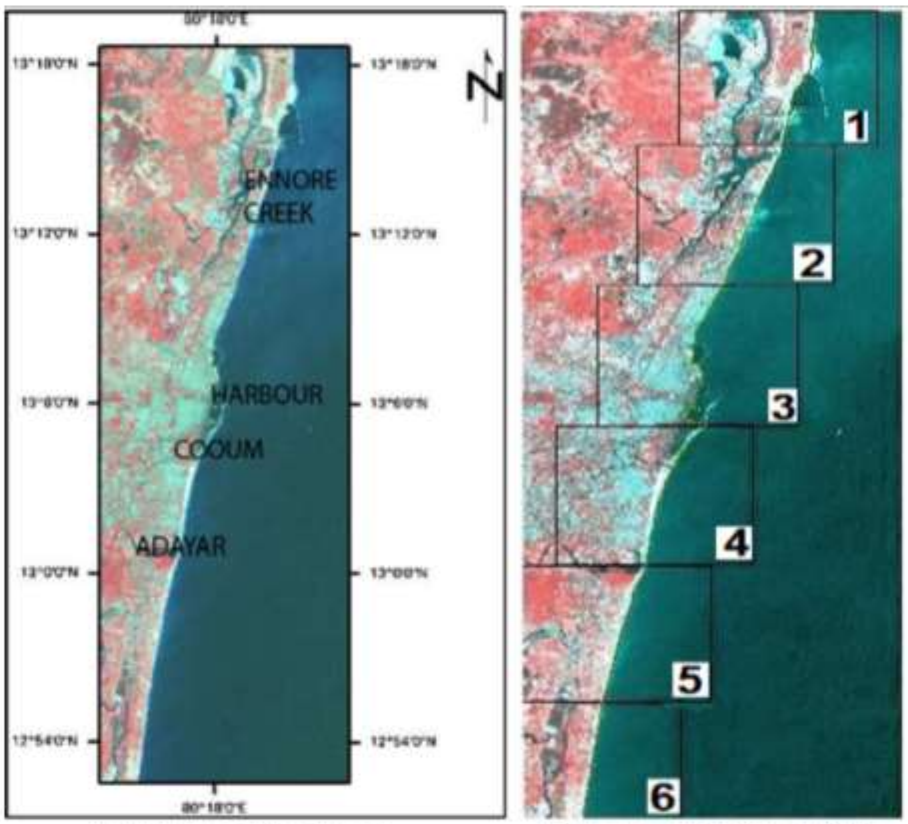


Figure 8: Temple tanks in Chennai. Source: CPREEC, 2008.

Kumar and Kunte (2012) studied the coastal area of the city spanning 56 km and concluded that the river systems act as inundation corridors to storm surges from sea and allow water to be carried upstream up to long distances, thus flooding the areas proximal to the river banks. Toward the north, increase in risk due to geomorphic features like flood plain, deltaic plain, salt flat, water bodies, sand beaches, and mud flats is abundant. The central and southern reaches of the city are mostly residential industrial areas with features such as beach sand, beach dunes and ridges along the coast thus minimizing risk. About 33.65 km of coastline in the South recorded accretion along the coastal stretches and has a low risk rating. IPCC estimates the change in SLR worldwide to be 1–2 mm/year. The entire coastline of 56 km is at a medium risk for SLR (Kumar and Kunte,2010).



Satellite Image of the Chennai

Study Area with the Coastal Grids

Figure 9: Coastline grid of Chennai city. Source-Kumar and Kunte,2012

After analyzing eight parameters for each grid of the area, and considering extreme storm surges and return period four issues are of great concern -land loss along the coast, damage to the ecosystem, erosion and subsequent degradation of shore which would eventually lead to loss of lives and economy (Kumar and Kunte, 2010). Refer image below.

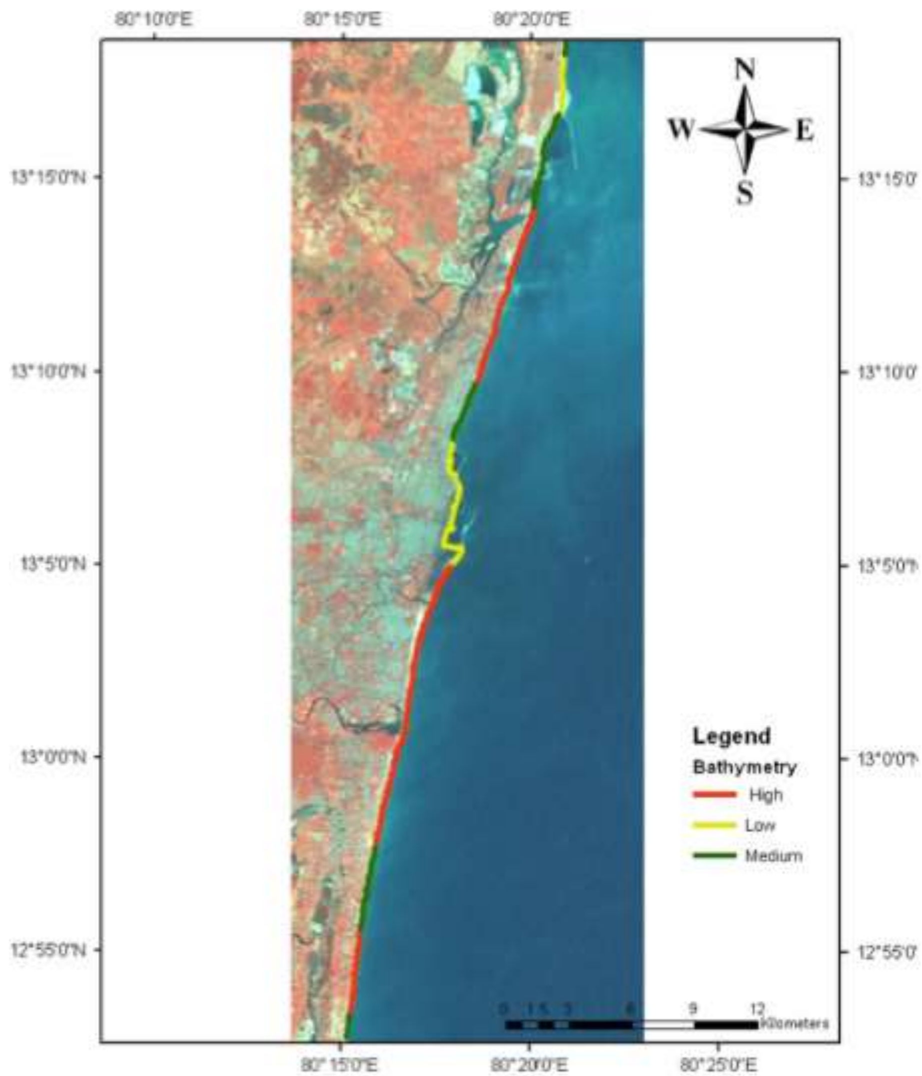


Figure 10: Risk and vulnerability along the coastline. Source: Kumar and Kunte,2012

A study conducted by Jayakumar and Malarvannan (2016) by analyzing the survey and topographic survey maps revealed that the coast of Tamil Nadu is highly dynamic due to both natural as well as manmade causes and it undergoes significant changes; the southern areas accrete while the northern areas are prone to erosion. The area further north of Chennai, toward Pulicat and Ennore creek in Thiruvallur district is narrow and covered by mud flats. Furthermore, manmade structures such as a thermal power station at Ennore in 1971, Ennore port in 2001, Kattupalli port in 2011 as well as Groynes were constructed. The middle section, occupied by Chennai is vulnerable due to urbanization, setting up of industry, and port and fishing activities making the shoreline vulnerable. The Southern part in Kancheepuram district which includes Muttukadu back waters, Mahabalipuram and Palar river are prone to accretion. Deposits were less in Palar river but increased in the discharge mouth of Adyar and Cooum rivers in Chennai.

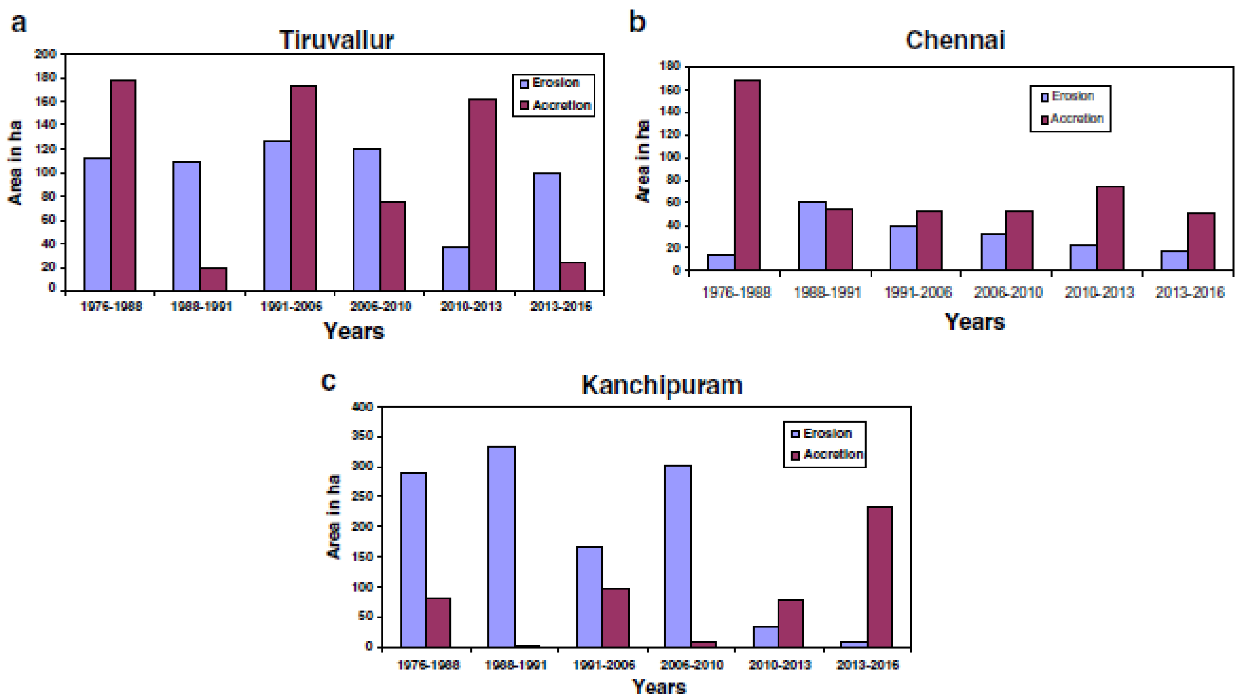


Figure 11: Changes in the area of erosion and accretion district-wise from 1976 to 2016. Source: Jayakumar and Malarvannan, 2016.

Cyclones and storm surges that result from them affect the shallow bays more, due to wider shelf and gentle slope characteristics that allows for uptake of water (Shetye et al. 1990). The repeated action of waves has led to berms in cul de sacs thus formed. Other coastal features such as lagoons, estuaries, creeks, spits, dunes as well as outlets from the rivers to the sea lie along the coast. The Marina beach that is famed as one of the world's longest runs along the entire coast from Ennore creek in the North to

Muttukadu creek in the South A study by Mani, 2000 explains that storm surges of 3–6 m height with an inland penetration of up to 8 km have occurred during cyclones between 1952 and 1993 in the Tamil Nadu coast. The probable maximum surge height along coastal Chennai as 5.45 m (BMTPC 1997).

Risk level	Range
Very low	0.000–0.216
Low	0.216–0.416
Moderate	0.416–0.576
High	0.576–0.818
Very high	0.818–1.000

Figure 12: Risk of Surge. Source: Geospatial Analysis for Coastal Risk Assessment to Cyclones, Poompavai & Ramalingam 2011

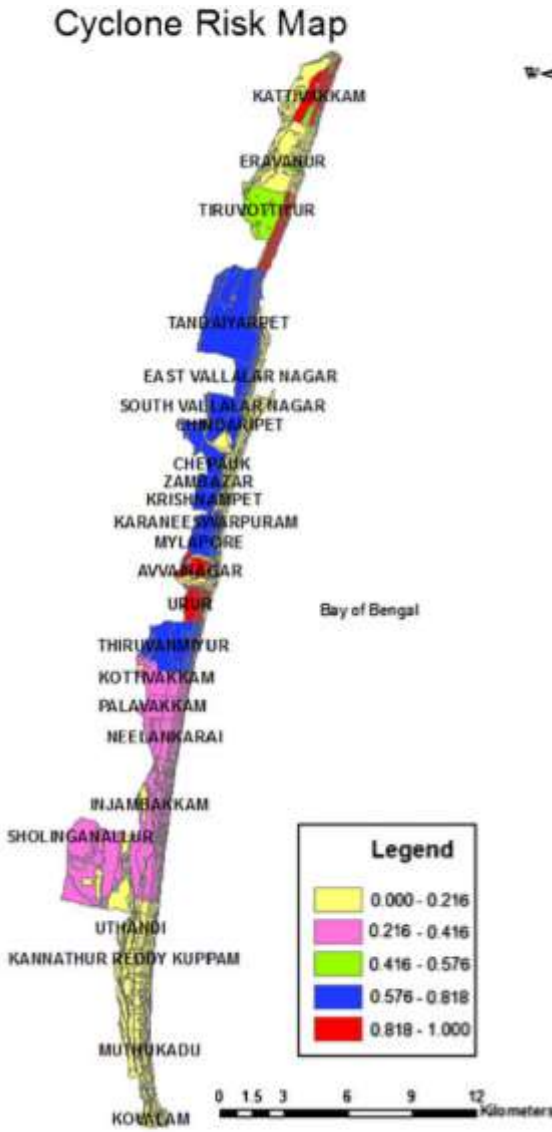


Figure 13: Cyclone risk map. Source: Geospatial. Analysis for Coastal Risk Assessment to Cyclones , Poompavai & Ramalingam 2011

Poompavai & Ramalingam (2011) studied the coastal vulnerability to storm surges and cyclones and concluded that northern coast of Tamil Nadu which includes Chennai are at high risk due to its location being in the tract of frequent cyclones as well as lack of adequate protection of the coast and its' population against these dangers.

Conclusion.

Overall, it is quite clear that Chennai needs to strengthen its defenses against floods, storm surges and cyclones and build capacity for storm water and adequate drainage as well as consider the damage to its natural environment and protect it before it is too late.

The following sub chapters will explore how Chennai can build resilience in the various facets.

2.4 Theoretical Background and Case Studies

2.4.1 Urban and coastal resilience against flooding

'Resilience' of any material is the maximum extent that remains under the elastic curve of a stress strain curve without breaking when an external stress is applied on it. Resilience of an ecosystem is its' ability to withstand strain without collapsing when an external force acts on it. 'Resilient ecosystems' have the ability to rebuild or adapt when required. When it comes to humans, resilience can be achieved in society by the ability to anticipate and plan and act as a community. Ecological systems are constantly impacted by human actions at al scales. Thus resilience should be achieved on socio-ecological levels. Such systems, also abbreviated as SES have 3 distinct characters: The extent to which the system can self-organize after an impact, Ability for capacity building and learning and retaining control of the function and structure even after undergoing significant change. (Resilience Alliance). Resilientcity.org defines a resilient city as one that has the capacity to absorb future anticipated shocks on infrastructure, technology and even economy, and to continue with the same functions.

The key difference between 'Resilience' and 'Sustainability' is that sustainable measures does not need to take into account 'Risk' and, thus attention is paid to increased efficiency but less attention is paid to recovery and prevention of the risk

(Khodabaksh et al, 2015). Events of a certain enormity that significantly disrupts a system can affect sustainability as the system will also need to be 'resilient' then (Martin Breen et al. 2011). Characteristics of a resilient system as defined by Martin Breen are as in the table below:

Characteristics	Description
Adaptive capacity	Equipping urban systems to deal efficiency with slow and radical changes
Self-organization	The process of internal organization within a system without being guided or managed by an outside source.
Transformability	Having the capacity to create a fundamental new system when the ecological, economic and social conditions make the existing system untenable.

Table 1 – Characteristics of a Resilient System, Source- Martin Breen and Marty Anderies 2011

'Adaptive capacity' is an aspect of resilience which reflects the ability of a system to effectively cope with shocks and it generally is for a short period of time (Khodabaksh et al, 2015). 'Transformability' on the other hand is the ability of the system to transform itself through reorganization when it can no longer survive with the current function it serves (Martin-Breen and Marty Anderies 2011) (Khodabaksh et al, 2015).

In the urban paradigm, resilience is borrowed from understanding how ecological systems cope external stressors (Davic and Welsh 2004). Resilience can be coined as "the capacity of a system to undergo disturbance and maintain its functions and controls" (Gunderson and Holling, 2001). Holling (1973) suggests that resilience is "the persistence of relationships within a system" and "the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist" (Barnett 2001, Carpenter et al. 2001).

Coastal areas and Socio-Ecological Resilience. Around 23% (over 1 billion) people live within 100km of the coast around the globe (Small and Nichols, 2004) and this is expected to rise to 50% by 2030. These populations are vulnerable to various hazards such as coastal flooding through storm surges, tropical cyclones, hurricanes and even tsunamis. The population at risk would increase to 50 million owing to sea level rise, climate change and increasing population along the coast by 2080 (Nicholls,2004). There is an urgent need to make the coast more adaptive to environmental changes worldwide (McClean and Tsyban,2001).

Vulnerability of social and ecological systems to disasters and extreme events are subject to the wearing down of resilience prior to as well as after the occurrence of disaster (Adgar et al,2005). Understanding linkage between humans and their ecosystem helps us to build resilience in areas that are the most vulnerable to floods and various natural disasters i.e. the capacity of the complex social-ecological adaptive system at the coast to absorb recurrent disturbances such as hurricanes or floods and the ability to retain essential structures, processes, and even to provide feedback (C. S. Holling, 1973; B. Walker et al 2004).

When these systems are resilient, they have various ways of living with, coping from unexpected shocks, and learning and changing accordingly by adapting. (Adgar et al, 2005). A multi-level governance system is needed to build capacity and to mobilize a varied source of resilience (Adgar et al,2005).

Elements of vulnerability	Local action	National and international action
Exposure and sensitivity to hazard	Maintenance and enhancement of ecosystem functions through sustainable use Maintenance of local memory of resource use, learning processes for responding to environmental feedback and social cohesion	Mitigation of human-induced causes of hazard Avoidance of perverse incentives for ecosystem degradation that increase sensitivity to hazards Promotion of early warning networks and structures Enhancement of disaster recovery through appropriate donor response
Adaptive capacity	Diversity in ecological systems Diversity in economic livelihood portfolio Legitimate and inclusive governance structures and social capital	Bridging organizations for integrative responses Horizontal networks in civil society for social learning

Table 2- Examples of local and regional scale actions to enhance resilience in social-ecological systems exposed to abrupt change, Source: Adgar et al,2005

The Tsunami of 2004 proved that formal and informal institutions with the capacity to respond to rapid change in environmental and social conditions are a key to mitigating the social effects of extreme natural hazards' (Adgar et al,2005). Instead of attempting to control nature and to be rigid through hard engineering, governments should attempt to strengthen the populations and the ecosystem they depend on (Adgar et al,2005).

Natural weather imposed hazards such as hurricanes, tropical cyclones etc that affect the coast cause extensive damage to human settlements, lead to loss of lives, and also impact coastal ecosystems such as coral reefs mangroves etc (Lugo et al 2000), (Pielke et al 2003) that the local community and economy may depend on. Anthropogenic impacts of climate change are now evidently likely to affect storm intensity and precipitation, leading to floods and damage of infrastructure even if climate change doesn't affect intensity at this point (Trenberth, 2005). Social vulnerability increases loss of life and damage to economy and infrastructure as much as natural and physical hazards (Pielke,2003).

Planning of resilient cities would differ in many ways, but their commonalities are listed (Langeveld, RDI, 2013) below:

- Straightforward, flexible and modular systems that adapt easily to changes.
- Locally available, renewable resources rather than non-renewable or hard to acquire or implement.
- "Know-how" contributes to resilience –understanding the system
- Resilience anticipates a dynamic system in future and prepares for shocks. Resilient cities should respond with dynamic design when confronted with natural interruptions and shocks (Abhas et al., 2013).
- The "Know-how" contributes to resilience
- A multi-function space that adapts to the user's requirement - diverse communities, ecosystems with varied socio economic parameters
- Durability increases resilience.

Coastal systems are struggling to regenerate after the onset of a disaster, more so than ever before. The need for socio ecological resilience needs to be understood and managed increasing incentives for knowledge sharing to help with governance. Social capital and capacity building that will support legal and political framework will also help enhance Socio-Ecological Resilience. Multilevel social networks are crucial for developing social capital and for supporting the legal, political, and financial frameworks that enhance sources of social and ecological resilience (Folke), Dietz et al 2003).

2.4.2 Vernacular Urban Resilience

Engineers and Planners pay no attention to understanding history, and there appears to be no endeavor to recognize the impressive design underlying the old systems (Mendis, 2007). This does not mean glorifying the past without scientific reasoning, but rather, understanding how our forefathers learned to adapt. We cannot accurately predict the future vents but can look back and learn from the past (Ripp,2013). Some of the ancient irrigation structures were so successful, they are in use to this day, such as 'Qanats' and 'Falaj' in Persia and Oman (Mendis, 2007). This in essence is true sustainable development. Many critics say that since present day development harms nature, measures should be taken to define sustainability in a way that it deals with healing nature. This in contemporary discussion leads us to 'Resilience'.

US Environmental Protection Agency, EPA emphasizes the "Four Pillars of Sustainable Infrastructure" to be -Better Management, Full-Cost Pricing, Water Efficiency, and Watershed Approaches to Protection (Mendis, 2007). But, this is not entirely acceptable in developing countries and, hence the need for looking back in time to foresee the future. In order for a settlement to be 'Resilient', the planning needs to be dynamic, flexible and adaptable and should consider that the contiguous environment 'system' that we are working on is constantly transforming due to external as well as internal forces. Vernacular strategies can be termed 'Resilient' as they have dealt with people, climates and changing environments and have still survived. One of the technical features of the ancient large reservoirs in Sri Lanka was the 'sorowwa' or sluice with its 'bisokotuwa' or access tower making them the first inventors of the valve-pit, more than 2100 years ago (Parker, 1909, 379). These 'valve towers' (Open wells that stand clear of the embankement) and 'valve pits' (that stand on it) regulate or stop outward water flow have been built in Europe for numerous reservoirs since mid-last century (Parker, 1909, 379).

About 50% of the total land in Bangladesh lies 6-7m MSL(mean sea level) and economic losses are compounded by socio-economic vulnerabilities. It is one of the worst affected areas by disasters such as floods, cyclones, storm and tide surges, riverine flooding and even droughts. (DMB, 2008). Model houses were built and three-stage community level meetings were held to collect local information and views of the people and craftsmen from various vulnerable areas and with the use of local materials, model houses were constructed to be resilient to floods, cyclones etc as per the selected area's vulnerability (Moles et al,2013).It was found that completed vernacular houses performed well in comparison to new ones and were accepted by the local community. Older structures after rehabilitation also served well. Education and training monitoring are carried out to ensure safety (Moles et al,2013).

A study of vernacular dwellings in Rathnapura concluded that houses built in 1800-1900 period had many flood mitigation features imbibed in them that we call modern (Dilhani and Jayaweera,2006). The authors summarized vernacular knowledge and construction practices for flood risk mitigation in vernacular dwellings of Rathnapura

In Malawi, like many other African nations, construction material is predominantly mud that is locally available. Mud stacked in clumps one over the other to form a wall lives up to 15 years. Mud is coated over irrespective of whether frames are made with wood, bamboo or even reed (Narayana Rao,2016)The courtyards in houses protect from the sun, and also heavy rains. They feature very narrow openings that act like a filtering element during the rains. These settlements integrate themselves to their surroundings by respecting climate as well as context, so, they gain energy efficiency. The orientation to the South helps heating using solar energy, and help with daylight, but protects from excess sunlight. Narrow streets act like ventilation corridors under the buildings.(Narayana Rao,2016) .Tamil Nadu has no rivers of its own and depends on monsoons for water. Flowing rivers from other states discharge into the sea here. In olden days, to make the most of the water passing through to the sea, they made a series of cascading tanks to connect near and far off tanks. The outflow from one tank ('Eri'- large tank) served as inflow for the next one in the series as the tanks discharged excess water after fillings its capacity. This was managed locally by communities through a decentralized process. (Gopalakrishnan,2014). A person who was dedicated to keep a watch on the water level was called 'Neerkatti' whose role was to channel water into fields of individuals for irrigation. He was paid in kind by villagers and the physical structures were maintained by the entire village and this process was called 'Kudimaramathu' (Gopalakrishnan, 2014). Ooranis were dug out tanks that would catch and store rain water for drinking purposes (Gopalakrishnan,2014). Proper use and understanding of built heritage that is passed on helps with socio economic preparation as well as making ourselves more prepared and, thus more resilient to the impending dangers based on how it was dealt with in the past.

Disasters are beyond human control and it is helpful to look at them with the prior experience in the region. Global paradigms have shown that replicated vernacular solutions during previous disaster events help in coping well with the situations we face. Due consideration and perhaps measures of strengthening these solutions may be crucial for countries, be it, India, Bangladesh, Malawi or any other place (Gopalakrishnan,2014).

2.4.3 Ecology and Landscape Urbanism

Ecology is a transdisciplinary science that focuses on relationships between living organisms and their environments. The term 'Ecosystem' was coined in 1935 (Frank, 1993*)*. By early 20th century different interdisciplinary works combined and formed the basis for a new integrated science which dealt with plants, animals and environment and was called 'Ecosystem Ecology'. These views were popular in disciplines ranging from natural sciences to governance, planning and large scale project management. Ecology in its critical sense combines social, mental and environmental issues thus informing design and practice.

Ian Mc Harg's design combined contemporary ideas of ecology and planning by late 1960's and 70's which demonstrated an analysis of the natural environment-geology, soil, water, habitat etc. This opened up the planning discipline to ideas of interconnecting cities, suburbs and natural world and, thus 'Landscape Urbanism' and 'Regional Planning'. Environmentally informed development strategies came into being for planners, development community and environmentalists. In 1980's and early 1990's, Richard Forman researched new directions in applied ecology which gained popularity along with Land Sat Imagery and computer aided Geographic Information System (GIS). At Harvard Graduate School, Foreman furthered his research and developed a new term 'Ecological Systems' which was based on matrices, webs and networks and characterized by adjacencies, juxtapositions and overlaps. Ecological systems, thus came to be recognized as dynamic and living systems as opposed to just physical elements. Adaptation, appropriation and flexibility were understood as benchmarks of a successful system. An ecosystem's ability to respond to changing environmental conditions defines this system's effectiveness.

Ecology has influenced landscape architecture and planning, but has also displaced some of landscape architecture's traditional aspects such a design theory and history to focus on aspects of natural science, environmental management and ecological restoration. Appropriation of ecology within landscape urbanism is limited to landscapes for entertainment and is yet to make its way towards contemporary built environments.

Reliance on technology to create a perfect future first began in 16th and 17th centuries when new advances came up in science and gave rise to capitalistic markets that assumed they could master over nature and believed that disease and poverty would be eradicated as living standards improved. This assumed competence to reign over nature has continued till this day, but only continues to draw a deeper line between the rich and poor. Nuclear weaponry and production of toxic wastes have also increased with growing competence between nations and their various industries. This has led to a more materialistic and mechanistic world with little regard for nature and culture. Polarization of humans and social world from the natural world leads to a dualism with a 'subject' and 'object' and concepts of environment are perceived to be external to mankind. The modern cultural paradigm has led ecological practices of landscape architects into two dominant streams – the 'Conservationist/Resourcist' who envisions that further information about ecological systems will enable progressive management and control of ecosystems, while the other branch 'Restorative/Ecocentric' espouses that ecological information can be used to heal or reconstruct 'natural systems'.

The former group, views landscape by assigning values people would have to various resources such as agriculture, forestry, tourism, built environment etc. Scenery and natural areas are also assigned a value by terming them as ‘heritage’ or ‘wilderness’ areas and are envisioned for future generations by balancing human needs and natural world. Quantification of the economic, social and ecological values lead to strategies for conservation. Thus, arriving at an apparently ‘value neutral’ rational criteria for evaluating land use and environmental system. An ecological system developed by Ian Mc Harg in the 1960’s called ‘Suitability Analysis’ quantified various parts of the ecosystem and measured impacts for various development scenarios and recommends the least disruptive land use. The objectification of nature to view it as utility causes devaluation and detachment between people and the natural world thus leading to the removal of all remaining emotional impediments to unrestrained development. (Worster, 1975, p 304).

In the latter approach, emphasis is on acquisition of technical knowledge to physically recreate landscapes at small scale and large scales to create ‘regional ecosystems’. There is less attachment to values and is more natural with a focus on ‘native’ elements. Restoration is usually ideological and is derived from a particular idea of nature and can degenerate into serving ‘purist’ nationalistic ideals. While the first group (Conservationist) utilizes ecology to further control the human environment, the other (Restorative) uses ecology to provide a rhetorical force to develop emotions towards the naivety of nature and errors of anthropocentricity. Both views eventually lead to the same paradigm which is often described as the structural cause for environmental and social decline.

Radical ecology emerged due to the failure of conventional ecological framework. This group focuses on culture as opposed to nature. Amongst the various branches of Radical ecology, the one that most closely relates to landscape urbanism is 'Social Ecology' (Zimmerman et al,1993). Social ecologists believe that people must function as 'moral agents' who creatively intervene to create diversity, freedom and self-reflexivity (Haraway,1991;Latour,1993 and Rose,1994). They see their projects as having moral imperative.

Ecology's role for Landscape Design is similar to the role of industrialization for modern architecture in the 20th century; wherein it acts as a catalyst for innovation but at the same time acts as the external disruptive force. Ecological systems aren't like machines that have preexisting parts. They have evolved over time and their history defines them. For instance, when vegetation cover is removed over a large area, a stable ecosystem forms with time in successive stages. Ecosystems are not homogenous structures; they bear a spatial system with biological and physical characteristics

Ecosystems are formed not just by parts but also by the interaction between those parts and their complexities are such that it is dangerous to look only at a fragment. If we do concentrate on just one fragment, the rest of the system would respond in unimagined ways. Thus, ecological systems have four essential properties that produce resilience and stability-

a. Systems property wherein may components act together to form a complex feedback interaction between them.

b. Historical quality which responds to not just present events but those of the past too.

c. Spatial interlocking by responding to events at more than one point in space.

d. Distinctive nonlinear structural properties with the appearance of lags, thresholds and limits.

Figure 14 -Landscape Urbanism Principles, Source- http://madeinjakarta.org/?page_id=42

2.5 Urban and Landscape Urbanism's Approach to Flooding

Urban design and the role of Blue Green Infrastructures (BGI's)- According to UN statistics, more than half of the world's cities are expected to face water crisis by 2025. This will increase the number of events as well as intensity of worldwide floods and droughts, thus affecting food supply, water security and health.

Structures in natural environments and those in urban settings significantly differ in the fact that those that are by nature undisturbed by manmade interventions have flexibility and resilience which helps in dynamically balancing small events to a larger disaster. Ecosystems adapt quickly after events of floods, avalanches etc. and over time, the impact of the disaster is unrecognizable. Blue green infrastructures (BGI's) help simulate natural environments in urban context.

Spaces in cities are scarce and land resources are shrinking due to a burgeoning population and increased demand for infrastructure and spaces of work, recreation etc to support these populations needs, pushing environment and need for green spaces to the backdrop. Urban flooding is also on the rise due to increase in impermeable structures, increasing surface run off and concentrating water collection in areas that should not accumulate water otherwise. Streams in urban areas often remain devoid of water in dry periods leading to destruction of natural habitats, fishes and plant life.

BGI's significantly impact micro climate as Blue (Water) and Green (Plants) help in filtration of air and holding micro particles dispersed by air, thereby having a cleaner environment by reducing air pollution. They also create corridors for biodiversity.

Some flood protection measures in urban and landscape design's approach to flooding (but not limited to these) are:

1. Waffle method
2. Green Growth Policy
3. Sustainable Urban Design Schemes
4. Floodable gardens, parks and buildings
5. Sponge cities
6. SUDS- Sustainable Urban Drainage systems
7. WSUD- Water sensitive urban design

2.5.1 Contemporary and Ecological concepts in Flood Mitigation-Policy and emerging trends.

Urban Drainage Systems. *SUDS- Sustainable Urban Drainage systems*. The term sustainable urban drainage systems (SUDS) were established in the UK in 1990s to make changes to unsatisfactory urban drainage approaches used at the time. This system involves creating ponds, wetlands, swales and basins to mimic natural drainage.

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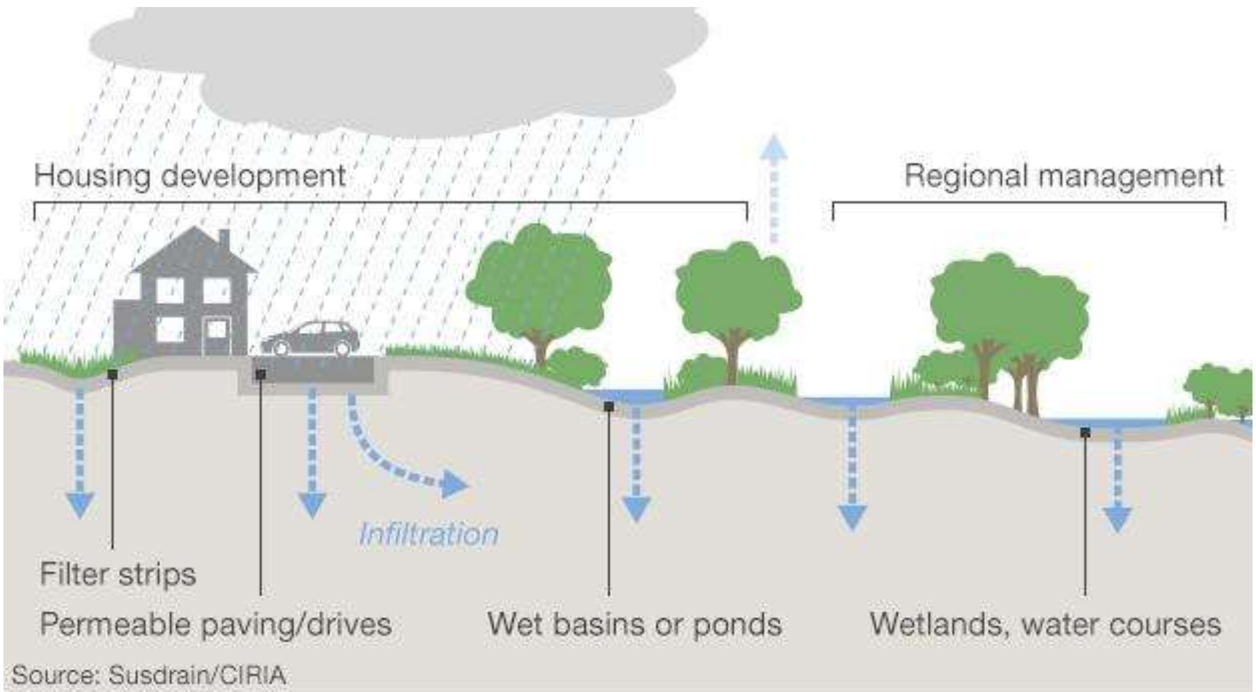


Figure 15: Development over a Regional scale rather than Housing level. Source: Susdrain/CIRIA.

Two examples for this system are below(not limited to these):

Bio retention. Runoff flows into shallow landscaped depression through the filter bed which has a mixture of sand, soil, and organic material as the filtering media with a surface mulch layer.

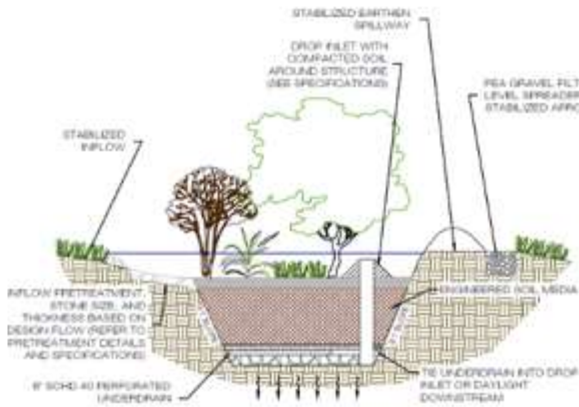


Figure16.Bio retention basin.
Source.http://www.vwrrc.vt.edu/swc/NonPBMPSpecsMarch11/VASWMBMPSpec9BIORETENTION.html

During storms, runoff temporarily fills 6 to 12 inches above the mulch layer and then rapidly filters through the bed. This can then flow back to storm drain system through an 'under drain' which is a perforated pipe in a gravel layer installed along the bottom of the filter bed. This is also called a Bioretention Filter. The system can be applied at various scales.

Micro-Bioretnetion or Rain Gardens. These are small, landscaped areas that reduce run off from individual rooftops, pathways and other household level developments. Inflow is either as sheet flow that flows directly into the system, or can be through downspouts.

Bioretention Basins. Used in parking lots and/or commercial and institutional rooftops, inflow can be either sheet flow or concentrated flow. They are preferred to be located in common areas or within drainage easements, to treat a combination of roadway and individual property runoff.

Urban Bioretention. These are structures such as expanded tree pits, curb extensions, and foundation planters located in streetscapes.

B.Retarding Basins - Melbourne, Australia. They are basically landscaped areas covered with grass and used for recreation or can be open water retaining structures that support biodiversity. Flood retarding basins are similar to large ponds in urban areas which integrate with the drainage system and store storm water runoff and control the flow rate to prevent overwhelming the drainage. They reduce impacts downstream and prevent surrounding houses and commercial spaces from being affected and also protects natural waterways. This stored water then gets released downstream safely. Since they store large volumes of water, they are like dams and need to be constructed to specifications. They are designed to mitigate 1 in 100 years flood events. Melbourne has over 200 of these flood retarding basins within it's' drainage system. Outlet structures and gratings are designed such that they don't accumulate debris and allow for maximum outlet flow during storms. Trees can't be planted on embankments and only grass can be maintained. Benefits, other than flood control, include pollution control, storm water management and recreation.

Figure 17: Retarding basins in Melbourne. Source: Melbourne water management

WSUD- Water sensitive urban design. The working principle involves thinking of water supply, waste water, surface water and flooding when designing rather than as an afterthought. It aims to minimize the hydrological impacts of urban development on the surrounding environment.

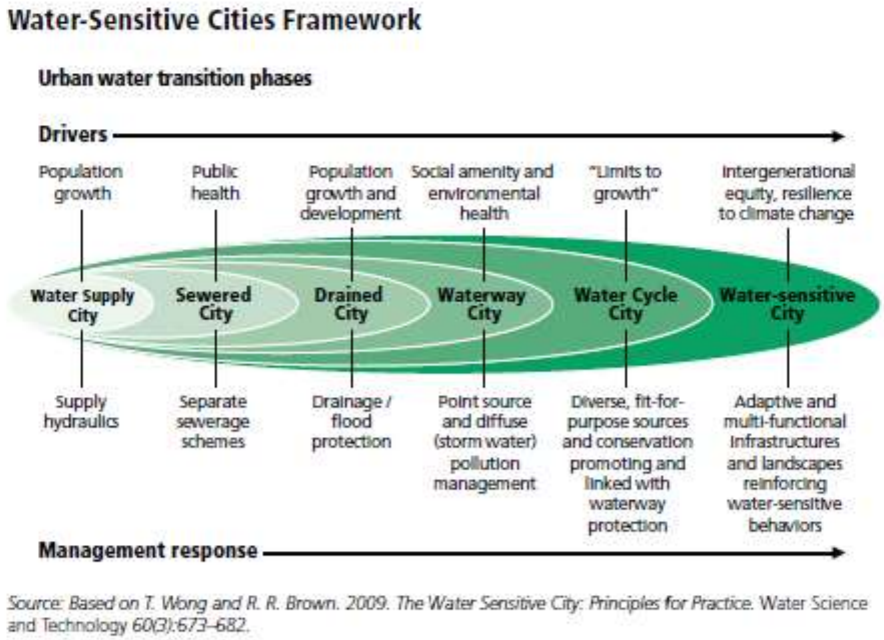


Figure 18: Water Sensitive Cities Framework. Source: T.Wong and R.R Brown. 2009.

This was started in Australia in the 1990's, Stormwater management is a component of WSUD. As it aims to control and manage flows to prevent floods and improve quality of water. Storm water harvesting that can be used to store water for non-potable uses to supplement regular water supply is also recommended (Lloyd et al, 2002).

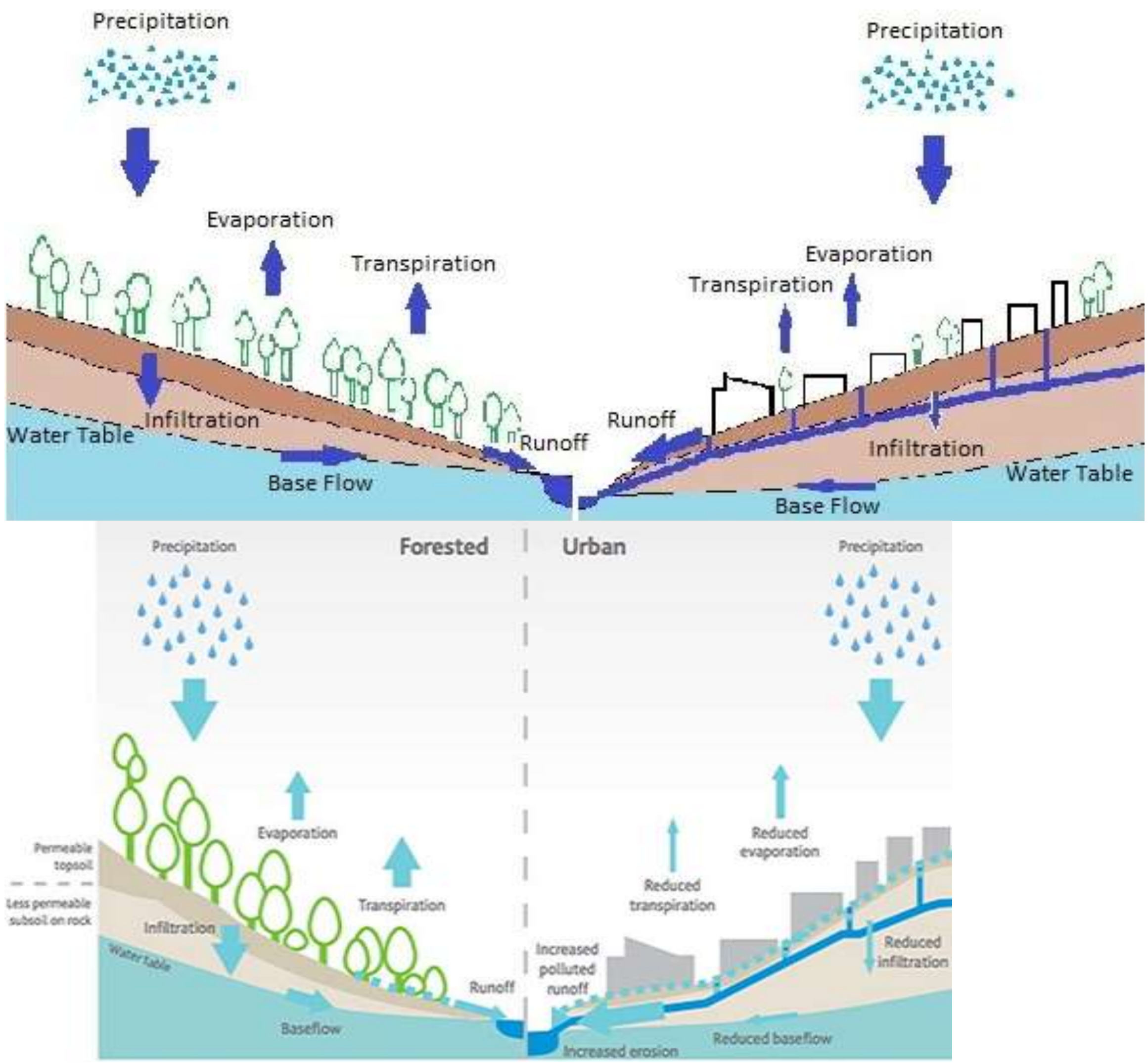


Figure 18-Water Sensitive Urban Design (WSUD) mimicking the natural water cycle and restoring waterways. Source-http://www.hobsonsbay.vic.gov.au/Environment-amp-Waste/Water/Stormwater-and-waterways

Main objectives of WSUD.

i. Protection and enhancement of natural water systems within urban developments.

ii. Integrating treatment of storm water into the landscape.

iii. Water quality protection

iv. Minimizing run off through detaining water

v. Reducing drainage infrastructure cost.

Sponge cities (Drought resilience)-China. This works by soaking rain water in different ways, ranging from permeable roads to rooftop gardens. It helps solve the dual problem of rapid urbanization and water scarcity in cities throughdeveloping ponds, filtration pools and wetlands, as well as construction of permeable roads and public spaces that enable storm water to seep underground. At least 60% of rainwater falling in the cities can be saved. They additionally protect beaches from excess run off.

Figure 19: Sponge City. Source-
http://www.initiatives.com.hk/uploads/2/6/5/3/26530155/4257253_orig.jpg

Floodable gardens, parks and buildings - London, Strand on green. This area in London floods regularly and instead of preventing it, the area is planned such that the flood can be enjoyed without effecting daily life.

Figure 20: Floodable gardens, parks and buildings. Source-http://www.gardenvisit.com/blog/category/sustainable-design/urban-design-flooding/

Waffle Cities –Building bunds in garden design. This is a cheap alternative to minimize flooding as it prevents water from going from zone to zone by creating bunds as in the case of a waffle. This is being considered in China, Los Angeles and other cities for flood prevention as well as water recharge.

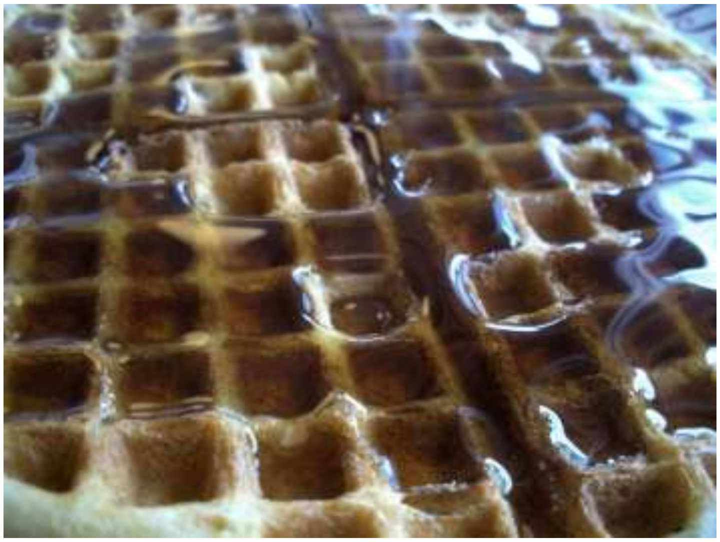


Figure 21: Waffle Cities. Source:http://www.gardenvisit.com/blog/category/sustainable-design/urban-design-flooding/

Some other ecologically sensitive designs include:

i. Copenhagen green finger plan

ii. Emerald Necklace

iii. China bubble gardens-Tiangen city

iv. Floating gardens of Yongning river park, China

v. Permeable walls and green (Mexico)

vi. Dechannelizing river Geneva

Green Growth Policy – Greening for economic benefits, wherein developers of large scale developments are encouraged to provide for greening and in return they may be allowed to develop a little more than allowed by policy.

Sustainable Urban Design Scheme – These systems act on a holistic basis.

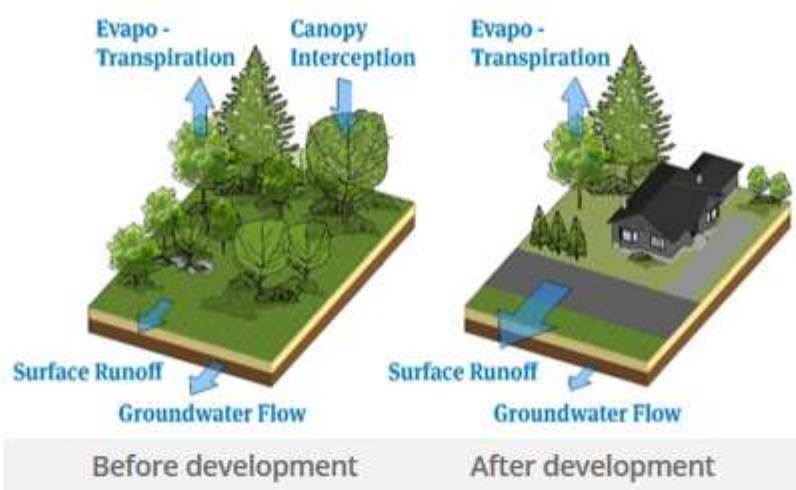


Figure 22: Sustainable urban design. Source.www.gardenvisit.com

The main principles are:

i. Raise embankments

ii. Detain

iii. Infiltrate

iv. Evaporo transpire flood waters

Other policies include but are not limited to -Low impact Development (LID),Best Management Practices(BMP) etc..

2.5.2 Engineering approaches to Urban flood protection:

Barriers are constructed as flood control structures along the coast or on river embankments to prevent storm surges and tidal flooding. Flood tunnels are flood management systems that can be implemented in dense urban areas due to lack of space to accommodate surface canals or storm water channels. It is like a very large storm water pipe and the term sometimes encompasses additional components such as retention basins, temporary storage tanks and associated pumps and infrastructure (floodlist.com, 2014). Some of these are discussed below.

Thames Barrier (London).Located in East London, this barrier is a unique flood control structure on the River Thames. It protects London from exceptionally high tides and storm surges from sea as well as floods due to heavy rains and river flooding. It has been existent since 1980s and is the second largest flood defense barrier in the world.
10 separate moving gates that can overall withstand 9000 tonnes of water forms the system. When closed, the barrier exposes a solid steel wall that seals the upper part of the river from the sea, thereby preventing further upward flow of water into the city. To control the amount of water to pass from under that gate to the river, the gates have the ability of partial closure, thus restricting water.

It needs to be raised (closed) only during high tide; at normal tide level, it is lowered to release the stored water slowly.

Figure 23: Location of Thames barrier. Source: Wikipedia

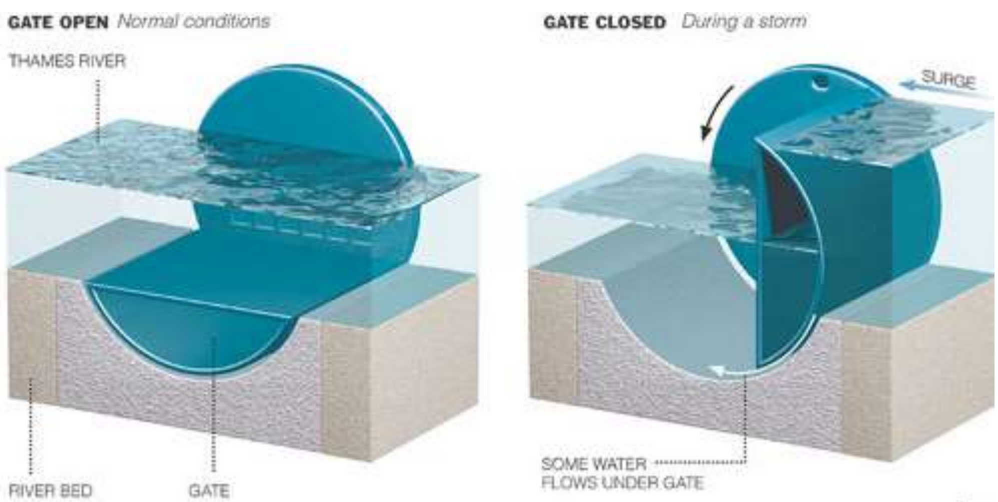


Figure 24: Thames barrier. Source-The environment agency.Britain(http://photos1.blogger.com/blogger/7184/598/1600/thames_barrier.jpg)

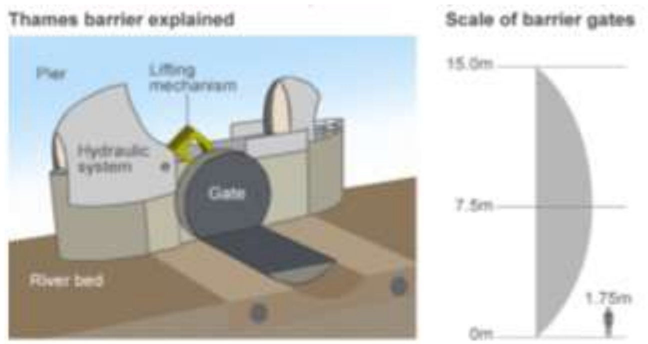


Figure 25: Components of the system. Source: https://www.gov.uk/guidance/the-thames-barrier.

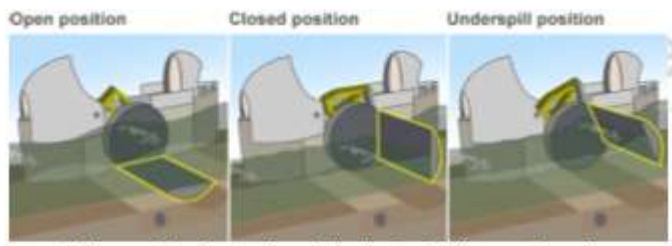


Figure 26: Working principle of the system. Source: -https://www.gov.uk/guidance/the-thames-barrier

Oosterscheldekering Barrier in the Netherlands. Largest flood defense barrier in the world that opened in 1986 after much difficulty constructing it. It is 9km long and is partially a closed dam. About 4 km in length and has huge sluice gates that remain open usually for passage of ships etc. , but if water level rises above 3 m, it is closed so as to avoid flooding land but marine and fishing activities can still continue safely. It was constructed as a response to catastrophic floods in 1953 and is designed to last for 200 years.

Figure 27. Oosterscheldekering Barrier. Images source: http://www.amusingplanet.com/2014/04/the-netherlands-impressive-storm-surge.html

The MAOUDC - Tokyo, Japan. The Metropolitan Area Outer Underground Discharge Channel located in Kasukabe, Tokyo and abbreviated as MAOUDC was completed in 2006 and is the world's largest underground flood diversion network to prevent overflow from major water ways in the city during rains and typhoons. The drainage channel was built 22 meters below ground level between 1993 and 2009, and is 177 meters long, 78 meters wide, 25 meters high with a maze of 59 reinforced concrete pillars each weighing500 tons supporting the ceiling.

Figure 28. MAOUDC flood storage below ground and discharge into the rivers. Source: Web Japan, 2012.

Figure 29. MAOUDC underground. Source- https://japanbook.net/en/article/1086.

Figure 30. MAOUDC. Source- https://japanbook.net/en/article/1086

Figure 31. MAOUDC. Source-http://gizmodo.com/tokyo-has-the-largest-underground-water-tank-in-the-wor-1696967098

The shield tunnel stores excessive water and displaces it into the Edo Riverwhich prevents the rivers, including Nakagawa, Kuramatsugawa, and Otoshifurutonegawa that frequently overflow during heavy rains, from overflowing. After heavy storms or typhoons flood water overflows from Tokyo's major waterways and rivers here through a 3.9 miles long tunnel system before being pumped into the Edo river. Since the tunnel started operation, overflow of river due to floods has decreased saving in damages amounts up to one trillion 400 billion yen.

SMART Tunnel - Kuala Lumpur, Malaysia. Due to tremendous growth of economy in the 1980's, population in Kuala Lampur soared and has reached over 7 million inhabitants. Constriction of river courses in the urban area had caused an increase in intense flooding. Storm water Management and Road Tunnels abbreviated 'SMART' was built as a unique multipurpose tunnel in 2007. It is the longest stormwater tunnel in Southeast Asia at 9.7km (6 miles), and the second-longest in Asia as a whole. Since the early 1970s, the government monitoring wing found that the average annual flooding has increased by 300 percent for the Klang River. Even though attempts were made to increase the river channels capacity, this wasn't fully achievable due to build areas.

The multi–purpose tunnel allows traffic flow when the tunnel was not being used to convey storm water. The tunnel needed is beneath road routes as it had to be in government-owned land and the funding was through Public Private Partnership (PPP).

Entering the SMART flood tunnel, Kuala Lumpur, Malaysia. Photo: flickr.com/photos/emrank/

Figure 32. SMART flood tunnel. Source: http://floodlist.com/asia/smart-tunnel-kuala-lumpur-malaysia

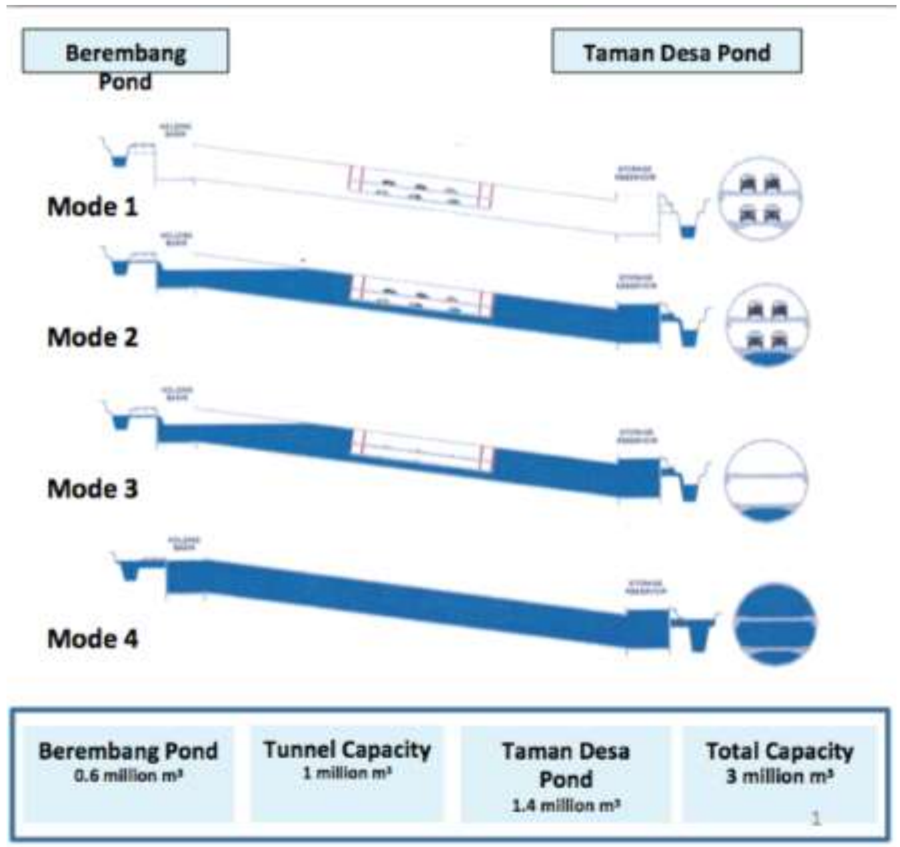


Figure 33. Working principle, SMART. Source- http://floodlist.com/asia/smart-tunnel-kuala-lumpur-malaysia

The tunnel begins just before the confluence of the Klang and Ampang Rivers, and flood water is diverted away, eliminating flooding in the city center. The tunnel is part of a larger flood mitigation system- the Kuala Lumpur Flood Mitigation System. Part of the tunnel includes a 4km (2.5 miles) long double-decker roadway beneath the city center, inserted above the storm water channel.

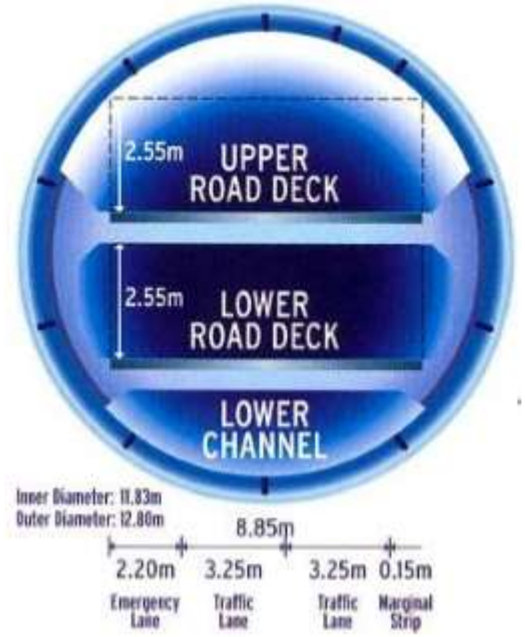


Figure 34. Motorway tunnel cross-section. Source: Adapted from the Study and Evaluation on SMART Project, Malyasia in University of Southern Queensland.

During minor floods, the storm water flows in the section of the tunnel beneath the road. When it becomes obvious that the full volume of the tunnel will be needed for diverting floodwater during a major storm event, the entrances to the tunnel are closed to traffic and the road tunnel is cleared of vehicles. Stormwater is then permitted to flow through the roadway section of the tunnel, so that the full 11.83m (38ft) internal diameter of the tunnel is available for diverting floodwaters away from the city center. After the threat of flooding has passed, the roadway can be cleaned and cleared for traffic within 48 hours, sometimes in as short a period as 8 hours after closure (floodlist.com,2014).

2.5.3 Case studies- The city as a system to prevent flooding.

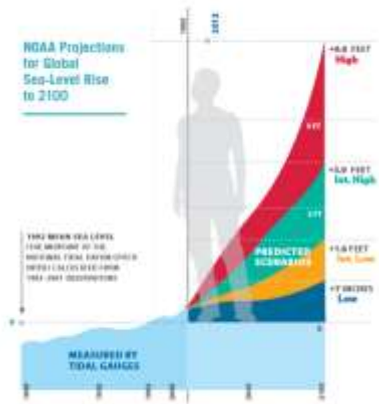


Figure 35. Sea level rise. Source- Global SLR projection by NOAA, Evans et al,2016.

1. Tybee Island Adaptation Plan Sea Level Rise and Community Resilience

Figure 36. Tybee Island. Source: Location map, Evans et al,2016

Tybee Island adopted a participatory approach that included the community, researchers from Georgia University, Georgia Sea Grant, and Stetson University to understand how coastal flooding risks in the city will be worse due to SLR in the future and considered possible actions for adapting the city to make it resilient for the impending danger.

Some of the problems faced by Tybee islands are: periodic tidal flooding, backflow of tidal water into storm water drainage systems that lead to flooding in low-lying neighborhoods and salt water intrusion into its ground water and erosion of its beaches.

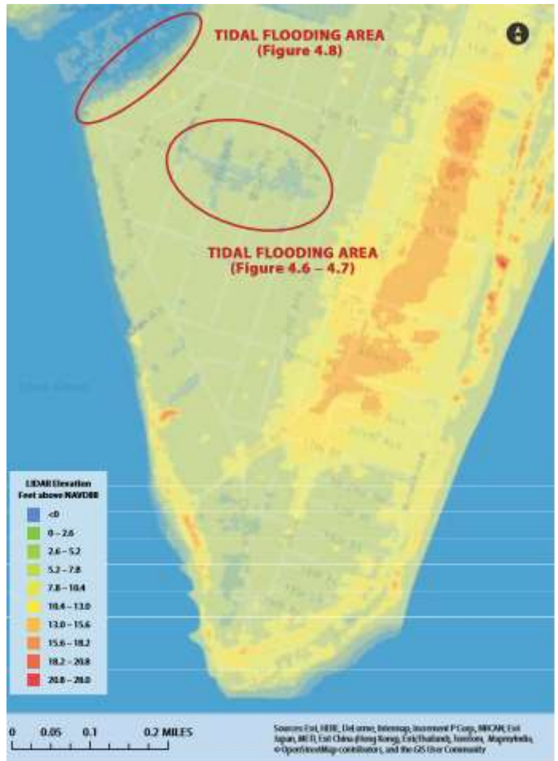


Figure 37. Tybee Island. Source- Tidal flooding areas, Evans et al,2016

Figure 38. Storm water backflow from discharge points, Source- Evans et al,2016.

Outreach and public town hall meetings with more than 4000 people were held, helping to raise awareness of the city's vulnerabilities and set planning priorities. As highlighted by Jason Evans from Stetson University

> "One of the key successes of this plan has been engaging the local knowledge that residents and community leaders already have in managing flooding, With this foundation, we simply assisted the island in anticipating future challenges and opportunities."

They proposed five adaptation actions after extensive consultation with stakeholders:

i. To protect public water supply, 2 of the 3 well pump houses that draw water from the aquifer that are prone to coastal flooding were proposed to be elevated in the near future along with flood proofing the street and pump house facility

ii. Due to long term SLR, the access road to Tybee islands, US Highway 80 is prone to repeat tidal flooding that risks public safety and blocking the evacuation route to the city. Thus it is proposed to elevate this road and modernize the bridges along them considering risk impacts of future SLR during design phase.

iii. Storm water systems recently were retrofitted taking into account flood scenarios for the next 50 years by constructing larger underground pipes for conveyance and installing tidal backflow prevention at the discharge points in low lying areas prone to experience flooding.

iv. The proposal to enhance the sea wall in low areas was dropped after technical analyses proved that very minimal tidal flood protection would be achieved, and the high cost of construction would only be offset under a very high sea-level rise scenario.

v. The erosion of beaches was attributed to construction of a harbor, north of Tybee Island and is exasperated by SLR. Beach nourishment was suggested. ‘Tybee Island Shoreline Protection Plan’ is an agreement with US Army corps engineers for periodic sand nourishment that has been successful for many decades. The City of Tybee Island and the Georgia Department of Natural Resources have substantially protected the shoreline through large-scale beach dune restoration activities.

2. New Orleans – Recovery after Katrina and plan for future

Figure 39. Shocks and stresses. Source-http://www.100resilientcities.org/cities/entry/new-orleans-resilience-challenge#/-_/

Figure 40. New Orleans. Source- http://www.lib.utexas.edu/maps/world_cities/new_orleans.jpg

When hurricane Katrina hit New Orleans in 2005, the city was extremely underprepared. The city did not have a comprehensive plan that could address disasters and the zoning ordinances were not updated. (New Orleans Planning Assessment Team, 2005Alter, J. 2005.) The storm surge, thus affected the levee system and breached it in many places. It also flooded most parts (up to 80%) of the city.(Louisiana Recovery Authority [LRA], 2006 Federal Emergency Management Agency. June 2006). It also highlighted the level of disaster in governance, and even though most of the population was evacuated, there were still losses of over 1000 lives and extensive damage occurred to property. Over 70% (Federal Emergency

Management Agency [FEMA], 2006) of the houses in the New Orleans metropolitan area were flooded (Brookings Institution, 2005). It took a year for 1/3 of the population to return after the storm and over 2 years for half of its population to return. The city had to create a plan and rebuild its economy as well as resilience.

In New Orleans, the catastrophe was compounded by the fact that different stake holders did not have any coordination between them. Planning done by the Department of Planning had no support from the mayor. The governor had poor relations with the White House, the Mayor and Governor did not work together and even the Mayor and city council had poor relations. The city dwellers did not participate in planning or governance and the city did not have a plan or vision for its' future.

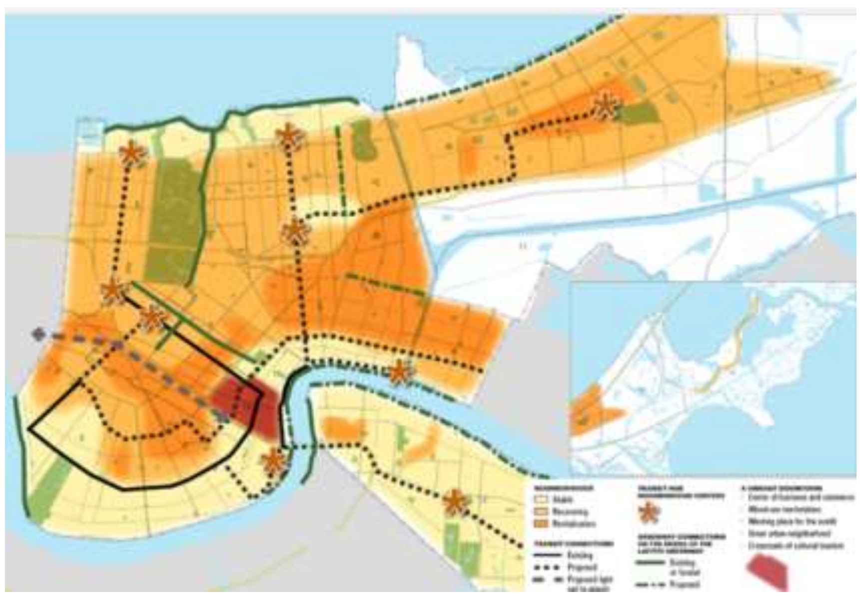


Figure 40. New Orleans. Source- http://www.goodyclancy.com/wp-content/uploads/2014/05/nola_mpczo_highlights-plan_goody-clancy.jpg.

New Orleans have also implemented Greater New Orleans hurricane and storm damage risk reduction system (USACE) in 2008, inner harbor navigation canal surge protection project and a coast wide plan(LaCPR) in 2009 which proposed structural as well as nonstructural protection methods.

The way forward: Growth of Economy, inclusive growth, sustainable growth, and improving quality of life were considered as the key indices for the future. The plan now makes the development process more transparent and has formal community participation. The participation has empowered citizens and civic leaders to call for consolidating levee board and merging the various property assessors into one office leading to more accountability. Neighborhoods now participate in planning and advocate for inclusive and integrated housing and facilities. Low-income households are provided with permanent affordable housing (Liu and Plyer, 2010). Fences, sea oats, and palm trees were planted for dune accretion. They also have private initiatives like 'project home again,' a nonprofit that helps those who cannot afford to rebuild or trade their vacant plots for new homes. They now have a comprehensive zoning map that covers CBD, mixed use spaces, neighborhoods and cultural and public open spaces and specific master plans are prepared such as master plan of parks ,etc.

Figure 42. Park Master plan, New Orleans, http://canalstreetbeat.com/wp-content/uploads/2014/02/City-Park-Master-Plan.jpg.

3. Netherlands and adapting by flooding the city to create new landscapes.

More than half of Netherlands is either at or below sea level. The lowest city lies 7m below sea level.

Figure 43: Title. Source-http://www.100resilientcities.org/cities/entry/rotterdams-resilience-challenge#/-

The Netherlands has decided to embrace flooding to adapt and live with it, rather than fighting the floods. They fought water for over 1000 years and then started building dykes. Weaknesses in river dykes were reported in 1977, but were ignored as houses would need demolition. This led to loss of lives and property. After repeat floods of 1993 and 1995; actions began to be taken against flooding.

All the while, consideration was given to building higher dykes, but it was realized much later that if a flood does breach the dyke it causes more damage than if it were to naturally flood. Hence, the idea of living and creating spaces for flood waters to enter the city so that they can be enjoyed rather than being a threat. The North Sea is unpredictable and Netherlands have now deviced a 1-in-10,000 year's protection from North sea to prevent inundation of agricultural land.

Figure 44. Netherlands location. Source-http://www1.american.edu/ted/ice/dutch-sea.htm

People who were forced to leave were either relocated or given compensation. The Netherlands has regional water boards with their own tax system. The money from taxes is used for dredging and maintenance of dykes. Climate change has been adapted into planning of the city, and there has been prohibition to build on flood plains since 1980’s. There are more ecological proposals on the beaches which allow for building sand dunes and enhancing coastal protection. Amphibious housing is another common experimental feature which is based on the ‘house boat’ concept that allows the house to float on water. Floating offices are also being considered.

‘Nigmegen’ is a one of the oldest cities in Netherlands that used to be flooded by the river ‘Waal’. Their initial plans were to lower groins and make a bypass for the river so that it would not flood the city. Instead, they came up with an urban regeneration plan to create leisure-water sports and nature trails etc and also to bring nature back to the city by having protected areas for birds and plants.

Before: Dikes on the north shore of the River Waal (seen as a roughly U-shaped squiggly line) come close to the river itself, creating a water bottleneck and flood risk during heavy rains. (Google Maps)

Figure 45. Nigmegen before intervention. Source-http://www.citiscope.org/story/2015/dutch-city-makes-room-its-river-and-new-identity

After: The dikes are moved back and a new channel allows more water to flow, reducing flood risk. An island is created in the river, creating room for new development, and new bridges connect residents on both sides of the river. (Room for the River Waal)

Figure 46. Nigmegen after intervention.. Source-http://www.citiscope.org/story/2015/dutch-city-makes-room-its-river-and-new-identity

Figure 47. Nigmegen after intervention.. Source-http://www.citiscope.org/story/2015/dutch-city-makes-room-its-river-and-new-identity

5. New York Resilient coast to Sea level rise –

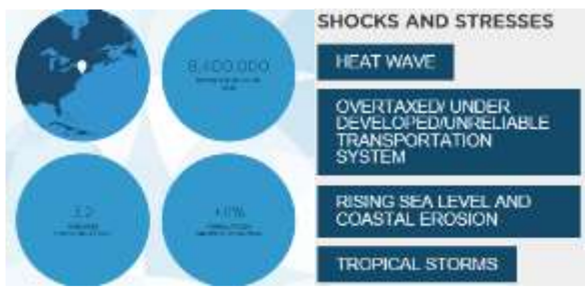


Figure 48. Shocks and Stressors. Source-http://www.100resilientcities.org/cities/entry/new-yorks-resilience-challenge#/-_/

GOAL- Reduce the city's vulnerability to coastal flooding and storm surge. The idea of being more ecologically resilient emerged because berms, floodwalls, or levees often restrict river's flow and channelize it, which forces the water a higher velocity, causing more damage. Also, when we prevent flooding in one place, there is the potential to worsen flooding in other places that may not have otherwise been affected as much.

Areas of flood risk in Lower Manhattan. Image: the BIG Team's HUD proposal

Figure 49. Areas prone to flood. Source- Flood risk areas- http://www.resilientdesign.org/a-dramatic-resiliency-plan-to-transform-new-york-city-the-big-u-moves-forward/

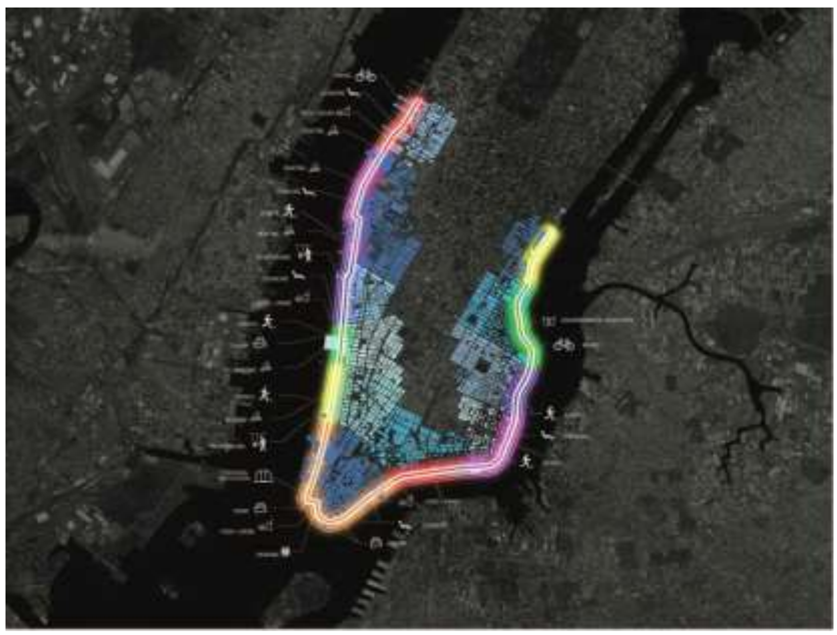


Figure 50. Intervention area . Source - https://www.lafargeholcim-foundation.org/projects/the-dryline

The Dryline (BIG U) is in response to New York's vulnerability to coastal flooding . The design is in the form of a protective ribbon south of Manhattan. The 12 km-long infrastructural barrier provides for ample public spaces and high-water barrier doubling as parks, seating, bicycle shelters or skateboard ramps. Embankments add green areas and spaces beneath elevated roadways are built out with pavilions for public use. In an emergency, the shutters close forming a floodwater barrier.

Figure 51. Coastal protection with parks.Source-https://www.lafargeholcim-foundation.org/projects/the-dryline

Lower Manhattan showing a protective berm and barriers along the coastline, wrapping around The Battery. Image from the BIG Team's HUD proposal.

Figure 52. Lower Manhattan. Source- http://www.resilientdesign.org/a-dramatic-resiliency-plan-to-transform-new-york-city-the-big-u-moves-forward/

Figure 53. Lower Manhattan. Source- http://www.resilientdesign.org/a-dramatic-resiliency-plan-to-transform-new-york-city-the-big-u-moves-forward/

Rendering that shows landscape features that serve as a protective berm along the Manhattan shoreline. Image: the BIG Team

The same view showing the berm protecting the City from flooding. Image: the BIG Team

Figure 54. Proposed landscape features. Source- http://www.resilientdesign.org/a-dramatic-resiliency-

plan-to-transform-new-york-city-the-big-u-moves-forward/

Figure 55. Progress timeline. Source-New York City Infrastructure Projects - The urban flood protection infrastructure project holcimfoundation.org

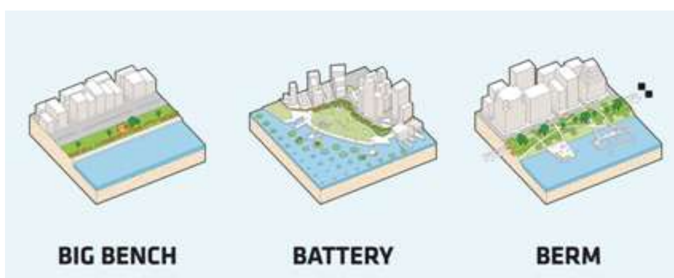


Figure 56. Using Nature's Defenses to Protect New York from Coastal Climate Risks. Source-New York City Infrastructure Projects - The urban flood protection infrastructure project holcimfoundation.org

5. Salt marshes on Jamaica bay for protection and restoration of wetlands along coast.

Jamaica bay is one of the largest coastal wetland ecosystems in New York.

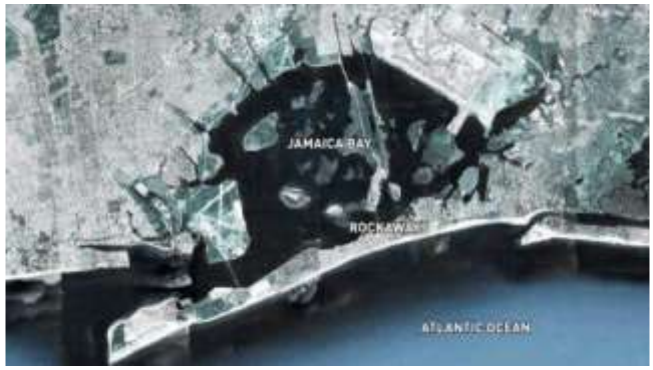


Figure 57. Jamaica bay location. Source-arquitectura.estudioquagliata.com

'Over the last 150- years, Jamaica Bay has experienced wetland and habitat losses due to a variety of factors, including sea level rise, anthropogenic manipulation (dredging and filling) throughout the bay, a loss of sediment, and increased tidal heights. Many of these changes have permanently altered sections of the bay' (Jamaica Bay Watershed protection plan, 2014)

The governor of New York strategized the use of natural barriers to protect New York harbor against SLR and storm surges. Coastal wetlands, marshes, oyster reefs, and dunes help to absorb storm surge and floodwaters and dissipate wave energy. These less costly soft solutions can be easily fixed and made adaptable to variable conditions and can be applied at various locations and managed locally. Thus, making them a better solution than 'hard' expensive engineering solutions. One of the successful options were planting a small oyster bed along with artificial reefs so as to evaluate oyster growth, survival, reproduction, water quality and ecological benefits given existing environmental conditions in the bay. The study revealed that oysters had populated and were healthy and surviving.

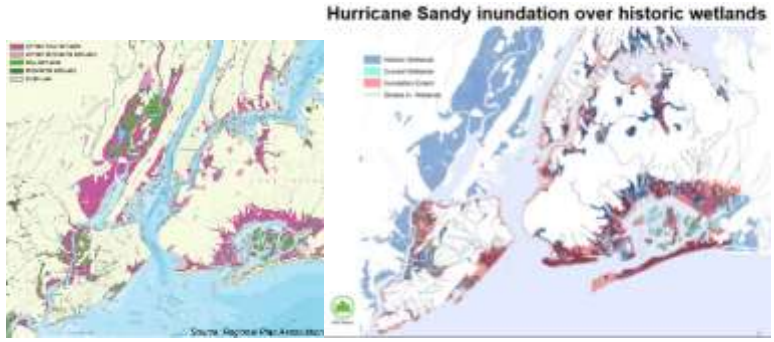


Figure 58. Inundation due to hurricane sandy. Source-Larson et al,2014

Figure 59. Ecological resilience along coast. Source-Larson et al,2014

The ongoing work to restore salt marshes in Jamaica Bay is a prime example of how we can protect and restore our coastal wetlands. And, there are significant opportunities to expand coastal ecosystem restoration projects to other areas of the state as discussed in the New York City Wetlands Strategy, the Comprehensive Restoration Plan for the New York-New Jersey Harbor Estuary, and the Long Island Sound Study.

Figure 60. City wide restoration plan. Source-Larson et al,2014

Growing oysters would help mitigate the wave impact during a storm surge and also additionally benefit in restoring reef health. Coastal wetlands protect from storm surge and flood and also provide other benefits that include:

- Improvement in water quality by filtering out pollutants in runoff.
- provide habitat for wildlife,
- opportunities for recreation,
- improve quality of life
- Reduce climate change impact by absorbing carbon dioxide.

Many Public-private initiatives have been tried at Jamaica bay.

Figure 61. Coastal wetlands for New York city, source- https://www.rdc.org/experts/ben-chou/using-

natures-defenses-protect-new-york-coastal-climate-risks

Resilience models for how to best manage ecosystems for resilience and sustainability have been produced and Jamaica bay serves as a center for education and the dissemination of knowledge about processes that affect resilience and contribute to changes in the urban ecosystem.

Other ecological pilot projects completed include: Sea Lettuce (Ulva) Harvesting , Algal Turf Scrubber ,Eelgrass (Zostera mariana),Ecological Atlas and Dynamic Reconnaissance Mapping of Wetlands, Stormwater Pilot Monitoring Program.

6. San Francisco Bay area –Bay area protection against Urbanization and loss of habitat

Figure 62. Shocks and stressors. Source-http://www.100resilientcities.org/cities/entry/san-franciscos-resilience-challenge#/-_/

Four key challenges and aspirations for San Francisco: remaining an equitable and inclusive city; access and mobility; resiliency and long-term sustainability; and place making. Based on this, long term and short term plans were devised.

THE STRATEGY

GOAL 1 Plan and Prepare for Tomorrow

GOAL 2 Retrofit, Mitigate and Adapt

GOAL 3 Ensure Housing for San Franciscans Today and After a Disaster

GOAL 4 Empower Neighborhoods Through Improved Connections

Figure 63. Proposed Strategy. Image Source- Patrick Otellini, Chief Resilience Officer ,City and County of San Francisco , http://sfgsa.org/sites/default/files/Document/Resilient%20San%20Francisco.pdf

Some of the challenges addressed include:

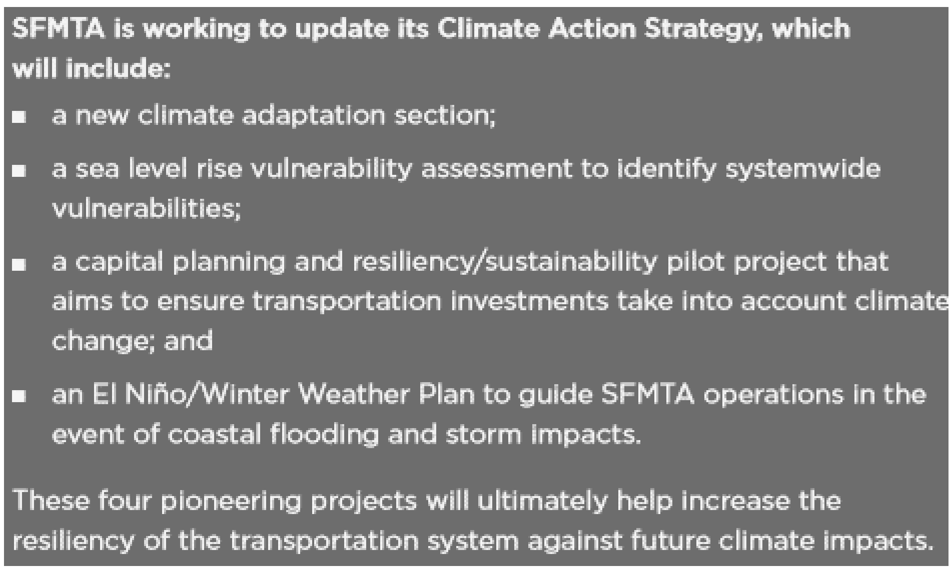
- Complete a long-term disaster recovery governance plan by 2018.
- Training Neighborhood Emergency Response Team members by 2018.
- Build and develop a more robust preparedness culture focused on training all levels of city management on response protocols and actions.
- Invest in infrastructure that increases mobility capacity and usage, while decreasing the distance to essential services.

Other plans include:

Implement San Francisco 2050 – Plan

- Urban Forest Plan envisions a greener and healthier San Francisco where trees grow and thrive on the City's streets.
- Transform the heart of San Francisco and improve the public realm
- A Resilient Waterfront—Considering SLR and planning developments and access to waterfront
- Become a City of diverse Neighborhoods with distinct characteristics.
- Develop a shared vision.
- Mitigate Climate Change Locally

- Adapt San Francisco to Climate Change
- Launch Regional Waterfront Design Challenge
- Promote Community Health Through Preparing for Climate Change
- Support Urban Watershed Planning
- Launch a Collaborative Community Proces
- Build Partnerships to Advance Resilience
- 50-year Long-Range Transportation Vision that include Liveable streets,Transit oriented developments(TOD) etc



SFMTA is working to update its Climate Action Strategy, which will include:

- a new climate adaptation section;
- a sea level rise vulnerability assessment to identify systemwide vulnerabilities;
- a capital planning and resiliency/sustainability pilot project that aims to ensure transportation investments take into account climate change; and
- an El Niño/Winter Weather Plan to guide SFMTA operations in the event of coastal flooding and storm impacts.

These four pioneering projects will ultimately help increase the resiliency of the transportation system against future climate impacts.

Figure 64. Climate Action Strategy. Image Source- Patrick Otellini, Chief Resilience Officer, City and County of San Francisco , http://sfgsa.org/sites/default/files/Document/Resilient%20San%20Francisco.pdf

CHAPTER 3: RESEARCH METHODOLOGY

Introduction to chapter

Initially, the approach and the introductory framework drawn upon by the literature review and case studies help in ascertaining the criteria and lens to look at the study area. This forms the preliminary part of the thesis document, while the second part details the study tools employed, process of data collection to assist in analysis and arriving at a conclusion in the following chapters.

3.1 Research Technique and Organization of the Thesis

The research questions are answered systematically by first doing a thorough literature review, understanding flooding and the problems associated with flooding particularly in coastal areas. Further, the problem of flooding with regard to Chennai is listed out. The literature review then proceeds to understand resilience against flooding, vernacular and contemporary flood mitigation strategies and urban and landscape design's approach to flooding. Case studies from around the world are then strategically picked out for a particular aspect they will serve to answer.

The thesis then investigates Chennai metropolitan area (CMA) and describes its various factors and parameters. Data collected from primary sources are used for this chapter. Data is also collected from general observation of the city, maps, interview and survey questions and after analyzing the collected data, the results and conclusion serves to fill the lacuna of knowledge in creating flood resilience in Chennai

Review of secondary data in the form of maps, past research and literature is carried out along with the study of various primary government documents for policy and recommendation. Data was also obtained in the form of questionnaires and semi structured questionnaires, interviews and site visits by the author to produce reliable data. The overall research follows a Qualitative approach, and through a systematic process, the research questions listed in the next sections will be answered.

3.2 Selection of Population for Data Collection

The overall sample population that responded to the questions was a mixed population selected by purposive sampling and were aged between 13 and 80 which include the local Tamil population as well as those who came from other states and settled in Chennai. The cohorts for the research was chosen as available but adhering to the criteria set by the author and the stakeholder groups were further divided as

- Focus Groups

Local government officials'/Development authority – hand delivered (10 persons)

Professionals/engineers and experts –online+ email +hand delivered (10-15 experts)

- Survey Groups

Coastal communities- 10 hand delivered (sample population- ages 25 and above only)

Slums and those near the rivers-10 hand delivered (sample population- ages 25 and above only)

Local residents – Facebook and other social media (Limited to 50 persons of any age group greater than 13)

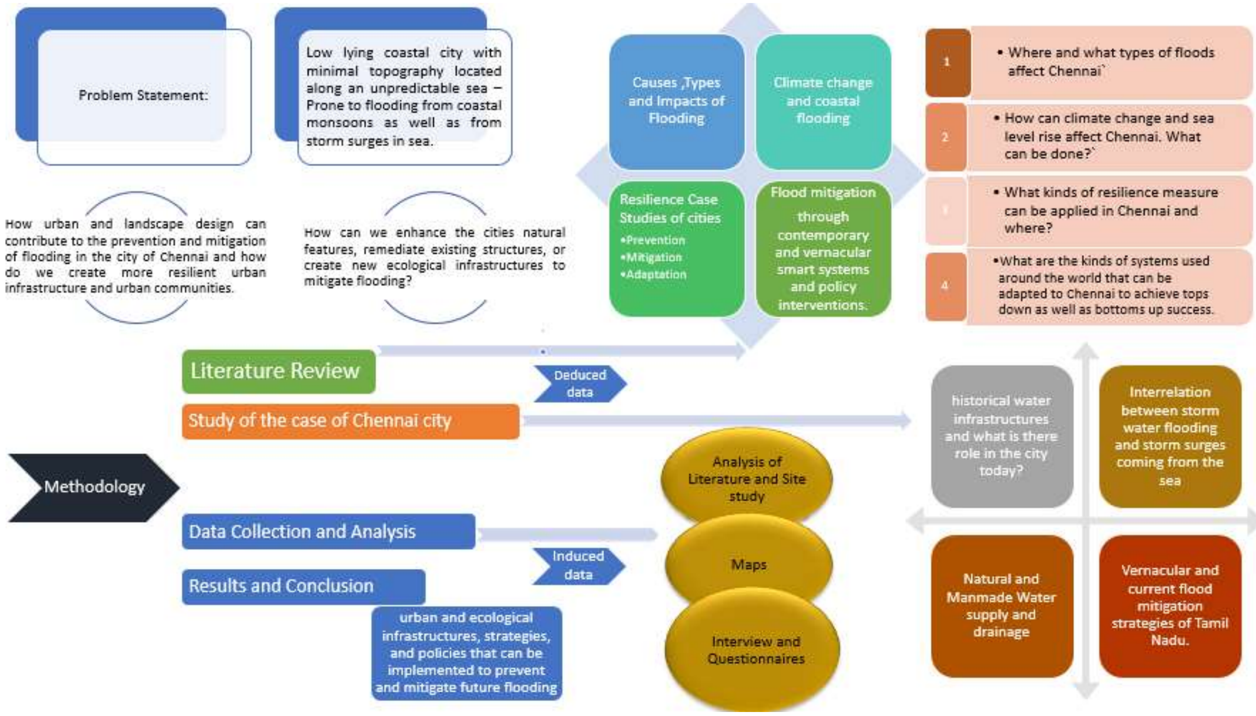


Figure 64: Research Diagram, Source- Author

The questionnaires were formulated by the author after referring to other precedents used by governmental agencies to understand flooding in their areas. Of particular relevance to this study questionnaire was ‘coastal flooding framing questions’ by the website data.gov.

Research Question	**How is this answered**
1. How does urban and landscape design contribute to the prevention and mitigation of flooding in the city of Chennai	Analysis of Literature
2. How to create more resilient urban infrastructures and communities.	Analysis of Literature
3. How can we enhance the city's natural features, remediate existing	Analysis of Literature

structures, or create new ecological infrastructures to mitigate flooding?	
4. What are the types of flooding that affect the city of Chennai? 5. What are the natural and constructed water systems in Chennai that are affected flooding? 6. What are the historical water infrastructures and what is there role in the city today? 7. What is the interrelation between storm water flooding and storm surges coming from the sea?	Analysis of Study Area- The city of Chennai from text, maps and available textual data. ● Understand urban development and hydrology in the city ● Understand the present condition of lakes, rivers, marshes and tanks and canal in Chennai city.-historic and contemporary infrastructure and what new systems are needed. ● Evaluate current and past effectiveness in terms of protecting the city against floods
8. What are the urban and ecological infrastructures, strategies, and policies that can be implemented to prevent and mitigate future flooding?	Urban and landscape urbanisms flood approach to flooding,engineering and vernacular approaches and Case Studies.- To suggest recommendations for improvement in functioning and maintenance through maps as well as social, economic and legal proceedings

	and community participation.

Table 3- Relevance of research question and inference gathered, Source- Author

3.3 Tools used for Data collection

Tool used	**Data Inferred**
Literature Analysis	Broader context – ● Causes, types and implications of floods ● Why we need resilience in cities from floods ● How climate change and global warming could increase probability of floods ● Urban design and landscape urbanism and approach to dealing with floods
Case Study Analysis	Study of various scenarios around flooding in cities helps gain comprehensive understanding and employable methods to prevent flooding.
Map Analysis	Implications of current urban design and built over areas in the study area, transport corridors and their interaction with the water bodies.
Site Analysis	Overview of the history, current condition of the study area and future plans
Focus group interview	● Interviews with local government officials/Development authority on the policies and actions that have been implemented or are planned.

	● Interviews with academicians, professionals and experts on viable options and approaches.
Survey Questionnaire	Investigate personal experiences of people and their perception of floods and impact in the city as well as to verify the absence/existence of some aspects highlighted by literature and site analysis through specific questions. The local community is thus able to contribute to the thesis through participation.

Table 4- Relevance of tools used and inference gathered, Source- Author

3.3.1 Literature and Case Study Analysis

Literature Analysis

Data pertaining to the types and causes of flooding in cities and the socio economic and environmental impact is studied along with how urban design and landscape urbanism currently address these issues in cities. The situation created by climate change and subsequent sea level rise on coastal areas are also reviewed. The anthropogenic and ecological factors leading to the floods are also enlisted.

Case Study Analysis

Case studies from around the world, particularly coastal cities with flood dynamics similar to Chennai have been selected. Vernacular as well as contemporary flood mitigation is reviewed upon and measures that improve resilience in terms of mitigation, adaptation and prevention strategies have also been looked upon.

Researching case studies helps bring us to an understanding of a complex issue and can add strength to what is already known through previous research. The advantages of this qualitative research method are that it helps examine real-life situations and provides the basis for the application of ideas and extension of methods as it involves learning from the conglomeration of multiple sources of data that have been used to success. It helps build upon, dispute or produce new ideas, and to explain a situation and to provide a basis to apply solutions to situations. Case studies results help facilitate an understanding of complex real-life situations.

"Empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used" (Yin, 1984, p. 23)

3.3.2 Map and Site Analysis

Map Analysis

Historic as well as recent maps of Chennai city have been analyzed to understand what has changed in the city and the approximate time frame of events. These changes are reflected in a map created by the author to point out areas where intervention can be carried out.

Site Analysis

Secondary data documents that highlight the current situation are reviewed. Historic emergence of development and the degradation of the city's natural and ecological features as highlighted by various researchers are considered as they provide valuable information on the current situation.

3.3.3 Interviews and Survey

Focus group interview

The sample groups interviewed include local government officials'/Development authority and academicians, professionals and experts to help produce results. The former group answers questions on the policies and actions that have been implemented or are planned as well as to highlight any gaps in research; while the latter's inputs help formulate viable options and approaches.

Survey Questionnaire

This component of the study targets local population to answer questions related to flooding and the city as well as gives them an opportunity to contribute suggestions to the overall development of the thesis thus engaging community participation.

3.3.4 Significance and Expected Outcome of the Research

The research is significant and urgent as the area of concern has been battered by cyclones and floods in the past years with its severity and impact on people and infrastructure increasing with each passing year.

The literature review, local and international case studies from around the world that deals with water systems is summarized in the form of diagrams and tables. Measures to prevent a system overload is proposed by having various levels of water storage-individuals can have an individual level water storage and then neighborhood level and thus moving upward, so that the approach is not just top down with policy but also bottoms up with community participation. An attempt is also made to produce a map to highlight possible interventions in the problem areas.

It is anticipated that the lessons learnt from studying the city of Chennai will help other coastal cities develop resilience in their cities against floods. The measures suggested strengthen cities against the imminent dangers of Urbanization, Sea Level rise and Global climate change and can be adapted to different cities across the world with a respect for their unique local conditions.

CHAPTER 4- CITY IN CONTEXT- CHENNAI, TAMIL NADU, INDIA

Introduction

The main Stressors in Chennai city as per resilientcities.org are as in the figure below. This chapter aims to gain an understanding about the city and its features and try and explain the potential vulnerabilities that can be modified to strengthen resilience.

Figure 67- Shocks and Stressors ,Chennai, Source- http://www.100resilientcities.org/cities/entry/chennai#/-_/

4.1 Physical Characteristics of the city

Location and Climate:

Chennai city, the capital state of Tamil Nadu in the south of India is geographically located at a Latitude of 13.08268 North and Longitude: 80.27072 East. Chennai is a part of the Eastern Coastal plains of India and is located at an average elevation 6m above sea level and the highest known point is a mere 60m above sea level.

Figure 67: Location map, Source-Worldmaps.com

Climate is hot and humid owing to its location along the equator and being situated next to the ocean coast. The hottest part of the year is the latter part of May up to mid June. Maximum temperatures range between 35–40 °C .The coolest part of the year is January, with lowest temperatures around 19–25 °C .

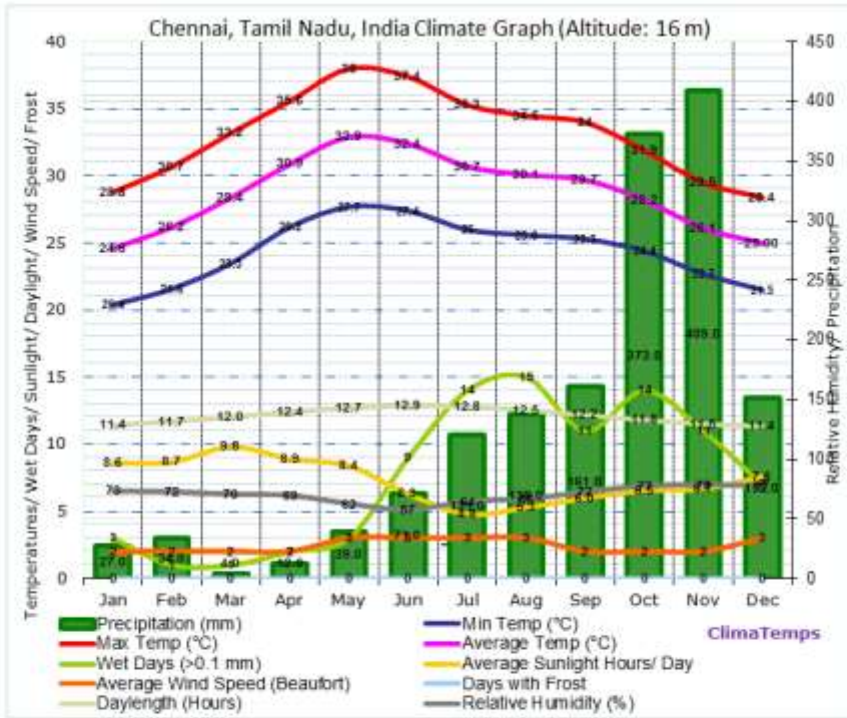


Figure 68: Weather and Rainfall data, Source- http://www.chennai.climatemps.com/

The city gets the vast majority of its regular precipitation from the Northeast (NE) monsoons between the months of October –December, which are called 'Winter Monsoons' . Average annual precipitation is around 140 cm. Cyclones in the Bay of Bengal time and again hit the city. Most rainfall occurs due to depressions in the Bay of Bengal, along which Chennai lies. The intensity and impact of tropical cyclones originating in the Bay of Bengal is increasing with every passing year. Storm surges are also generally accompanied during this period.

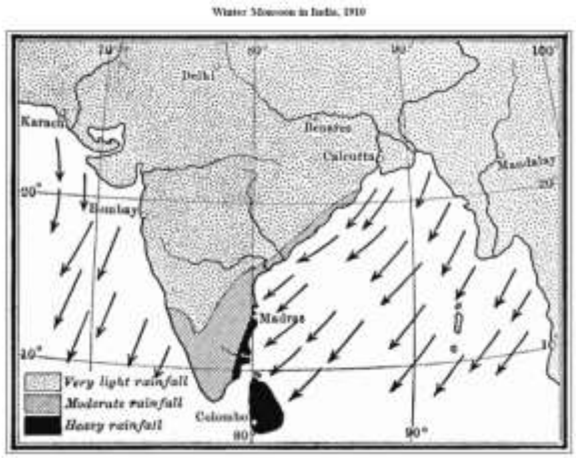


Figure 69: Winter monsoon, Chennai, Tamil Nadu. Source-

https://etc.usf.edu/maps/pages/2100/2115/2115.htm

Prevailing winds in Chennai are normally southwesterly in the middle of April and October and north-easterly for the rest of the year. Chennai has depended on the yearly rains of the rainstorm season to recharge groundwater stores, as no real live streams move through the area. Water table is at 2 meters for more than a large portion of the year.

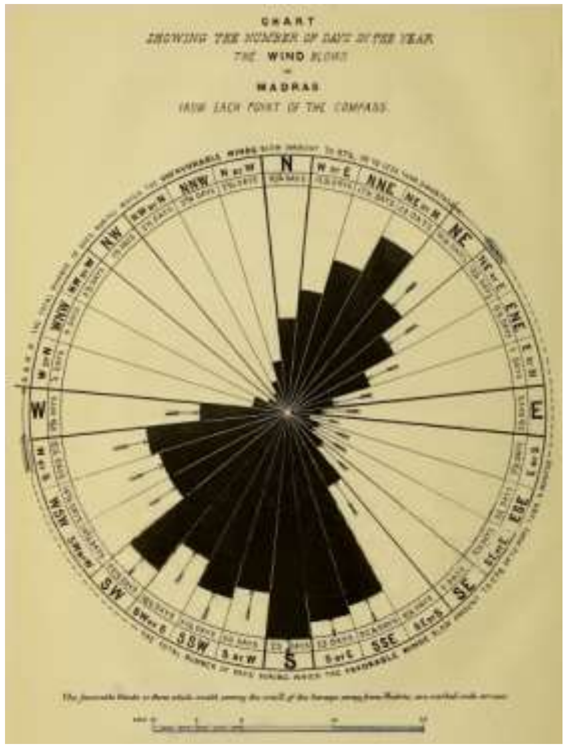


Figure 70: Wind Directions throughout the year, Source- British gazetteer map, 1900's

Geography and Terrain

The city is almost as flat as a pancake and has a Mean sea level (MSL) of 6.7m and many areas lie at Sea level. Chennai has a terrain slope varying from 1:5000 to 1: 10000.

4.2 Urban Morphology of Chennai city

4.2.1 Historical Overview of Development of City and Infrastructure

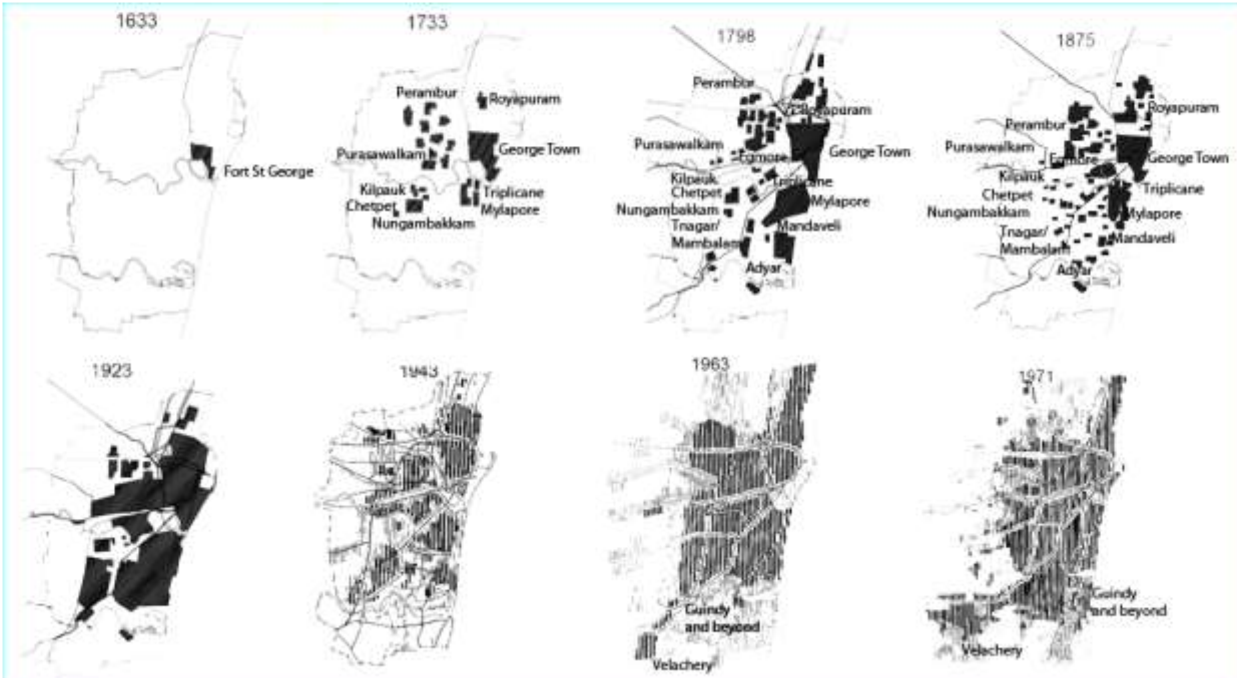


Figure 71: Historic growth of Madras since 1633, Source: Author's interpretation of CMDA map

Portuguese settlements emerged around Santhome by 16th century. But the Urban development of the city began with the British. They began by acquiring land for a factory for the British East India Company in 1639 that acquired a site from a local chief for and called the area 'Fort St George'. This is where the city of Madras can be said to have begun and expanded from.

Ancient History- Up mid 1600's

Madras (present day Chennai) was derived from 'Madrasapattinam' as the name was before the English settled in the land and was well known in ancient history .Old stone age settlements dating back to 250000 BC and megalithic settlements were found on Pallavaram hills and Kundrathur.

- Ptolemy's 2nd century map mentions the port at Mylapore. The Romans traded in gold for pepper and fine cloth from the port in this period.
- Mylapore and Triplicane were famous Hindu religious centers dating back to the 8th century .

- Santhome was well known to Arab merchants in 9th and 10th centuries.

The 17th century and Portuguese Influence:

- Portuguese arrived in 1522 and constructed a fort and settlement around Santhome. Mylapore was adjacent to this locality and had a new temple.
- In **1600's Madras began as a series of scattered settlements , each of which grew around a temple as a nucleus.** Mylapore was the most important area.
- Within the city, s**mall settlements were existent in Purasawalkam, Egmore, Nungambakkam, Saidapet and Thiruvateeswaranpetta** etc. Many suburban areas existed in the same format. **Each village had its own agricultural production and household industries that were not interfered into by change in the political scenarios.**
- Initially **earthen roads that were sufficient to ride carts along, developed linking Egmore, Purasawalkam and Aminjikarai on Poonamallee High road and Triplicane and Mylapore on the road leading to Thiruvanmiyur.**

Imperial Colonial History - From Mid 17th century – Mid 20th century

- **Three-mile long strip of land lying along the coast between the Cooum delta and the Egmore River encompassing an area of about five square kilometres bought** from the Vijayanagar king by British.
- British constructed their settlement at Fort St George,a new town emerged around it- "Chennapatnam''- A name that was soon adopted for the whole city.
- Population estimates by 1646 were about 19000 but grew to 40000 in 2 decades.
- **The Corporation of Madras**,the second oldest surviving one in the world and the first in India **was formed in 1688.**

- Churches and many private buildings emerged in and around the Fort
- **Bridge in 1710 at Egmore came up over the flood equalizing cut in Cooum – Elambore rivers.** The main access road to Egmore till 1931 remained this road in front of Central jail.
- **The Egmore bridge,also promoted settlement of people toward current day Moore market.**
- When congestion increased in the Fort, **Garden houses were created in Peddanaikanpet**.

By 1733, congestion in George town area, led the weaving community who lived there to relocate to an area near Thiruvotriyur due to availability of abundant open space.

Washing community moved westwards. Potters moved outside the Fort on the North, and formed **Kospet as a new colony .**

- The British, meanwhile found opportunity at ***Triplicane, and formed their settlements*** there owing to its' economic stronghold. Muslims predominantly settled in this area and the area became almost as significant as George town.
- Construction o**f Marmalong bridge in 1724, made Mount road a prominent landmark**.
- St Thomas Mount gained religious significance.
- Roads for access such as Marshalls , Halls and Montieth and Casa Major were thoroughfares by Development in Late 1700's
- ***British started living along the Cooum*** **-** Mowbrays and Royapettah high road, provided access to them.
- **The low lying swampy land,west of George town remained devoid of any development.**

By the end of the century, the area around the fort was 69 kms with 16 hamlets that formed the city.

- **Road networks developed in Radial patterns till this period.**

Development in 1800's

- **Road networks emerged in the form of ring roads from 1810.**
- The corporation looked into improving the city and **divided the city into 8 divisions**.
- Many parks such as Richardson, Napiers, Peoples park came up beginning around the 1850's along with a museum and Zoo.
- When Royapuram station formed in 1862,people moved northwards and settled.**The swampy low lying area of Perambur which lay enroute to Royapuram developed as the railway line passed through it.**
- Central railway station formed in 1872 and was connected to the main line. A pier for the harbor was constructed by 1862 and it was further developed in the following years and the harbor was completed in 1896 located east of Georgetown.
- **Sand accretion and formation of the 2.5km stretch between land and sea led to many public buildings being constructed in front of the beach in early 19th century**, which are significant and in use to this day.

Mount road was important and connected to Triplicane High Road,Chamiers,Edward Elliots and Royapettah High road which formed the important roads at the time.

- **The principal roads, leading out of Georgetown ,in 3 main directions- North,west,south remain the main transportation framework to this day for Chennai.**
- Railways also emerged, radiating from the center in these 2 directions.
- ***The North of Mount road was developed as new residential areas.***
- ***BrickKiln road and Perambur Barracks connected Poonamallee high road with Konnur road and extended toward the railway.***

Development in the 20th Century

- The city was the commercial, military and administrative center of South India as a whole.
- By 1901,***population in the city rose to 5.4 lakhs and the city covered about 70 sq kms.***
- The fort and many ***prominent landmark buildings already existed along the beach***.
- ***George town was mixed use area but mostly a business area.***
- ***Main areas of residence included- Chintadripet, triplicane, egmore, mylapore, purasawalkam, vepery and royapuram.***
- ***Areas outside these areas were covered with gardens and agricultural lands and interspersed with elite bungalows.****Chetpet and Kilpauk emerged in this way as well.*
- ***Industries were in George town or Perambur.***
- ***A distance of 5-6 km from Fort St George on both sides of Mount road,were commercial*** establishments such as clubs,hotels and businesses.
- **Nungambakkam tank lay westward to Nungambakkam *and railways served, north,west and south west corridors.***

By 1940,population surged to ***8.6 lakhs in an occupied area of 80 sqkm.***

Development between 1901 and 1941

- 1931- the electric suburban trains were commissioned between Beach and Tambaram.Thus **areas upto Tambaram** were developed.**Lots of low lying areas were filled/reclaimed.**
- **The area occupied by Long Tank in Nungambakkam, was proposed to become a planned residential neighborhood.**Even developed areas were considerably filled in.
- **The city had good water supply and most areas were sewered.**
- Cheap and quick modes of transport were available due to electric trains.
- Main roads were wide enough and shaded due to trees on both sides forming an avenue.

- By 1941-Madras enjoyed urban amenities with rural atmosphere.

Haphazard City Development 1941-1971

- **Tremendous growth in population - Population passed 1 million around 1943 and doubled in about 2 decades to about 2 million.**
- ***In 1950, the city boundaries stretched 129 sq.kms and included Saidapet and Sembiam*** which were separate settlements till that point.
- **The western and Southern regions of the city grew fast increasing in residences and industrial suburbs.**
- **This period saw deterioration in water supply and drainage and formation of slums in various parts. Anna nagar in the west and Sastri Nagar in the south developed as large residential areas after Tamil nadu state housing board was created.**
- **The city boundary began to be less defined and developments included adjoining areas.Growth was not regulated and infrastructure available didn't match up. In addition to this, population growth and addition of vehicles on the road, are problems that continue to this day.**

Growth of the city from 1971 onwards

- **By 1970's the city took on a semi circular form and extended in 5 directions--North, NW, W, SW, and South from the center ie,Georgetown.**
- George Town and the Harbour which ensured that all lines that were formed connected back or emerged from this center which continued to be the commercial center.
- **Thus a radial and ring road pattern formed.**
- ***Areas along the main arteries along which economical transport was available by now, developed as compared to far away areas, with residential development mainly moving W and SW.***

- The SW areas such as **Tambaram,Alandur and Pallavaram** followed along the electric train lines. These areas however, **lacked in facilities for public use as well as commercial activities** and people continued to use the main city for this. Most of the total population of the state of Tamil Nadu thus resided in the capital city of Chennai and the city became the hub of urbanization with socio-economic activities aimed towards it.
- **The old residential areas- Purasawalkam,Triplicane,Mylapore,George town and Royapuram had their distinct feature of row housing and the main roads for shopping.**
- The ***newer residences in Mylapore and Thyagarajanagar had high density bungalow type houses*** as opposed to the exclusivity that areas closer to the CBD such as Egmore, Nungambakkam and Chetpet provided from earlier times.
- These intervening areas were developed for ***multi storey residences, offices and hotels to cater to the growing needs of the CBD.***
- **Rural areas on the fringe continued to be fertile land. Paddy was raised in the North and West while Casuarina was raised along the sandy coast ,south of Chennai.**
- **George town and its' southward extension- Annasalai formed the CBD.More than 48% jobs and workplaces of Madras metropolitan area were located here** and trade, financial and banking agglomerations appeared.
- The **North and West continued as industrial area interspersed with residences**
- New industries were located outside the city limits on the outskirts. Upto **40 % main industries were along North-Ennore and Manali, and along West-Ambattur and Avadi and about 10% in Anna Salai moving South Westward.**
- New buildings that were Public or semi public started to be scattered and **new public offices came up in Nungambakkam and Anna Salai rather than just along the Marina and Egmore.**
- **Higher education institutes moved to suburbs.**

5.2.3 Population and Growth Crisis between 1970s- Early 21st century

Chennai city					
Population	17,49,000	24,69,449	32,76,622	38,43,195	43,43,645
Extent (sq. km.)	128.83	128.83	176.00	176.00	176.00
Density (persons per sq.km.)	13576	19168	18617	21836	24680
Decadal growth rate	---	41.19 %	32.69 %	17.29 %	13.02 %
Chennai Urban Agglomeration					
Population	19,44,502	31,69,930	42,89,347	54,21,985	64,24,624
Decadal growth rate	...	63.02 %	35.31 %	26.41 %	18.49 %
Chennai Metropolitan Area (including Chennai City)					
Population	...	35,05,502	46,01,566	58,18,479	70,40,582
Extent (sq. km.)	...	1189	1189	1189	1189
Density (persons per sq.km.)	...	2948	3870	4894	5921
Decadal growth rate	...	...	31.27 %	26.45 %	21.00 %

Source: Census of India, Second Master Plan for Chennai Metropolitan Area 2026, http://www.thaibicindia.org.in/study/tamil_nadu/Demographic, dated 14.08.2010, http://www.tn.gov.in/cma/Urban-Report.pdf, dated 14.08.2010.

Figure 72: Population growth in Chennai, Source-Sekar and Kanchanamala,2011

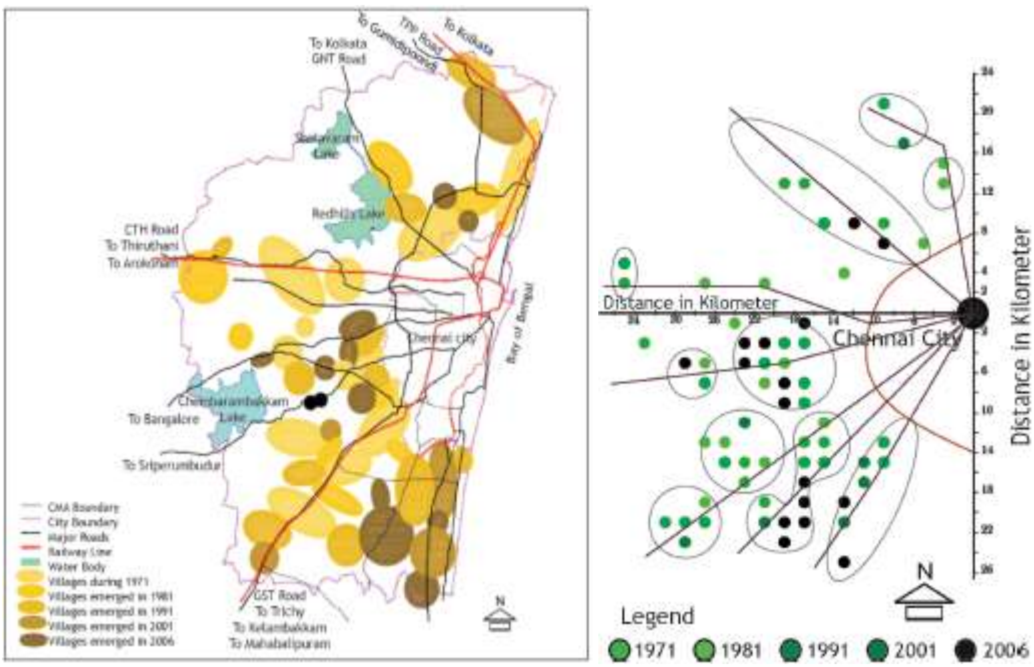


Figure 73: Migration of Population and Emergence of Villages from 1971-2001, Source-Sekar and Kanchanamala,2011

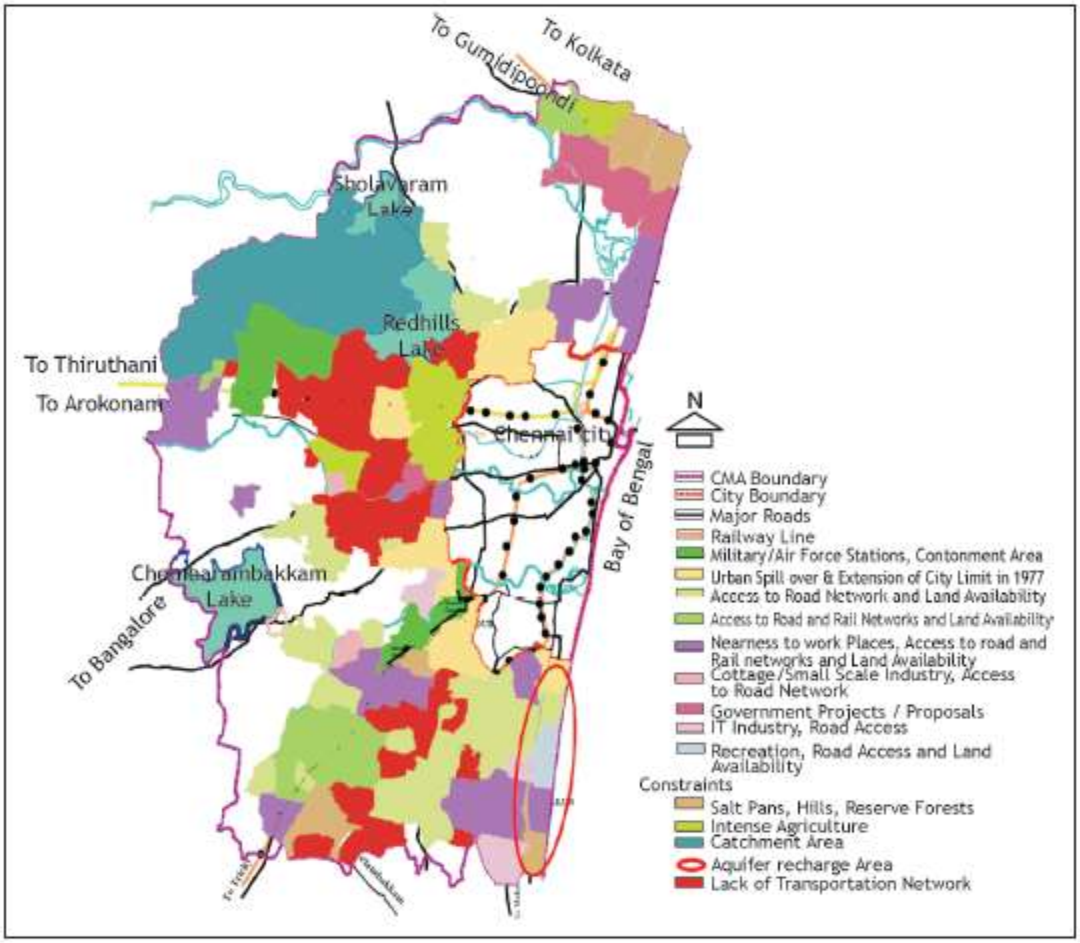


Figure 74: Reasons for growth of City between 1971 and 2001, Source-Sekar and Kanchanamala,2011

Reasons for Growth	Villages emerged during the year				
	1971	1981	1991	2001	2006
Urban spill over and extension of ciy limit in 1977	Alandur Ambattur Madhavaram Valasaravakkam Porur	Ullagaram-Pu-zhuthivakkam	Kottivakkam Palavakkam Ramapuram Nandambakkam	–	–
Access to road network and land availability	Poonamallee Kundrathur	Naravarikuppam Padianallur Sembakkam	Thiruneermalai Mangadu Puzhal Mudichur Madipakkam Peerkankaranal Karamabakkam	Okkiamthorapak-kam Pallikaranai Madambakkam Neelankarai Polichalur	Nazarathpet Sithalapakkam Medavakkam Vengaivasal Kovilambakkam Mathur
Access to Road and Rail networks and land avail-ability	Tambaram	Pammal Chitlapakkam Minjur	Nadukuthagai Perungalathur	–	–
Nearness to work places (industries / institutions), access to road / rail network, land availability	Thiruvottiyur Pallavaram	Thirumazhisai Thiruninavur	Nerkundram Manali	Perugudi Sholinganallur Vandalur	Adayalampattu Vanagaram Chinnasekkadu Perubakkam
Cottage/Small Scale industry, access to road network	Thriuverkadu Anakaputhur	–	–	–	–
Government proj-ects / proposals	Kathivakkam	–	–	Vallur	Nolambur
Military / Air Force Stations	Avadi St. Thomas Mount cum Pallavaram Contonment	–	–	–	–
IT Industry road Access	–	–	–	–	Manapakkam Karapakkam Semmencheri
Recreation, Road access, land avail-ability	–	–	–	Injambakkam	–

Figure 75: Identified Reasons for growth of City between 1971 and 2001, Source-Sekar and Kanchanamala, 2011

4.2.2 Overview of Public Infrastructure

Transportation –The city has extensive network of roadways that originate from fort St.George and expand in three principal directions, which have now expanded to five directions.

There was a port at Mylapore since the 2nd century which was maintained first by the ancient ruling dynasties and then by the Portuguese, followed by the British. There exists a satellite port further north, near the Ennore creek. Railway networks have played a significant part in development of Chennai and suburbs and the services of MRTS and CMRL have further progressed ease of travel in Chennai.

System	What forms the system	If Man made By whom	Time period	Managing body	Remarks
Ports	Port at Mylapore	Pallavas and other South Indian dynasties	2nd century	Ancient ruling dynasties Portuguese for a brief time	Maritime trade started earlier than 1639 on the sea shore Chennai.
	Port of Madras	Later renamed Port of Chennai, 2nd largest container port in India.	It was used as a passenger travel port prior to India's independence from the british. It is now used as a container port.	British East India company Currently maintained and owned by Chennai Ports trust	It was an exposed sandy coast till 1815. The initial piers were built in 1861, but the **storms of 1868 and 1872 made them inoperative.** Artificial harbor built in 1881 but still **vulnerable to the cyclones, accretion of sand inside the basin due to underwater currents** forced change of access to the port from East to North East during British period. The 2004 Tsunami caused about 2-3m dredging of the port entry area and made it the deepest in the East coast. The port plans to create an artificial beach from Napier's bridge along Cooum river to the fishing harbor in the North for protecting the port in the future from natural disasters.
	Ennore port located 2.6 km north of ennore creek.	Satellite port controlled and owned by Kamarajar Port Limited	Still in use	Kamarajar Port Authority,Govt. of India.	At threat from **tropical cyclones.** Lies in Seismic Zone III - moderate risk of **earthquake.** **Shore erosion**. – Closure of creek mouth by sand bars.

Roadways	Road networks were initially - Radial and ring pattern emerging from George town in 5 directions by 1970's	British till 1947. Corporation of Chennai	Established in 1885- Marina Beach road is formed 1895: First tram car service is inaugurated	Currently maintained by Highways authority,PWD, Corporation of Chennai	At risk due to improper storm water drain. The newly proposed CMRL that is currently being implemented runs predominantly over the road networks risking safety if an earthquake does occur.(Seismic zone 3)
Railways	Southern Railways	British	1856: First Railway line from Royap uram to Arc ot is built	Owned by Indian Railways. Currently connects Chennai to most major and minor cities	Age old infrastructure that is well maintained but still at a risk from cyclones and heavy rains.
Chennai Suburban Railway	Suburban railway network that Connects Chennai main city with suburban areas along West, North and South.	Southern Railways Indian railways	commuter rail system since 1931	Built by British in 1931, and taken over by Southern railways.	Still at a risk from cyclones and heavy rains.
MRTS - Mass Rapid Transit System	Elevated line constructed almost wholly over the water bodies in the city .Owned and operated by Southern Railways	Indian railways	Operational since 1997	State owned subsidy of Southern railways , Indian railways Proposed to be taken over by CMRL	Still at a risk from cyclones and heavy rains. Well functioning, cost effective travel solution but heavy infrastructure that burdens roads and waterways alike. Areas under the MRTS lines have become hotspots for emergence of informal slum settlements.
CMRL– Chennai Metro Rail Limited.	Rapid transit system throughout the city imposed upon the road networks	CMRL owns, operates and maintains.	Began partial operations in June 2015.	Chennai metro rail services (CMRL) to have all surface, over ground and underground rail networks within the city to be under one organization. They plan to acquire MRTS.	The excavated tunnels have acted as storm surge corridors that carry water into the city. It was not anticipated when the construction and boring of tunnels began.

Table 5- Analyzing the various transport systems in the city, Source- Author

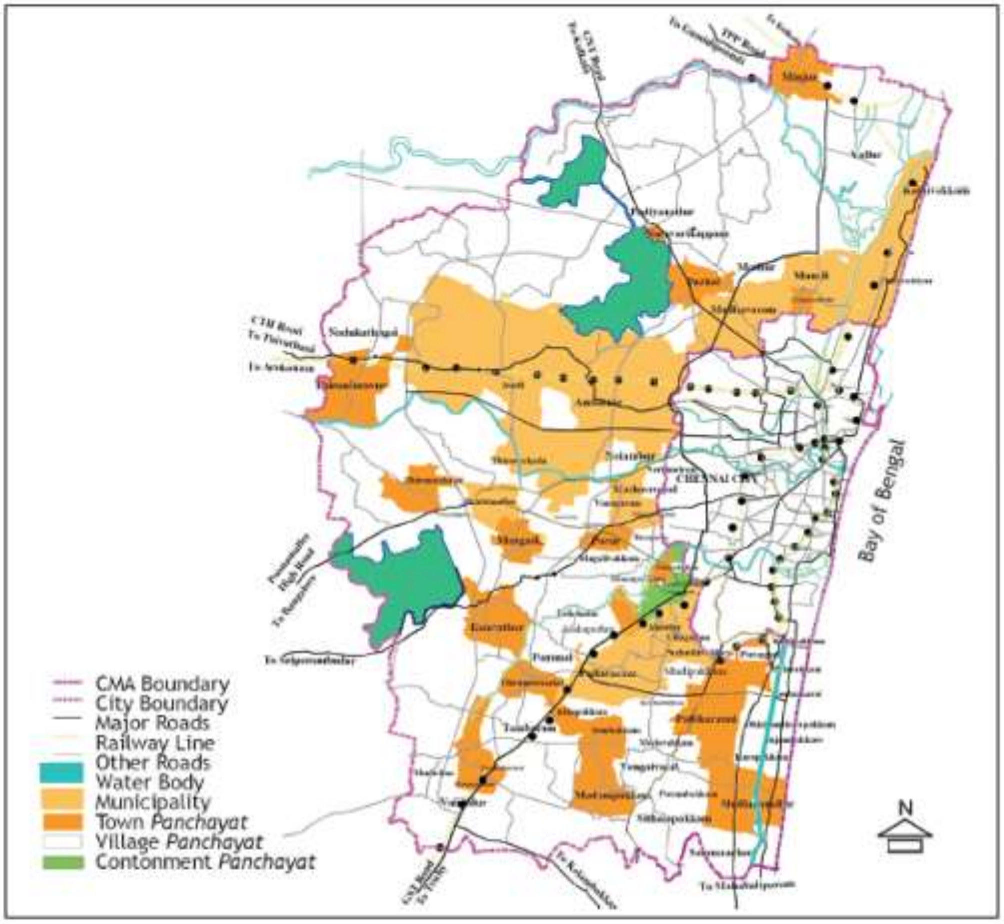


Figure 76: Administrative Boundaries and Transport in CMA, Source-Sekar and Kanchanamala,2011

4.2.3 Geological composition of Chennai's Terrain

Land in Chennai is of varying geological composition and varies from Sandy areas near the coast , Clayey soil in most parts of the city and some others being hard rock areas. In coastal areas, runoff from rain percolates easily whereas in clayey areas, they are held longer by the soil but help recharge the groundwater.

The city also falls in a moderate damage from earthquakes (Zone III) even though there haven't been any recorded

4.2.4 Formation of Hydrology in the City

Three major water courses travel through the city in addition to numerous tanks and lakes/reservoirs as well as a marshland and a man made navigation canal.

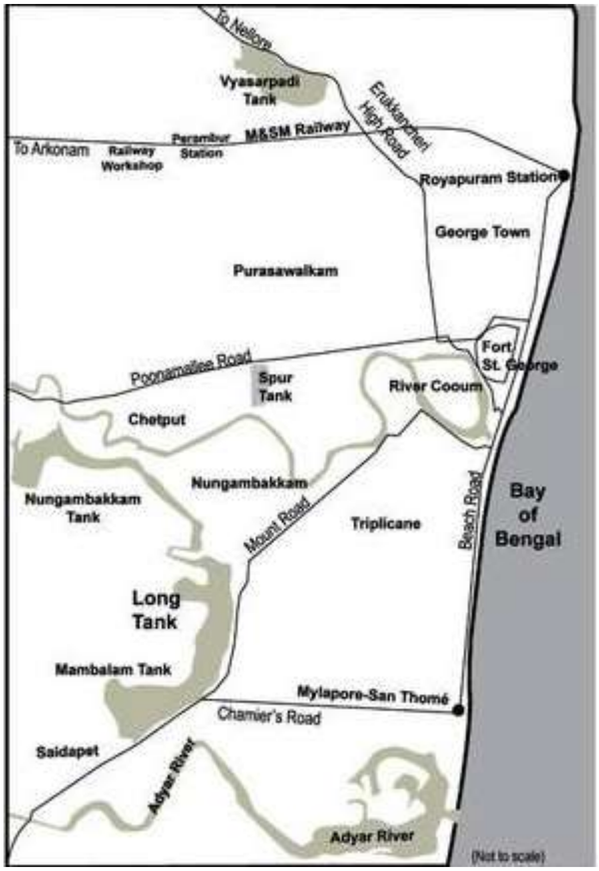


Figure 77: Historic tanks and water bodies that have disappeared, Source- British maps

Understanding Water in the City from a historic perspective

As a result of sea level rise in the 16th century, Madras had sand ridges along the coast which inundated settlements. When the sea withdrew, lagoons and ridges were formed.

- **The ridges were chosen for new temples and settlements due to the relative safety offered and the lagoons filled up with time.**
- Two larger ridges, one being about 12’ high formed between Broadway and Beach and the other one, along Mint Street.

The land rose gently from the beach line to the ridge and fell along the valley where a drainage canal ran, along present day Broadway.

It again rose to the 2nd ridge along Mint and fell into a valley of present day Buckingham canal.This ridge continued along Thiruvottriyur High road.

On the South, **a sand ridge (present Marina) ran from the mouth of Cooum to present day**

Presidency College falling into a depression which was considerably huge in the rear side (present day College grounds).

A **U shape ridge running along Besant and Lloyds road enclosed Ice house with Parthasarthy temple lying just north of the ridge.** A wide depression also existed between the southern ridge and Mylapore.

Another ridge,along Luz church road linked Santhome cathedral and Luz church. ***Santhome and Adyar mainly developed around the ridge.***

Mount road, was along a tank bund at a higher level.

Toward the east, the land gradually fell to triplicane high road and Luz.

Westwards, present day **Vyasarpadi and Perambur were sparsely populated and periodically inundated owing to their low lying nature. People's park was a low lying area too but Purasawalkam high road was on a ridge. Western to this road, lay the Otteri Nullah (Otteri Channel).**

Cooum river and Elambore (or North) river which flows into the Cooum mouth, originally ran very close by,(present central jail area) inundating the whole area during floods. A cut linked the 2 rivers and **equalized floods**. By 1710, the Egmore bridge was constructed across the cut between the 2 rivers to access residences along the Cooum..

- **The building of the harbor in 1896 helped accrete sand to Its' south forming a 2.5km wide beach between land and sea. The west of Nungambakkam was covered by Nungambakkam long tank.**
- **The area occupied by Long Tank was to become residential by 1940's.**

4.2.4 Main components of the urban water system

Water supply, Waste disposal and Storm water drainage systems form the main urban water systems. In Chennai, all 3 of these depend on the rivers, lakes and marshes in the city.

i. Water supply in Chennai City:

- The networks for water and drainage were first laid out in the city by the British and were later updated but are not competent to meet current demand.
- The earliest known organized water supply dates back to the 18^{th} century. The protected surface water supply system was formed in 1872.Improvements which included addition of filtration and pumping stated by 1914
- Surface storage networks are fed by Kosasthalaiyar river and the system comprises of Poondi, Redhills and Cholavaram(Combined capacity= 183 million cubic metres.
- Red hills lake , located 6km in the NW direction along GNT road supplies water to Chennai city. The lake is fed mainly by Kosasthalayar river. Across this river, a dam constructed created Poondi reservoir.
- Downstream,the anicut was constructed at Thamaraipakkam and this diverts flow through an upper supply channel to Cholavaram lake, from where it flows to Redhills lake.
- A separate lined channel from Poondi connects to the upper supply channel and ensures loss of transmission by avoiding pass through along the seasonally dry river bed.
- Many small lakes in the NW of the CMA are also connected to redhills lake and runoff in the catchment areas of these lakes are fed back to redhills. The water from Redhills lake gets filtered enroute closed conduits to Kilpauk water works, from where it gets further treated and supplied to the city.

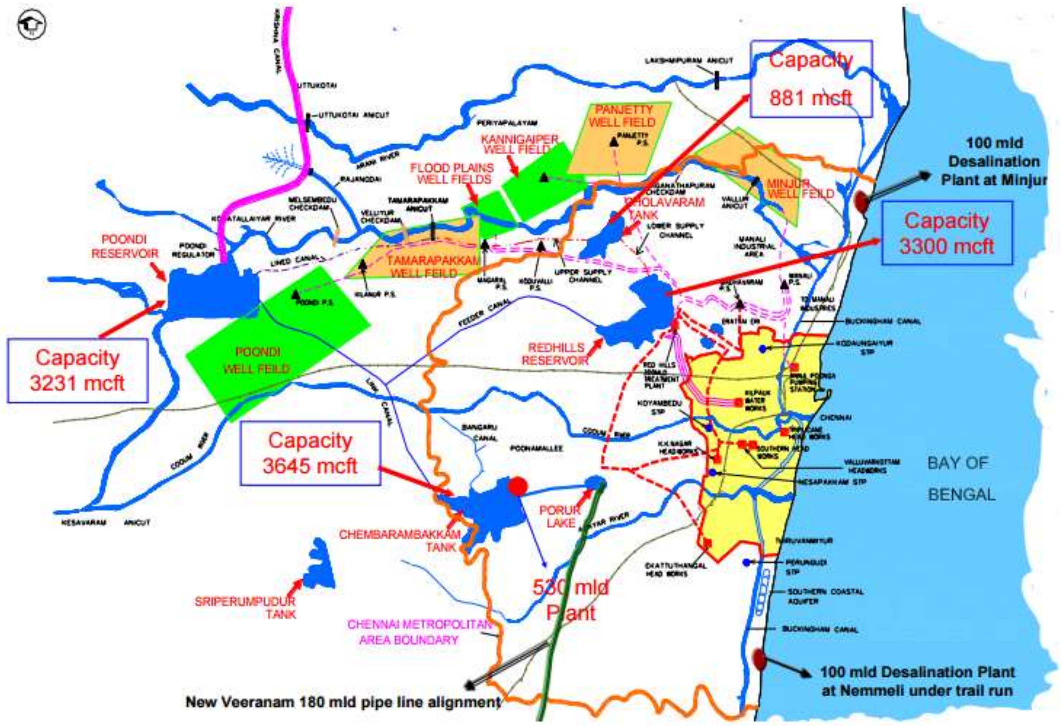


Figure 78- Water supply map for Chennai City, Source-

http://icrier.org/pdf/chennai_CMWSSB_Delhi_Feb2013.pdf

Organizational Structure:

As with any city experiencing rapid growth, unmet demand by the population has put a strain on utilities such as water and drainage. Until 1978, Chennai Municipal corporation bore the responsibility of construction, operation and maintenance of water systems. It was transferred to the CMWSSB beyond this point. PWD controls the major supply sources to the city. The irrigation department under PWD controls Poondi reservoir,Redhills and Sholavaram lakes, While its' Ground water cell investigates ground water resources and augments supply within CMA.

Large scale neighborhoods such as those by TNHB were supplied with water supply facilities by TNHB itself by utilizing ground water sources and extending the city's water supply. Construction and supply of water in rest of CMA fell into the hands of TWAD board on a B.O.T basis wherein it was transferred to the local body and the local body made the necessary payments. CMWSSB now plans to cover water supply and sewerage for such areas.

By 1972,capacity of Redhills and Cholavaram had to be raised and the government acquired irrigation rights. The lakes are mostly rain fed and depend on the NE monsoon between October and December. As the lakes are shallow, evaporation losses amount to about 43% today.

Ground water supply:

Sources for groundwater include well fields, coastal aquifer, Neyveli aquifer, reverse osmosis plants for brackish water to name a few.Between 1960s and 70s,aquifers North and NW of the city at Minjur,Panjetty and Tamaraipakkam were tapped and so were aquifers along the coast(from Thiruvanmiyur to Kovalam).UNDP aided a study to assess potential for developing a groundwater source in the city's North East.A buried channel, believed to have been the course of Palar river, that dates back to a thousand years was found. Well field extending 50 km in length and 5km width was found hydro geologically feasible for water extraction.

Sources / Reservoirs (5) + Desalination Plants (2) + Water Treatment Plants (5) – 1494 MLD further, addition of 100 MLD Desalination Plant at Nemmeli since Feb 2013

Water Distribution Stations (Head Works) – (16) 4444 kms

Distribution Network (2930 Kms) & Networks in added areas (1514)

House Service Connections (4,93,903) Erstwhile City (3,96,483) + Added Area (97,420)

Total Consumers (7,29,389) Erstwhile City (5,95,600) + Added Areas (1,33,789)

Table 6- Sources and Distribution details for water supply, Source- CMWSSB Records,2013

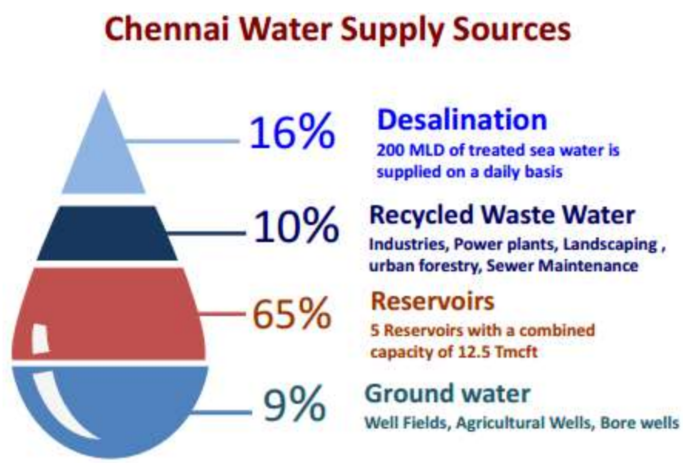


Figure 79- Water Supply Sources for Chennai city, Source-CMWSSB

Areas/Sources	Current Managing body	Time period of existence	Responsibility of the Organization
All water supply	Chennai Municipal Corporation	Till 1978	Construction, Operation and Maintenance
CMA water supply	CMWSSB	1978 till date	Water supply within Chennai
Poondi reservoir, Redhills and Sholavaram lakes	PWD – irrigation dept.	20^{th} century	Maintain flow levels and discharge
Ground water resources	PWD- ground water dept.		Responsible for investigating groundwater supplies in CMA and augmenting supply
Large scale neighborhood projects	TNHB		Supply of water through groundwater and extending city water supply for large scale neighborhood developments
Rest of CMA	TWAD board on a B.O.T basis and then local body		Construction by TWAD board and built at the expense of local body and transferred for

	future maintenance and operation CMWSSB to acquire for supply.

Table 7- Management of water resources and responsibility, Source- Author

ii. Waste Disposal Systems in Chennai city:

Sewage plan in Chennai:

Chennai's first sewage plan was conceived in the 1860s and a proper system was installed in 1891. Improved and expanded since, including a zonal reorganization in the 1960s, it hasn't been able to keep up.

Currently there exists a centralized sewage treatment process for sewage which isn't well organized.The sewage from the city first goes to the Sewage treatment plants (STP's) located at various points in the city and then after treatment gets dropped into the nearest rivers,which flows towards the sea.But on its way, up to 700 other outfalls add untreated sewage to the rivers thus polluting the rivers and the sea into which it flows and the beach where it flows through. Most of the used water is treated in 6-7 effluent treatment plants that do only secondary or tertiary treatment before discharge into the rivers.

Sewage generation per day (580 MLD)
Connections (4,45,260) - Erstwhile City (3,67,297) + Added Area (77,693)
Length of Sewer main (4265 kms)- Erstwhile City (2875 kms) + Added Area (1390 kms)
No. of Pumping stations (218) - Erstwhile City (198 nos) + Added Area (20 nos)

No. of Treatment Plants (10) - (Treatment capacity available 558 mld) End Product : 35 MLD Secondary Treated sewage given to Industries 516 MLD let into City Waterways after secondary treatment)

Table 8- Management of Sewage, Source- CMWSSB Records,2013

Figure 80: Sewage Treatment Plants in Chennai, Source- CMWSSB

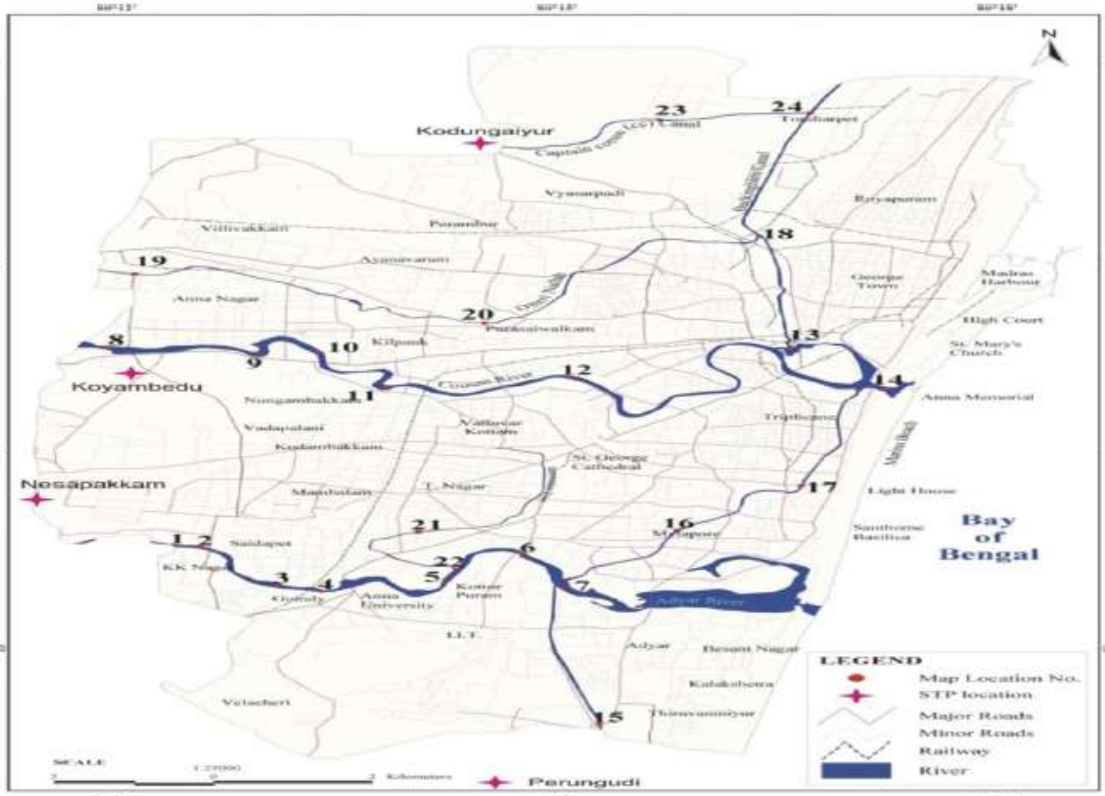


Figure 81: Sewage Treatment Plants(STP's) in Chennai as source of pollution in Adyar & Cooum Rivers
Source- Gopala Krishnan, Centre for Environmental Studies, Anna University, Chennai.

iii. Clogged storm water Drains:

Figure 81: Clogged entrance to storm water drain. Source-Chennai pollution board.

Insufficient coverage and capacity of storm water drains and lack of Proper connectivity to major canals and waterways is a major crisis that Chennai faces.This combined with poor maintenance will lead to more crisis in Chennai due to lack of storage as well as discharge.

Figure 82: Roads and storm water drains during major storms.
Source-http://www.icwar.iisc.ernet.in/wp-content/uploads/2016/06/BN_IITM_Chennai100RC.pdf

Storm water drains are desilted twice a year by the respective zone it falls under.31 canals in the city fall under the Chennai Corporation and are disilted periodically. The desilted material gets dumped in Perungudi or Kodungaiyur dumping grounds.

iv. Water bodies and Marshlands in the city

Chennai city is comprised of a number of small and large Waterways. To understand the dynamics of water flow during floods, it is imperative to understand the terrain, and the nature of flow of water through the city. The lives and livelihoods of hundreds of millions of people will be affected by what is done (or not done) in the city. We need to understand how the processes that shape urbanization create or exacerbate risk to a range of hazards, including those that climate change will introduce or is likely to increase.

Figure 83: Development Plan for Chennai Metropolitan Area, government of Tamil Nadu, Chennai.

Source: Down to earth

Figure 84: Watershed Map of Chennai, Source-, CMDA seminar on Waterways.

The 3 main rivers that run through the city in the East west direction are – Kosathaliyar (Also called Koratalayar) , Cooum and Adyar .The Cooum almost partitions the city into half and the Adyar River further divides the south of Chennai into two parts. A manmade Buckingham canal runs parallel to the Sea coast through the length of the city and meets the tidal creeks of Pulicat lake (The 2nd largest lagoon in India) in the North and Kovalam creek (also called Muttukadu backwaters) in the South. Other smaller canals and drains that include Otteri nullah, Mambalam drain and Captain cotton canal(North Buckingham canal) amongst many others,drain into these water bodies.

Figure 85: Rivers, Canals and Drains in Chennai, Source-

http://epaper.timesofindia.com/Repository/getimage.dll?path=TOICH/2010/04/09/5/Img/Pc0050900.jpg

Chennai has many environmental assets, including around 3000 water bodies. Some of these include:

1) A long sea coast with two tidal creeks – The Adyar Creek and Ennore Creek.

2) Second largest lagoon in India – the Pulicat Lake.

3) Lakes- Redhills, Chembarambakkam, Poondi, Sholavaram and Porur and many smaller ones

4) Wetlands and Swamps – Pallikaranai, Oggian Madugu, Madhavaram and Ennore.

6) Many Estuaries and backwaters, such as the Adyar Estuary and Creek and a large number of smaller lakes, eris, ponds and several temple tanks. Some of these are described below:

Buckingham canal-

Figure 86: Buckingham canal in early 1900’s(left) and Buckingham canal with MRTS line running over it and slum settlements below(present time).Source- Studies and Research related to Cooum Sivakolundu,, National Institute of Ocean Technology, Chennai

Kosasthalayar river-

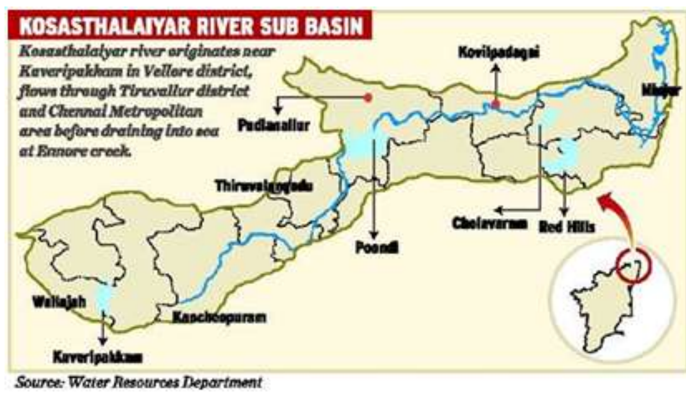


Figure 87: Kosasthalayar sub basin map. Source- WRD, Government of Chennai

Cooum River-

Cooum river that flows through Chennai originates in Thiruvallur district and runs 65km within Chennai city.

Figure 88: Cooum sub basin map. Source- WRD, Government of Chennai

River / Drainage System	Orgin	Location of confluence with Bay of Bengal	Total Length in Km.	Length in City Limits in Km.	Length in CMA in Km.	Total Catchment Area in Sq.Km.
RIVERS						
Kosasthalaiyar	Krishnapuram (AP) for nagri am / Kaveripakkam (Vellore District) for Kosasthalaiyar arm	Ennore Creek	136		16	3757
Cooum	Cooum Tank (Thiruvallur District) Kesavaram for diversion from Kosasthalaiyar	Cooum Mouth near Napier Bridge	72	18	40	400
Adyar	Adanur Tank near Guduvancherry	Adyar Mouth	42.5	15	24	1142

MAJOR DRAINAGES					
North Buckingham Canal	Ennore Creek	Cooum North Arm	58	7.1	17.1 up to Ennore Creek
Central Buckingham Canal	Cooum South Arm	Adyar Creek	7.2	7.2	7.2
South Buckingham Canal	Adyar Creek	Marakkanam	108	4.2	16.9 up to Kovalam Creek
Otteri Nullah	Padi & Villivakkam Tanks (Abadoned)	Buckingham Canal near Basin Bridge	10.2	10.2	10.2
Virugambakkam - Arumbakkam	Virugambakkam Tank (Abadoned)	Cooum River near Nungambakk-am	6.36	6.36	6.36

OTHER DRAINS					
Kodungaiyur Drain	Kolathur Tank, Madhavaram Tank	Buckingham Canal through Kodungaiyur Tank	6.9	6.9	6.9
Veerangal Odai	Adambakkam Tank	Pallikaranai Swamp	2.78	--	2.78
Captain Cotton Canal	Vyasarpadi Tank	Buckingham Canal near Tondiarpet	6.9	6.9	6.9
Velachery Drain	Velachery Tank	Pallikaranai Swamp	2.14	2.14	2.14

Figure 89: Rivers, canals and drains and their sources. Source-, CMDA seminar on Waterways.

- Pallikaranai Marshes

Figure 90: Pallikarnai marshland reserve forest. Source-Survey of India topo sheets (1972)

Tanksystem in Chennai

Tanks refer to dugout reservoirs, with steps on all sides that can access the water. They are also called ‘Kulam’ and are usually rectangular or square in shape. It was used in combination with ‘Aeri’s’ in areas with less rainfall to retain all water that fell on the ground. Surface area of tanks vary between 2000 Sq.m-3000 Sq.m. Traditionally, settlements were formed as villages that came up around a temple and tank..Tank restoration scheme was launched in the city in 1883 on the recommendations of the Famine Commission. Under the scheme, a memoir detailing the hydrological features was drawn up. Most tanks in the area form 'system eris' or tanks which are a part of integrated water harvesting systems, and are situated in the basin of one of the rivers flowing through the area.Upto 124 tanks were in CMA in addition to 39 temple tanks.

Primary functions served by the tank were:

1. Storage- Prevents against droughts during low rainfall periods.

2. Flood control – Presents run off, erosion of soil, and water getting collected in settlements as all water in the area was channeled into the tanks.
3. Maintenance of Ground water and wells.

Temple tanks have cultural as well as socio-religious significance. They were used for float festivals at the end of monsoons as well as ritualistic cleansing .As an example, Kancheepuram has 7 temple tanks corresponding to the 7 days of the week but having their unique importance. (Cox, 1894).These tanks also recharged surrounding wells .Funds were channeled to maintain the tanks by the rulers of the past. 39 temple tanks still exist in Chennai city, but are drying due to depletion of groundwater and rapid urbanization. Commercial and residential settlements in the catchment area blocked the flow of water into the tanks, by blocking the inlet paths .Thus rain water easily runs off into the sewer and reaches the sea, (Cudworth and Bottorf, 1969). Thereby, flooding areas that pose as obstructions in its path.

4.2.4 Flood an Droughts in Chennai City

Madras, including the districts of Chengalpattu is not traversed by any large rivers. The only sources of water were monsoon supplies, and reservoirs that store water on a large scale. Local irrigation resources were developed under native management from time immemorial by tanks or channels, There were upwards of 40,000 tanks, producing about £1,500,000 per annum as Gross Irrigation Revenue collected by Public works department during the British period. These tanks however were not maintained or given due importance.

Droughts are believed to be caused predominantly by failure of monsoons, deforestation and increased non permeable surfaces that prevent water from being stored as groundwater. Mismanagement of water resources due to lack of awareness and disregard are causing havoc in cities that depend on monsoons for replenishing water supply. Millions of cubic feet of water drain into the ocean without being utilized and flooding the areas it passes through due to destruction of previously created storage areas.

The National Waterways Development department emphasizes that we waste millions of cubic feet of water by not utilizing it and this drains into the ocean by passing through areas that get inundated. A 15,000 km long waterway covering the entire country was proposed to prevent floods as well as droughts.

Major drought years in Chennai were- 1832, 1872, 1885, and 1916 and the Great Famine in 1876-1878. This also, affected much of India between 1876 and 1878.

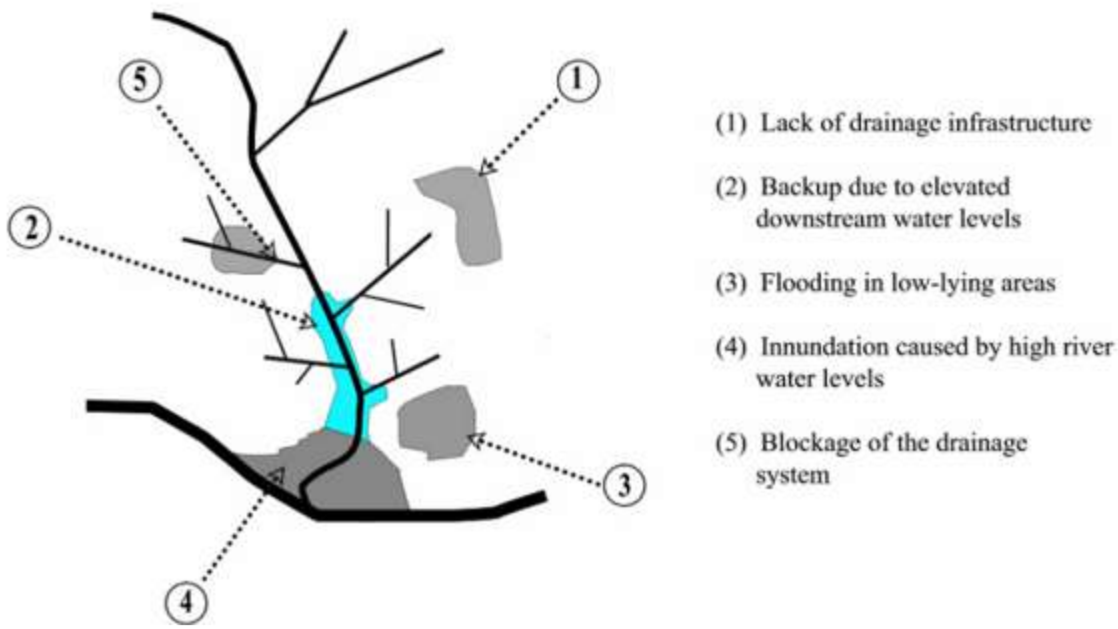


Figure 91: Storm water management problem in Chennai and other developing countries (2005). Source- http://www.icwar.iisc.ernet.in/wp-content/uploads/2016/06/BN_IITM_Chennai100RC.pdf

CHAPTER 5- DATA ANALYSIS

5.1 Synthesis of data from Literature and Case Studies

Data Analysis tables -Author's interpretation

1. Understanding Waste discharge through the city:

Waste systems	What forms the system/What is the problem?	Why it was built/What is its purpose?	Authority responsible and what should be done (Author's suggestions)	Citizens role
Storm water drain network	The storm water drains run along the road networks but are often clogged and is extremely under the required capacity even if fully functional.	It was built for safe discharge of storm water but as the city continues to expand,there is not enough storm water drain to cover for the areas.We thus need to look at other options to conserve water and prevent damage,.	Strom water drain department under corporation of Chennai. Measures should be taken to increase the combined functioning of storm water drains,canals and other small water bodies and dumping of waste in these systems should be made punishable.	Nil, Citizen partnership should be encouraged at neighborhood and household levels.
Run off	Run off gets discharged into rivers and sometimes floods areas that are low lying.	Run off if conserved using schemes like SUDS,Low impact development etc can prove to be beneficial to improve groundwater	Storm water drains department,Corp oration of Chennai needs to make rules	Paved materials cause more run off.No attempts to save.Citizens need to be educated on methods to save

		and save water.	stringent for green areas in neighborhoods and houses.	and reuse water.
Marsh and Canal	Marsh is a low lying swapy area that has been heavily encroached and disregarded.Construction has blocked storm water flow into the system further shrinking it .	If functional,it could have arrested flood waters and releasd them slowly,thereby preventing or atleast minimising damage from the Adyar river as well as replenishing ground water in the area.	Maintained by Greater Chennai corporation and desilted but not enough is done to conserve or prevent waste being dumped and encroachments	Citizens contribute to encroachments,lack of maintenance of small water bodies that may fall under their control in individual or group owned properties.Waste is continually dumped into canals and industrial effluents also land up there.
Sewage disposal	Primarily at household level	Sewage goes to STPS,and is treated upto secondary level and is dumped into the rivers.	Maintained by CMWSSB- Chennai Metro water services. Departmental conflicts are evident in the use of rivers both for carrying stormwater by corporation and for dumping waste by metrowater.	Citizens watch their rivers get polluted and add insult to injury by adding some more plastics and other wastes.
Garbage disposal units	-area wide	Area wide garbage disposal systems eventually dump the waste at Perungudi and Kodungaiyur where Sewage treatment plants function.But no attempt is made to sort the garbage and it all lands up on pallikarnai marsh(Perungudi) further degrading the marsh.	The waste generated by the city can be used for eco -farming,producing bio gas as a clean fuel alternate and can even be used for local gardens within households instead of adding the load.Organic farming can be encourages in houses,apartments,communities and even neighborhood	Citizens should be encouraged to grow produce in their gardens and laws should mandate permeable gardens in the setback areas with only one area permitted for parking also to be permeable material.

			levels.	
Industrial waste water removal	Industries dump their wastes in rivers,thus polluting the secondary treated water flowing to the sea.	Industries should sort and treat theri own waste after which they should go to Sewage treatment plants to be treated atleast to secondary level before discharge.	Private companies and governmental institutes like leather industry etc.	Citizens need to empower themselves with the support of gvernment and well as NGO'S and have neighborhood surveillance teams that keep a check on industrail waste dumping in the rivers.

Table 9-Discharge of waste through the city. Source-Author

2. Understanding Water Flows through the city:

Water systems	What forms the system	Who controls it	Why it was built/What is its purpose?
Natural:			
Rivers	1.Kosasthalaiyar flowing to the sea	Kosasthalayar originates in Thiruvallur district,It has a northern arm that originates at Nagari river in Andhra Pradesh that joins at Poondi reservoir and is clean till it reaches Chennai district. Runs for 136kms.It discharges at Ennore creek.	**The 3 rivers passing North, South and Central to the city naturally flows to the sea but connects to the Buckingham canal before doing so.All of them run from West to East.** **All 3 rivers are severely polluted with CMA,with Cooum and Adyar being worse than Kosasthalayar.** **Kosasthalayar is the longest and has many more check dams in use and planned on it and serve for water supply as well.Check dams recharge ground water in 10km radius.** **Cooum is the most polluted running through the center of the city and through the main CBD. 32 kms of it run through the urban core while the remaining is on rural fringes upstream.16km run through CMA.** **Adyar causes most damage as there is an ecological disconnect with all surrounding water bodies and rapid urbanization along this part of the city.**
	2. Cooum to the Sea	Originates in Thiruvallur district and runs a length of 72kms till Bay of Bengal . Elambore river(called North river used to converge at Cooum but this was separated by a flood equalizing cut in 1700's	
	3.Adyar to the sea	Originates near Chembarambakkam in Adanur Tank,	

		Kanchipuram district and runs a length of 46 km in total and discharges at Adyar estuary.	**Adyar and Cooum have some restoration plans by the government but there are no current results visible.**
	Further North-Arani river to sea Further south,Palar river to the sea.		**Arani river further North drains between Pulicat and Ennore** **And Palar river drains near Mahabalipuram**
Marsh	Fresh water marsh connects and discharges at Okkiyam madavu and forms an integral ecosystem that supports variety of flora and fauna.	The Pallikaranai marshlands are a set of wetlands that lie in south of chennai. They act as the flood sink of Chennai	**Encroachments and indiscriminate dumping of waste have reduced capacity.** **Various governmental and non governmental institutions lie on this fragile ecosystem.** **Together with Kovalam and Muttukadu backwaters and Pulicat lake form an integral ecosystem that connects to more ecological systems further south and north of CMA.**
Manmade: Tanks		Indian religious establishments-Temples for temple tanks and other tanks controlled by various bodies	**Existent since the ancient times as part of central temple tanks that were used for festivals and also had the additional benefit of ground water recharge and storing water.** **Some tanks that were existent were not part of the temple tanks.** **But after 1971, 'Eri development schemes' came up which permitted building up on 'eris',these systems were destroyed and often clogged.**
Canal	Buckingham canal (Captain cottons canal) N and S	British ,Currently under revenue department,Government of Chennai.	**Navigation and famine relief in British period and was well maintained.It is said to have protected the city from storm surges and tsunami as well as it lies parallel to the coast and acts as a line of defense. Extreme disregard has led to complete disuse of the canal except for dumping waste.**
Reservoirs	Series of reservoirs-mainly Poondi, Redhills and Cholavaram.	PWD, Govt.of India	**To store excess water (rain fed) and to supply water to Chennai city**

Table 10- Purpose of the water systems in the city and their use today. Source-Author

3. Usage of Water and Drainage Elements in Chennai city today

Systems	Functionality	Intended for	Status today	Intervention
1. ***Water Systems***				
Lakes	To support the reservoir's capacity and to store rain water	Water storage	Many within CMA have disappeared	Nothing concrete has been done to prevent encroachment. Political influence and disunity has led to loss of function.Some are being restored after having lost most of its capacity.
Reservoir	Reservoirs are the storehouses of water that is supplied to the city	Water storage and water security	A lot of water when reservoir capacity is filled, gets wasted through Adyar,Cooum and Kosasthalayar rivers and land up in sea as there is no way of storing them due to loss of capacity of lakes and tanks.	Sewage and waste dumping in the rivers continue. There is no additional storage created or network of water storage in place as of now.
Tanks	They helped with storm water drainage and stored some of the water for community potable uses. Temple tanks served community and cultural purposes.	Water storage and culture	Many tanks are in disuse or severely polluted or built on. Temple tanks are heavily silted and many have blocked off storm water access due to inflow of sewage.	In the past, there was an efficient system of harvesting water that has totally been disregarded. (Explained in next table 4)
1. Drainage				

Systems				
River	This was supposed to have been clean water that went from reservoir overflow and the origin till the sea.	Served as scenic gateways till the confluence of sewage,household and commercial waste as well as citizens disregard made it a stinking stagnant water body.	Stagnant for most parts of the year. Monsoons and discharge from reservoir can cause havoc of flooding and sewage and storm water mix.	Some efforts to clean Adyar and Cooum but no substancial results. There are notmany attempts made to reconnect with local water bodies due to the pollution.
Canals	Buckingham canal was created as a navigation canal, served as a scenic gateway and for transport . Other smaller canals and drains helped drain storm water with its' robust connectivity that prevented floods.	Does not serve the intended purpose of travel anymore.Nor is it scenic.Concrete jungles of the MRTS lie over almost the entire length of the canal in CMA.	Severely polluted, disregarded and stagnant. But still protects the city from storm surges .	Nothing visibly done to clean even though waterways authority of India and JNNURM schemes showed interest.
Marsh	Flood sink of the city	Lots of the marsh areas have been lost to senseless urbanization.	The parts that are intact even though polluted on fringes, support wildlife and try to serve its function of retaining rain water.	The surviving parts have been declared part of reserve forest due to citizen initiatives.
Storm Water drains	Created along the length of roads but not along all.	Intended for protecting the city by safe discharge of storm	Unable to meet the current demands and incapable of supporting the further	The city has been planning a storm water drain plan as currently each zone maintains its own storm water system and there is no

	water but over burdened in capacity	growth that the city is experiencing towards the suburbs.	integrated plan. That explains the havoc caused by floods.
Summary- More citizen initiatives are needed to save the rest of the water bodies in the city. But this would require stakeholders to unite rather than work in closed circles and completely remove the users(citizens) from the process.			

Table 11- Suggested interventions for increasing functionality and efficiency. Source-Author

4. Historic water harvesting system

The smallest body to accumulate water was called a ‘Kuttai’ ,The biggest water body was called ‘Aaru’ which is the equivalent of River.

Name (In Tamil)	**Name(In English)**	**Purpose in the monsoon harvesting system**
Kuttai	Puddle or small Pond	Smallest water collection point (more or less like a depression.
Kulam	Tank or pond – eg: Kovil Kulam(Temple pond)	Larger than Kuttai –Used for Non drinking purposes. Can be used for bathing etc.
Oorani	Drinking water tank/Spring/ Dug out pond / Surface water storage tank	Small tanks larger than Kulam-Traps rain water runoff and stores for future use. Mostly in rural areas
Yaenthal	Water swamp/marsh	Land serving as water catchment
Thaangal	Place around the water tank	Areas where people were-around the water tank.
Karanai	A place between - joint/knot – eg: Water swamp	Retains rainwater and slowly releases out-area with a high water table.
Kanmaai	Vast spans of water storage (collection of tanks)	Balances water levels.
Yeri /Eri	Large water body like a lake/irrigation tank	Where the water has flown into /drains into.
Aaru	River	Regulates water flow

Table 12- Monsoon harvesting system in ancient Tamil nadu. Source-Author interpretation from tamil source.

5. River Flood experiences during last decade’s 1976-2008

Year	Area	Extent of damage	Cause / Remarks
1976	Adyar	· Adyar Kotturpuram were completely submerged · TNHB quarters submerged	· Chembarambakkam tank overflowed(28,000 C/s) into Adyar river. · Tidal backflow- Due to high tides, Flood water could not enter Sea.
1985	Adyar	Encroachments along the banks submerged	· 63000C/s from Chembarambakkam released into Adyar
1996	Adyar, Cooum and Kosasthalayar Rivers	· All 3 rivers overflowed	· Overall surplused water in all rivers around - 80,000 c/s · Poondi Dam surplused andreleased into Kosasthalayar river · Chembarambakkam · Tank surplused into Adayar – 20,000 C/s · Ageing infrastructure- 125 year old Karanodai Bridge lying South of Kosasthalayar collapsed .It became dysfunctional after its three spans were washed away by heavy flows in the river.
1998	Kosasthalayar	City flooded	3 people trapped in flood plains of Kodungayur drain
2005	100 year record rain in 1 day	50,000 people evacuated.	Cooum flooded -20000C/s,Adyar-40000C/s Over flows on Otteri Nullah, Cooum, Adayar, B'Canal, Virugambakkam- Arumbakkam
2008	Adyar		Adyar-15000 C/s

Table 13- River flooding –Adyar Cooum and Kosasthalayar. Source-Author's interpretation of Flood data from various sources.

Descriptive Section Summary from the tables above - What is the problem?

Some of the main problems that contribute to flooding can be listed as:

- Disregard for traditional water flow systems that kept the city relatively flood and drought free.
- Rapid Industrial development of Suburbs such as Perungudi, Sholinganallur etc which adjoined Pallikarnai marsh led to destruction of the marsh land.
- Special Economic Zone (SEZ) attracted investors. eg: Ennore, Nandampakkam etc.
- Decrease in open area- Colleges, Hospitals, private buildings as well as Public and Governmental have come up on vacant parcels of land and replaced green areas.
- Urban planning has completely disregarded hydrology in the city, thus polluting water sources while rendering others useless or by constructing roads, buildings and other infrastructure.
- River courses that discharged into the sea are polluted and even encroached upon. This, along with the Buckingham canal lying parallel to the Sea from North to South of Chennai has also fallen into disuse and encroachment by government, private owners and slum settlements.
- Ground water is contaminated by indiscriminate dumping of waste. Other water bodies such as rivers have sewage effluents and rubbish dumped in them.
- Sea water intrusion has led to salinity in ground water and aquifiers.

- Re-charge structures like lakes, tanks, ponds and other wet lands have been overlooked and usual flows of water have been tampered with, resulting in floods in the urban core of the city as well as its periphery.
- The Marsh land has been used for a wide variety of functions - waste disposal, housing, commercial as well as industrial activities reducing flood retention capacity.

Segment	*2003*	*2005*
Garbage dump	50.25 ha	57.24 ha
Area impacted by garbage dumping/sewage	58.75 ha	132.25 ha
Northern Segment	227 ha	150.56 ha
Southern segment	284 ha	279.65 ha

Figure 92: Fragmentation of Pallikarnai marsh. Source-Vencatesan,J,2007, Protecting Wetlands, Current science.

Building	*Area Occupied (ha)*
Metropolitan Rapid Transport System (MRTS)	92.405
Film Employees Federation of South India (FEFSI)	34.410
Ashram Latha Rajnikanth Trust	5
Tamil Nadu Agricultural Marketing Board	12.150
Dr. Ambedkar Law University	8.100
Judicial Academy	6.070
MMRD Road 200' width	13.600
IIT, Chennai	17.810
National Institute of Ocean Technology (NIOT)	20.250
Government Free Pattas	2
Land allotted for Ex-servicemen	61.675
Total	**273.60**

Figure 93: Fragmentation of Pallikarnai marsh detailed list. Source-Department of Geography, University of Madras

- The original marshland lying 20km south from the city center called ‘Pallikarnai marsh’ was about 5000 hectares (ha) in the 1950’s and drained approximately 250 sq.km of the city. But, by 2010-11, due to rapid urbanization, the marsh and the smaller satellite wetlands and pastural land around it have been urbanized thus permanently damaging the flood sink area of the city.
- Urban development on the marsh, resulted in the local train networks such as MRTS- Mass Rapid Transport Systems, and National level institutions such as National Institute of Ocean Technology and many others as well as private institutions occupying the marsh making it shrink in area.
- Planning could not prevent encroachments to valuable ecological infrastructure such as lakes, tanks and ponds either due to the lack of a central unit to maintain the water bodies as they fell under different departments of the government and sometimes even the army or private individuals.
- The Tamilnadu Town and Country Planning was amended to preserve wetlands only recently but by then, most of the ecological imbalance has already taken place.
- Inadequate storm water drains- Inadequate storm water drains - The city has 855 km of storm drains against 2,847 km of urban roads.(NIDM,2011)
- Inadequate sewage systems- The sewage system was originally designed for a population of a little over half million at 114 litres /capita/day of water supply. Even after modification between 1989 and 1991,it remained inadequate.(NIDM,2011)

Causes of floods in Chennai:

- Increased severity and Intensity of Tropical cyclones and Storm surges along the Bay of Bengal.
- Northeast (winter) monsoons from October-December has been unpredictable bringing sudden heavy downpours
- Disregard for varying geology of Chennai's terrain- Sandy areas adjoining the coast percolates rain water run-off quickly while clayey and hard rock areas hold water in the soil longer and allows slow percolation.
- Construction along and subsequent destruction of water infrastructure and clogging water flows.
- About 650 water bodies that include big lakes, ponds and storage tanks that formed a network, has been destroyed. Currently there are only around 27 of these remaining, (NIDM, 2011).Those that survived are much smaller than their original extent.
- Pallikarnai marsh lost around 90 per cent of its original extent, as revealed by a study conducted by Tamil Nadu Pollution board (TNPB) in 2002. The same year, saw a major flood event and areas surrounding the marsh were badly affected.
- When the city expanded southwards, the government only considered the land value. Water bodies, marshes etc were seen as potential waste grounds.
- Capacity reduction for withholding and discharge of monsoon rain waters- The total area of 19 major lakes in the city has nearly halved from 1,130 hectares to about 645 hectares reducing the ability of the water bodies in the city to store or discharge excess rain water.

- Land use changes- In some areas, upto 99% green cover has been replaced by impervious surfaces. The peak flow (the maximum on the spot discharge of water) has increased by 89% between 1997 and 2001 due to rapid urbanization.
- Perungudi, located North-East of Pallikarnai marsh was treated as a dumpyard and in 2002, comprised 32hectares of land. This doubled to about 75 hectares in 2013.
- Around 273.50 ha was allotted to different institutions by 2010 as revealed Tamil Nadu State Land Use Research Board further disrupting the water flows that would have otherwise not flooded the city.
- Even after the repeat flood events, there are further allotments on the marsh that brings a further area of 474 ha area as already allotted or occupied. (Sakthivel et.al)
- By 2014,the Government had spent about 400,000,000 or more but hardly any flood protection could be achieved and the city continues to flood.

5.2 Data Analysis from Maps and Site Analysis

Monsoon in Chennai, Tamil Nadu:

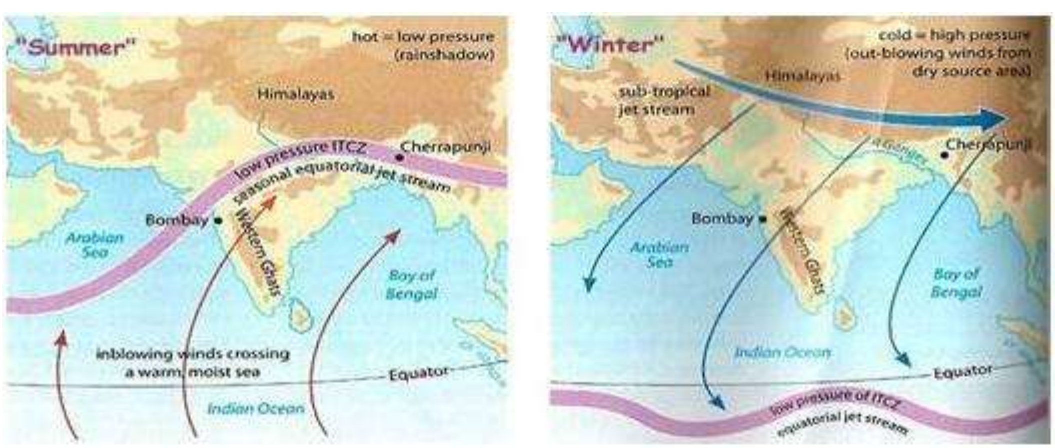


Figure 94: Monsoon types and how it affects Chennai. Source- Chennai Met department.

Chennai is located on Eastern Ghats. Tamil Nadu gets most of its rain in winter from NE monsoons between October and December. In summer, SW monsoons that originate in the Arabian Sea cause heavy rains in the Western coast. However, due to the lack of relief features such as mountains etc in Tamil Nadu, the winds have less moisture by the time it reaches Eastern Ghats, thereby, minimizing rainfall in Chennai during summers. However, in winter, the retreating monsoons build high pressure on the mainland and low pressure in the Indian Ocean due to wind direction from land to sea. These dry winds cross Bay of Bengal and pick moisture while crossing Bay of Bengal and cause rains.

Even though Tamil Nadu lacks relief features in the form of mountains, It does have water bodies along the coast due to rivers from adjoining states having meandering courses discharging into the sea at Chennai.Coastal water bodies such as Sunderban forests(NE) and Pulicat lake ,north of Chennai and Odiyur lagoon and Point Calimere further South of Chennai help form rain bearing clouds in East coast as the NE monsoons pass over them as well.

Hazard Vulnerability of Chennai city:

Chennai city lies in an area of moderate damage in the event of an earthquake and lies in the cyclone prone area where wind speed would be greater that 50m/s.

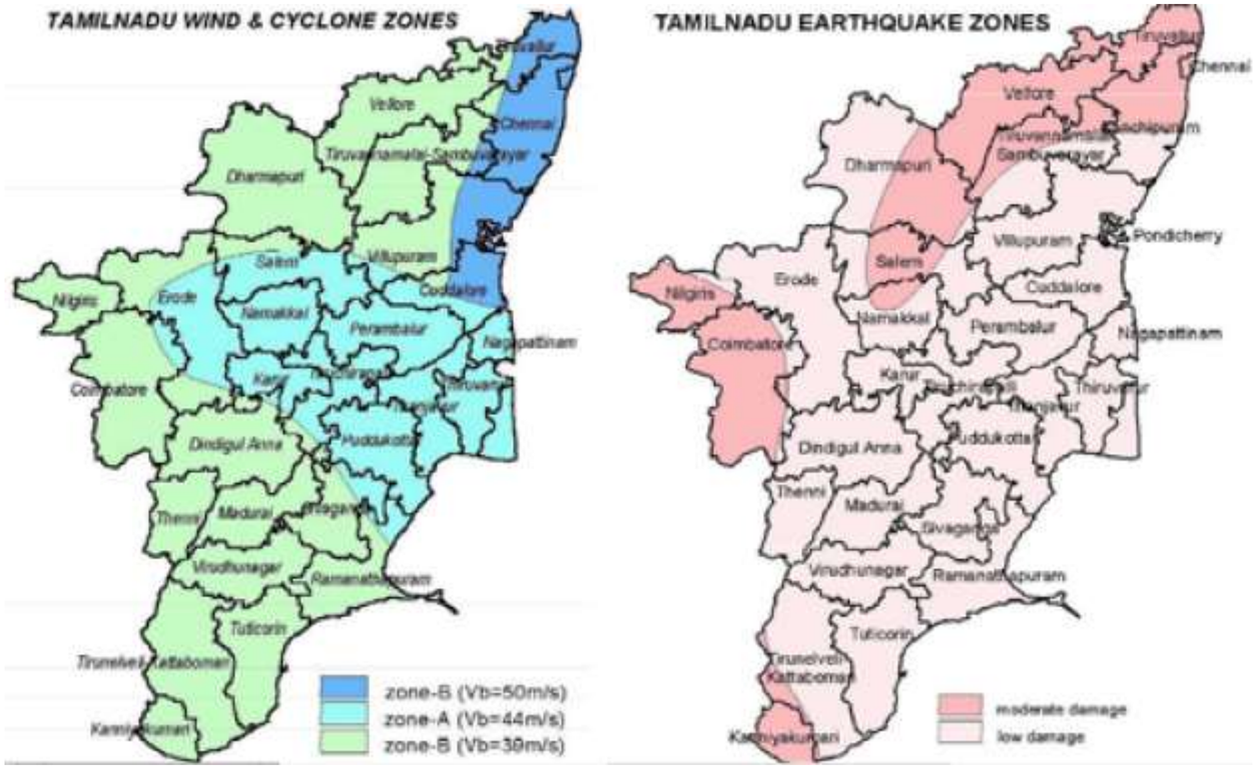


Figure 95: Hazard Vulnerability of Chennai city. Map source: CMDA

The Chennai Metropolitan area (CMA) for a distance of 20m inwards measured from the coastline is also prone to extensive flooding as shown in figure below. The floods can be in the form of storm surges or cyclones.

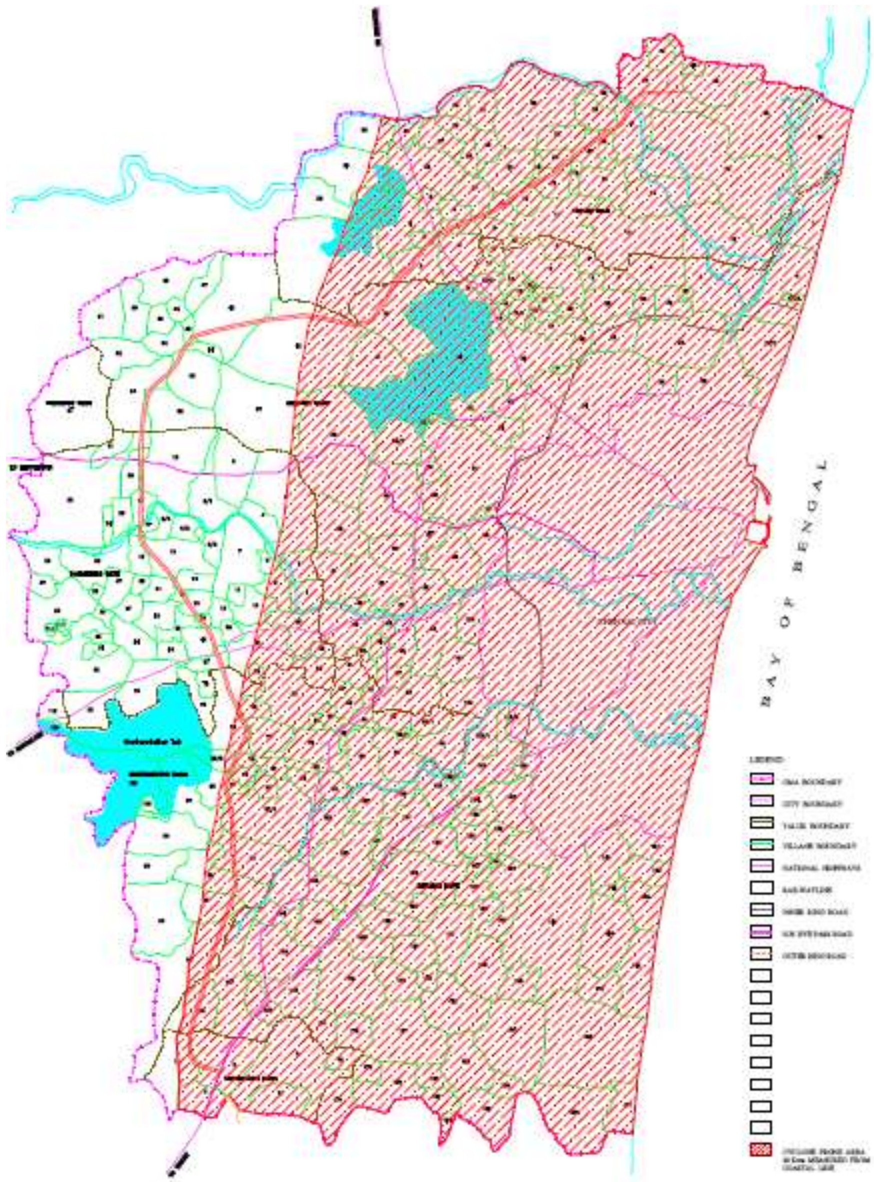


Figure 96: Inland Cyclone affected areas. Map source: CMDA

The river systems act as inundation corridors to storm surges from sea and allow water to be carried upstream upto long distances thus flooding the areas proximal to the river banks. Tidal backflows bring water into the rivers rather than getting released into the sea.

5.3 Survey and Interview

Survey Results

Most respondents interviewed felt that the main problems faced by them are water shortage and flooding. More than half the respondents felt that the government failed to recognize the importance of lakes and ponds in preventing water shortage.

Connecting rain water collections to lakes and ponds through manmade lines was cited as an innovative way by some engineers for dealing with the problem of flooding in the city. They felt this would successfully divert the excess water stagnant in any particular area to a series of interconnected lakes and channels, thereby not only mitigating floods but solving the problem of water distribution to various areas of the city that they were unable to supply water to.

Another concern raised by a significant number of respondents was the issue of garbage disposal in Chennai. They felt that large scale dumping of wastes into the lakes and ponds in the city has led to clogging of natural flow of water and reduction in capacity of the water bodies, thereby making them more vulnerable to flooding during heavy rains.

Effective waste disposal systems and recycling mechanisms were suggested as effective solutions to fight the water problem. Employing local people to collect waste, recycle paper and plastic and their appropriate disposal will solve multiple problems at various levels. Proper waste disposal will protect the water bodies, at the same time providing employment opportunities to the community. A significant reduction in pressure on natural resources like trees would also be ensured if materials like paper are recycled are appropriately.

An example cited was the community around the Vellore Golden temple which employed the local women in the area for waste management from the temple. This not only saved the water bodies around the temple, but also provided ample employment opportunities for a community of around 150 women, where much of the male population are alcoholics and unemployed.

A novel approach suggested by one of the respondents was to create water bodies called "lake ponds". These are water bodies combining the advantages of both lakes and ponds. Lakes are by definition over land surface whereas ponds are dug into the earth. If both are combined, the reservoir capacity would be almost tripled and this would partially solve the water storage problem.

Summary of data from Focus group interview

Sabari Green- Neernilagal nilavaram- 28th jan 2017

Chola dynasty constructed may lakes and tanks in the city. Ponds were used for general purposes while Oorani's were used to store drinking water. After 1960's there has been neglect to protect lakes and water bodies. Government didn't take serious actions. This led to systematic encroachments, lack of funds and responsibility due to distribution of water bodies to Individuals, Industries ,Army, Railways, Defence, environment, PWD, Fisheries ,Corporation and other departments within the government and also local level bodies such as Panchayats. PWD (Public works department) owns about 60% water bodies in Tamil Nadu with the remaining shared by the different stakeholder mentioned,

The city has expanded and people have settled in areas beyond Guindy in the past 2-3 decades. The city is flood as well as drought prone. Veeranam aeri supplied the city with water in 2001-16 without which there would be an intense shortage of water. It was vacated in 1940's due to a drought whereby people in the city had no water at all.

Inefficient storm water drains and partially used or lack of funds at municipality level has also led to mismanagement in water management in the city.

Disregard for lakes as storage areas for water. Muarasampet lake from which water went for agriculture had an 'ayacut' (a place where water is diverted for irrigation) .But for over 3 decades,due to decline in agricultural practice,this place was used for dumping garbage. Aadambakkam aeri which was about 20' in depth now has about 15000 houses built on it. Medavakkam High road was a part of Alandur lake.(Encrochments have taken place from all segments of society). 2.4 acre Maamkulam lake owned by PWD is encroached by Iron scrap workers on one part. This encroachment is politically motivated and hard to be controlled.

The Perungudi marsh has about 330 acres of garbage dump. Between the stretches of Perumbakkam and Medavakkam, most encroachments are Government buildings that have come up on sensitive marshlands.192 lakes drained into the marsh but due to lack of maintenance and encroachment from inside towards the outside, these areas for water to flow into the marsh were cut off.

Velacheri aeri was about 265 acres,of which; 165 acres was given to Tamil nadu housing board (TNHB).

Indentified reasons for contamination of water bodies-

Authorities initially didn’t designate areas for ground water preservation or recharge, garbage was dumped in marshes and near water bodies- all leading to contamination.

Underground sewerage project which was funded by World Bank at Alandur became a model for other municipalities but was hardly implemented by others. Thus improper drainage also flows into the water systems in places.

People living along the Cooum in slums were moved to city outskirts Kannagi Nagar etc but this was futile as they were day labourers who worked small jobs in the city and the travel was not a sensible option for them, so they often returned.

Ground water was completely disregarded when garbage was dumped into important water drain and recharge areas.

Lack of Coordination between stakeholders and even between people working for the same cause (NGO’S) for recognition purposes.

Chennai has over 200 wards and 6 zones. Metro water however supplied only 40% of the city’s water supply.

Summary of Results from the Section:

1. Planning doesn’t recognize long term issues with encroachment of water bodies. Sometimes, political interventions hamper any regulation in this direction.

2. Extensive intervention politics by the politicians.

3. Lack of coordination amongst stakeholders who work for the same case due the need for recognition more than the cause itself..

4. Inadequate storm water drains and lack of a regional water plan

5. Excess concrete and impervious surfaces in houses compared to the past.

6. Real estate sometimes, in order to make profit, constructs beyond limits and prefers paying fines for regularization.

7. Money from World Bank, Central government etc are misused and not adequately spent. Widespread corruption also leads to blockage of proposed interventions.

8. Waste sorting not done at individual/community level. Lack of any scientific waste sorting at all. Waste is just dumped in dumping grounds and often burned.

9. Lack of public awareness

10. Transport infrastructure lies on the water infrastructure completely disregarding its' presence. Eg: The MRTS on Buckingham canal.

11. Lack of jobs- Encroachers are moved to city outskirts while most of them work for meager daily wages within city ,making the commute and the option of living on the outskirts unviable, forcing them to return.

12. CMRL is built almost entirely on roads while there was no prior plan for this. The roads were not designed to cater to this.

13. Unchecked vehicularisation and increased demand for parking and impervious surfaces.

14. Lack of reliance on renewable sources of energy.-for eg: Power can be generated from sea due to strong currents.

15. Disregard for protection of finite ground and surface water.

16. Active and more expensive desalination processes rather than replenishing existing water sources.

17. No consideration for floods and subsequent droughts-As water is allowed to run off and not stored or recharged.

18. Dispose of garbage and other waste in water bodies and rivers.

19. Lack of segregation of waste water and rain water outflow from city. These often get mixed and flow down rivers sue to discharge from Sewage treatment plants.(STP).

20. No mandatory water conservation techniques such as gated communities, apartments, houses in neighborhood etc to have water storage ponds/tanks etc.

21. Neighborhoods on water flow chanels - Interconnecting of canal, lakes and rivers will ensure that water has a place to flow to rather than flooding neighborhoods that have blocked existing flow networks.

22. Areas where the water bodies have been connected eg- Kosasthalayar and Cooum river traditionally flooded less than the Adyar river where water bodies are not connected.

23. Kosasthalayar basin(Thiruvallur and Arani districts) , Adyar-Palar basin in Kanchipuram district etc have 1000's of small lakes and ponds that are not connected to the water bodies.

24. Originally water flow was from streams to rivers and then discharged into the sea. This system is disrupted. There was a ancient system of water flows in tamil literature.

25. The main rivers that carry water don't have adequate check dams to prevent erosion. Indigenous check dams cost a fraction of a cost as compared to the expensive counterparts. But even this is not being implemented.

26. Palar river that runs 420 km in Andhra Pradesh and remaining 140km in Tamil Nadu has more than 40 check dams in AP while hardly any in TN.

27. Illegal practices -Sand Mafia steals precious river and lake sand which can be sold with very high profits in neighboring states. Thus there is a hidden agenda behind rivers and lakes not being revived.

28. Absolute disregard for water resources- Tamil Nadu is water scarce and landlocked with Tamaraparani being the only lake originating in TN. Even then upto 250 TMC is wasted every year from Tamaraparani.

CHAPTER 6- RESULTS & DISCUSSION

6.1 Identified Macro level Causes and location of floods in Chennai city

Flood Location	Type of Flood	Causes and Intensity of the flood	Other problems	Solutions/key features identified	Applicability , Scale of Intervention – Community /govt/ combined
Sea	Coastal	Cyclones, Storm Surges, Tidal flooding, Tidal backflows that run through the rivers and affect main city	Sea level rise, Coastal erosion in North towards Ennore, Formation of sandbars at Ennore creek, Coastal accretion along Adyar and Cooum river mouths.	Sea level rise cannot be entirely prevented but Sea level rise plans need to be in place from the Government along with evacuation plans. Coastal erosion can be reduced by ecological interventions Coastal accretion will add more land.But river mouths need periodic cleaning to make sure water discharge isn't affected.	Long term sustainable solution would require coastal settlers, governments, NGO's and other stake holders to hold transparent and inclusive meetings to devise a plan. Real estate needs a regulation as well.
Canal	Storm surge	Acts as a barrier between Sea and Land as an inland waterway Storm Surge/Tsunami, excess rainfall	Prevention of discharge of water safely due to plastics and other garbage and untreated sewage effluents makes it difficult to connect to other water bodies.	Canal needs to be cleaned and its boundaries need to be protected and connected to other ecological infrastructure at the coast so that it can act as a park for residents. Methods such as bioremediation can help clean the canal as well.	Combined intervention will be the only sustainable solution as it gives ownership and distribution of work load to citizens and Government alike. Public-private partnerships PPP can also be promoted, though there should be a policy that prevents any vested interests.
Lakes	Pluvial	Stores excess water But also contains garbage and encroachments that have led to loss of complete lakes	Filling up of lakes to build properties, lack of maintenance. Dumping of Industrial waste.	These water bodies can be cleaned with ecological interventions and a new life can be given to it.	Lakes and tanks along with other water bodies should lose individual ownership and should be given to individual

		or parts of it.			neighborhood groups – Governo –Citizen groups comprised of a body of governmental, Go and residents of the locality
Tanks	Pluvial	Storage of rain water	Contamination of water making it unfit for use.	Once cleaned ,tanks and lakes can connect and store excess water during a reservoir discharge situation or	Governo –Citizen groups .But local neighborhoods should stop their contaminants from entering the tanks and lakes.
River	Riverine	Superfluous sudden discharge from reservoirs upstream causes flood downstream while flowing to the Sea. To make it worse, Tidal backflows that push water back from draining into the sea flood neighborhood along the river and as far as the water can reach. Back flows from the rivers also meet the travel metro rail corridors and pass through them as well.	Contaminated rivers even though they carry water from the very source that supplies the city's entire water supply.	There is a need to have alternate plans for the river to discharge into the sea other than just Adyar and Cooum rivers. There should be a plan to arrest water upstream by connecting to the innumerous tanks and lakes rather than just releasing into the river. Tidal backflows can be prevented by installing backflow preventers at the river discharge mouth into the sea. However banks of the river need to be protected from any are form of encroachment and should be made protected land. Policy intervention to make encroachment and waste dumping a punishable non bail able offence.	PPP to clean up the rivers and restore its lost significance. Governo –Citizen groups for policing the PPP.
Urban Agglomera tion	Urban floods , inundation ,	Storm water drain networks need to be strengthened and even supplemented at neighborhood and zone levels and should consider a		Disregard for natural drain is glaringly evident throughout the city with loss of lakes, tanks, rivers, wetlands and marshes. An immediate intervention needs to unite stakeholders and policy interventions, court orders for eviction as well as	PPP for storm water infrastructure throughout city

		water master plan for the whole city at a macro level and the 3 districts of Chennai,Thiruvallur and Kancheepuram at a regional level. Blocking areas of natural water flow have led to neighborhoods getting flooded. The rail corridors underground also pose significant risk and may need to cut off access during floods.		Efforts to unite all water bodies under one non politically motivated body needs to be an immediate goal. Strengthening and supplementing storm water drains through parks, retention basins, marshes and other ecological interventions such as vertical gardens and greening of pavements and introduction of permeable roads and paving etc need to be introduced. Neighborhoods and houses need to be encouraged and forced to save rain water in overhead tanks and have permeable grounds, waffle gardens etc. Waffle gardens can also be promoted in areas adjoining the marsh to help restore the balance and retention capacity. In short, Chennai needs to become a Sponge city to soak up all the water that is being washed out in the form of run offs.	including permeable materials and Vertical gardens under MRTS and other areas.. Government needs to provide infrastructure to neighborhoods. There should also be Governo – Citizen groups that are supported by the government to create neighborhood water supply grids that will enforce a park and water storage facility for each neighborhood.
Slums	Pluvial, storm water, and Riverine,			These under privileged persons need to be rehabilitated within a 2km radius of their local jobs or new jobs need to be created for them in these proposal plans for maintenance of water bodies. They need to be empowered rather than just be relocated to city outskirts where they cannot sustain a living an hence they are forced to return.	Government and NGO’s + community

SUMMARY - At all levels, micro as well as macro- all stakeholders should be held accountable on monthly progress meetings.

The planning process needs to be transparent and involve citizens and end users. Pollution control needs to be enforced on all members of civic society, irrespective of background.

Planning of the systems need an effective non –egoistic approach from all stakeholders and team of experts who work towards a common goal rather than have splinter groups that refuse to unite for the need for recognition.

The entire process needs to be under a non politically influenced ,new wing of the government such as the collector or a

multi specialty group that comprises individuals from all disciplines working hand in hand over all levels, macro and micro, within the city, within the districts and region.

Table 14- Location,Type and Problems of flooding with proposed solutions. Source-Author

6.1.1 Application after Case Study Analysis

Selected case study	Context	Urban space	Implemented System(s)	Remarks
San Francisco bay area	Urbanization and loss of habitat	Bay area protection	Sea level rise	Ecological resilience
New Orleans	Dynamic systems including economy	Overall improvement of situation	Master plans and income generation plans	Overall resilience
New York waterfront	Mitigation-water front	Resilient Coast	storm surge protection	Coastal Resilience
Tybee islands	Community Resilience	Georgia's sea level rise plan	Coordination between stakeholders Sea level rise	Coastal and community Resilience
Netherlands	Adaptation	Intentionally flooding the city	Living with floods and enjoying it	Learning to adapt rather than prevent always
Jamaica Bay	Protect and restore coastal wetlands	Salt marshes	Protecting valuable ecology and training and educating people	Ecological engineering
Mexico	Vertical gardens	Highways and city wide	Protection from pollution as well as soaking up rain water along with imparting qualities of beauty in Urban environment	Ecological resilience and Landscape architecture.
Engineering solutions				
Singapore	Smart tunnel	Highways	Multi modal transport and the fact that storm surges flood tunnels.	
London	Thames barrier	River – sea interface	Can be closed to prevent storm water surge and tidal over flow. Helps discharge water safely from city.	
Netherlands	Oosterscheldekering Barrier	Sea /Storm surge	Protects from storm surges	
Japan	MAOUDC(Metropolitan Area Outer Underground Discharge Channel)	Roads and Infrastructure-City wide	Underground water storage in crowded heavy urbanized	

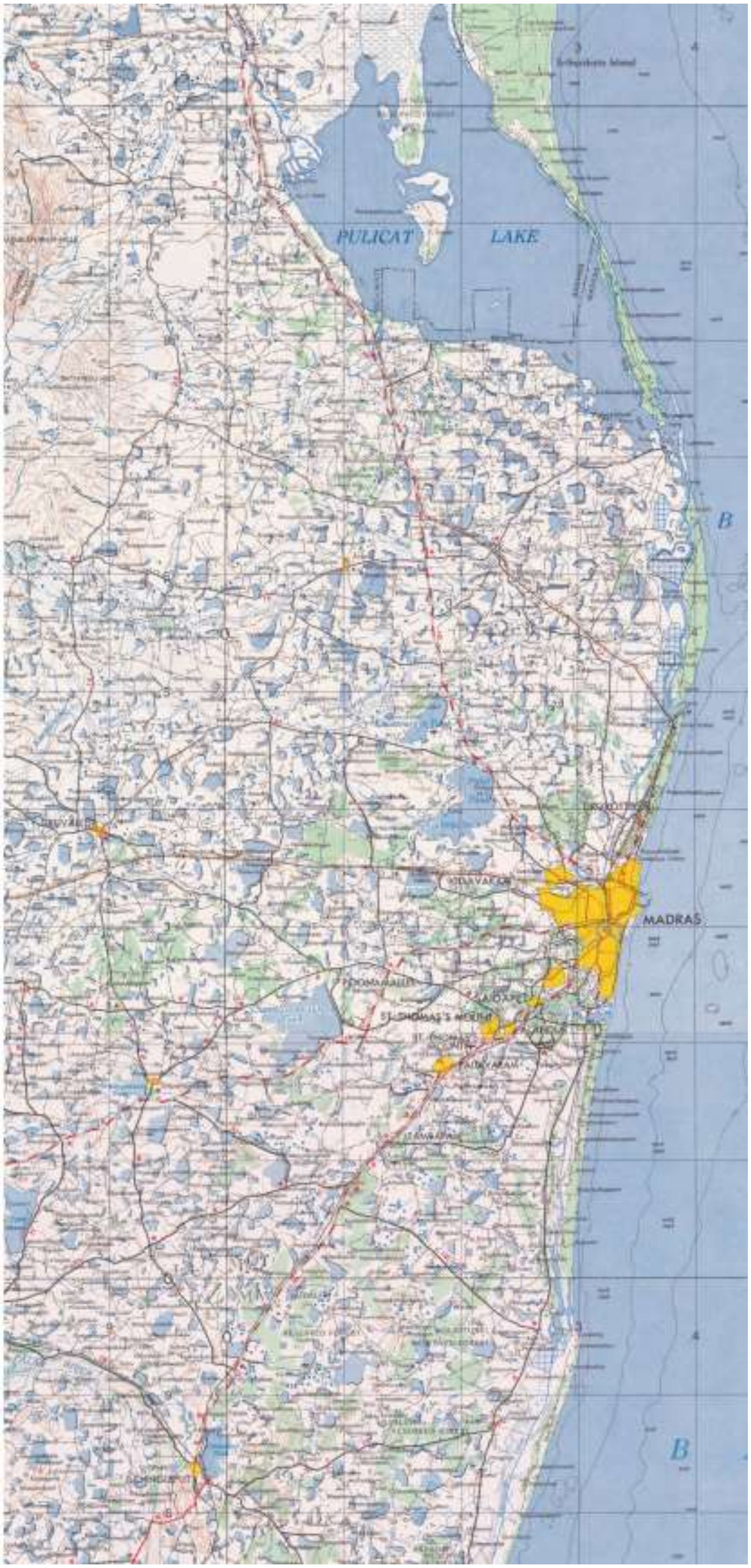
			cities	
Vernacular solutions				
India – Traditional Water storage systems	Tamil Nadu’s water harvesting system	All levels- regional, city wide and neighborhoods	Safe storage of water preventing floods and droughts alike.	Community Resilience + City wide resilience and water safety.
Chikwava,Mali	Resilient Vernacular Architecture	Housing and Neighborhood		Community Resilience
Sri lanka	Flood risk mitigation strategies for dwellings	Housing		Vernacular Resilience
Bangladesh	Flood risk mitigation strategies for dwellings	Housing		Vernacular Resilience
Urban Drainage Systems. SUDS- Sustainable Urban Drainage systems. (SUDS)	Creating ponds, wetlands, swales and basins to mimic natural drainage.	Bio drainage,Bio retention filters,rain gardens,retention basins	Make changes to unsatisfactory urban drainage approaches	Urban and Landscape Design strategies Learning to adapt rather than prevent always
WSUD - Water sensitive urban design.	The working principle involves thinking of water supply, waste water, surface water and flooding when designing rather than as an afterthought.	*i.* Protection and enhancement of natural water systems within urban developments. *ii.* Integrating treatment of storm water into the landscape. *iii.* Water quality protection *iv.* Minimizing run off through detaining water *v.* Reducing drainage infrastructure cost.	It aims to minimize the hydrological impacts of urban development on the surrounding environment.	
Sponge cities	This works by soaking rain water in different ways, ranging from permeable roads to rooftop gardens. Developing ponds, filtration pools and wetlands, as well as	It helps solve the dual problem of rapid urbanization and water scarcity in	Drought resilience	Urban and Landscape Design strategies

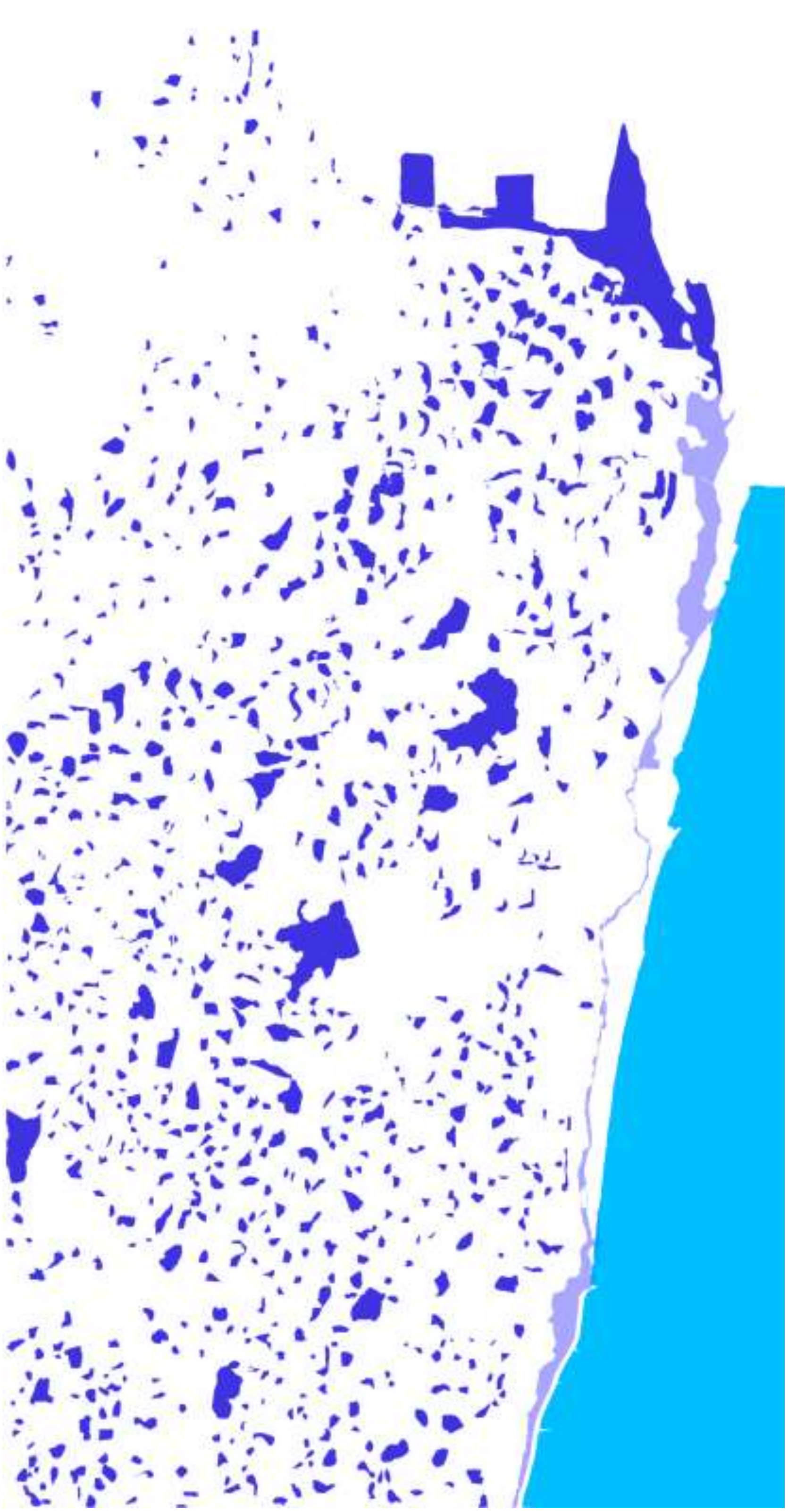
	construction of permeable roads and public spaces that enable storm water to seep underground.	cities through		
Floodable gardens, parks and buildings	Strand upon Green, London Adaptation	Resilient infrastructure.	Living with floods and enjoying it	Learning to adapt rather than prevent always
Waffle cities and waffle gardens	Prevents water from going from zone to zone by creating bunds as in the case of a waffle.	cheap alternative to minimize flooding	This is being considered in China, Los Angeles and other cities for flood prevention as well as water recharge.	
Green growth policy	Greening for economic benefits	Will work well in large scale projects	Can be implemented as enforcement upon industries and large scale developers.	Using powers responsibly and for the benefit of citizens.

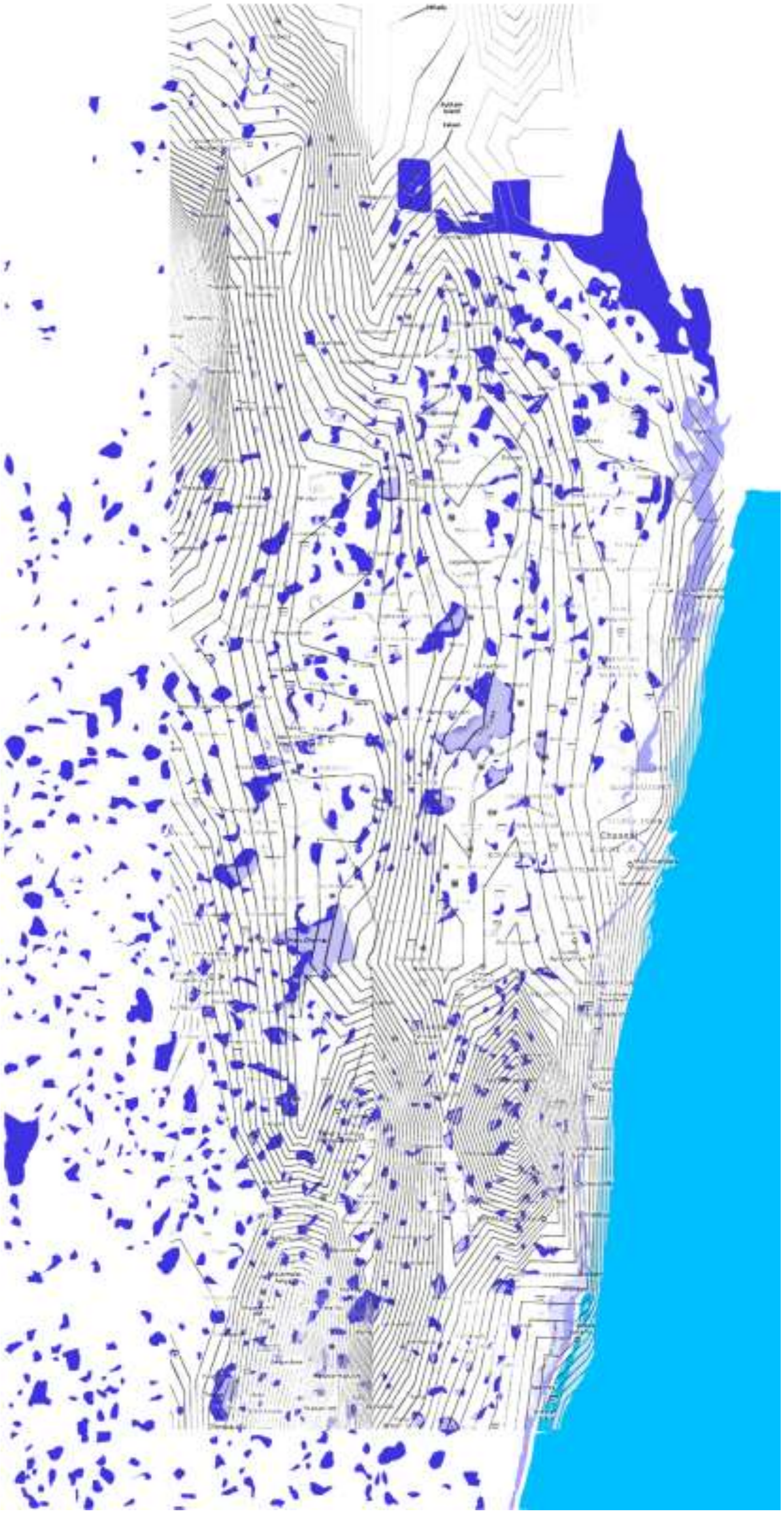
Table 15- Application of resilient solutions derived from Case studies at various identified macro locations in the city. Source- Author.

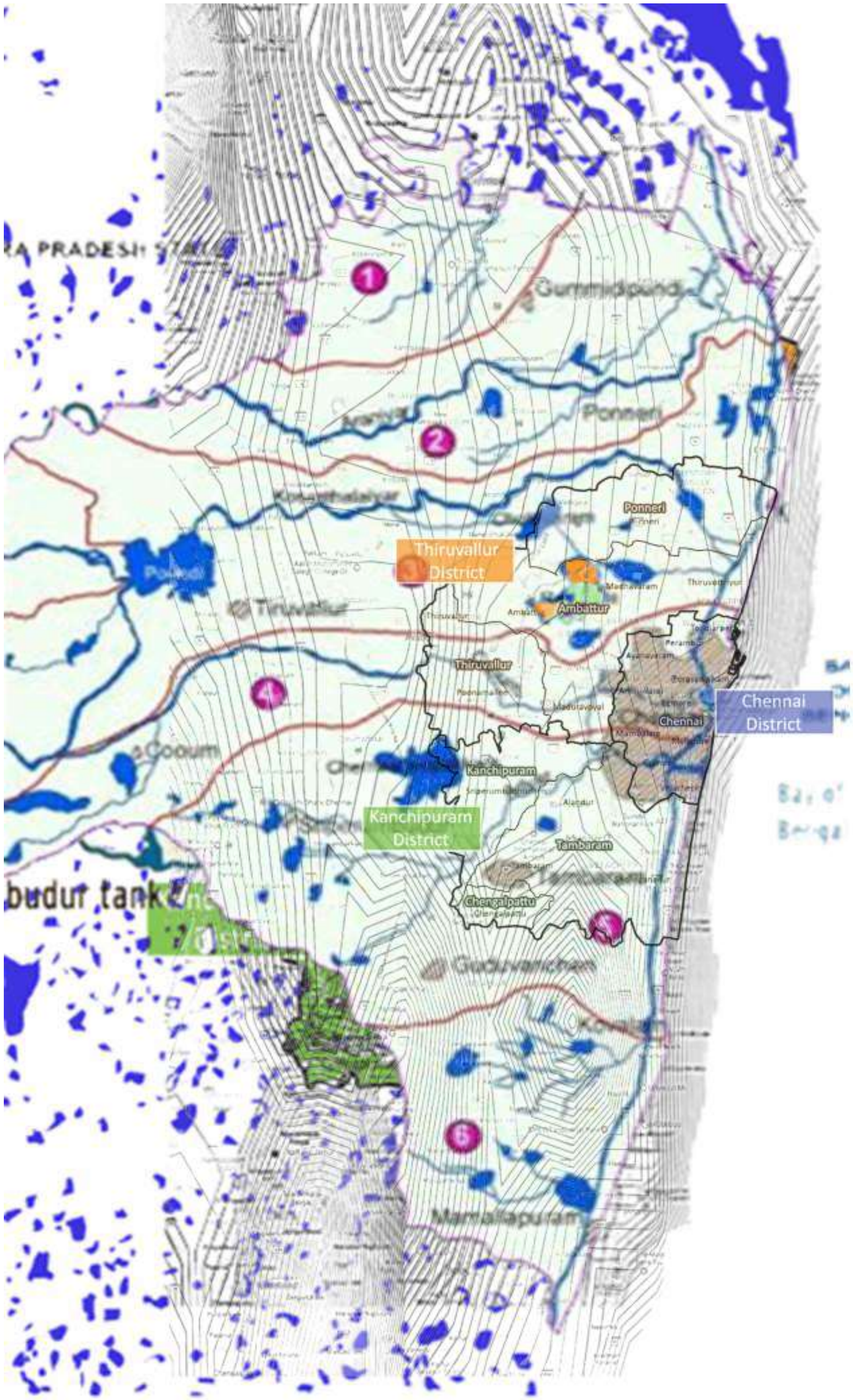
6.1.2 Portfolio of Maps

Analysis and Suggested Diagrammatic mapping of Intervention


PULICAT LAKE
MADRAS
B
B

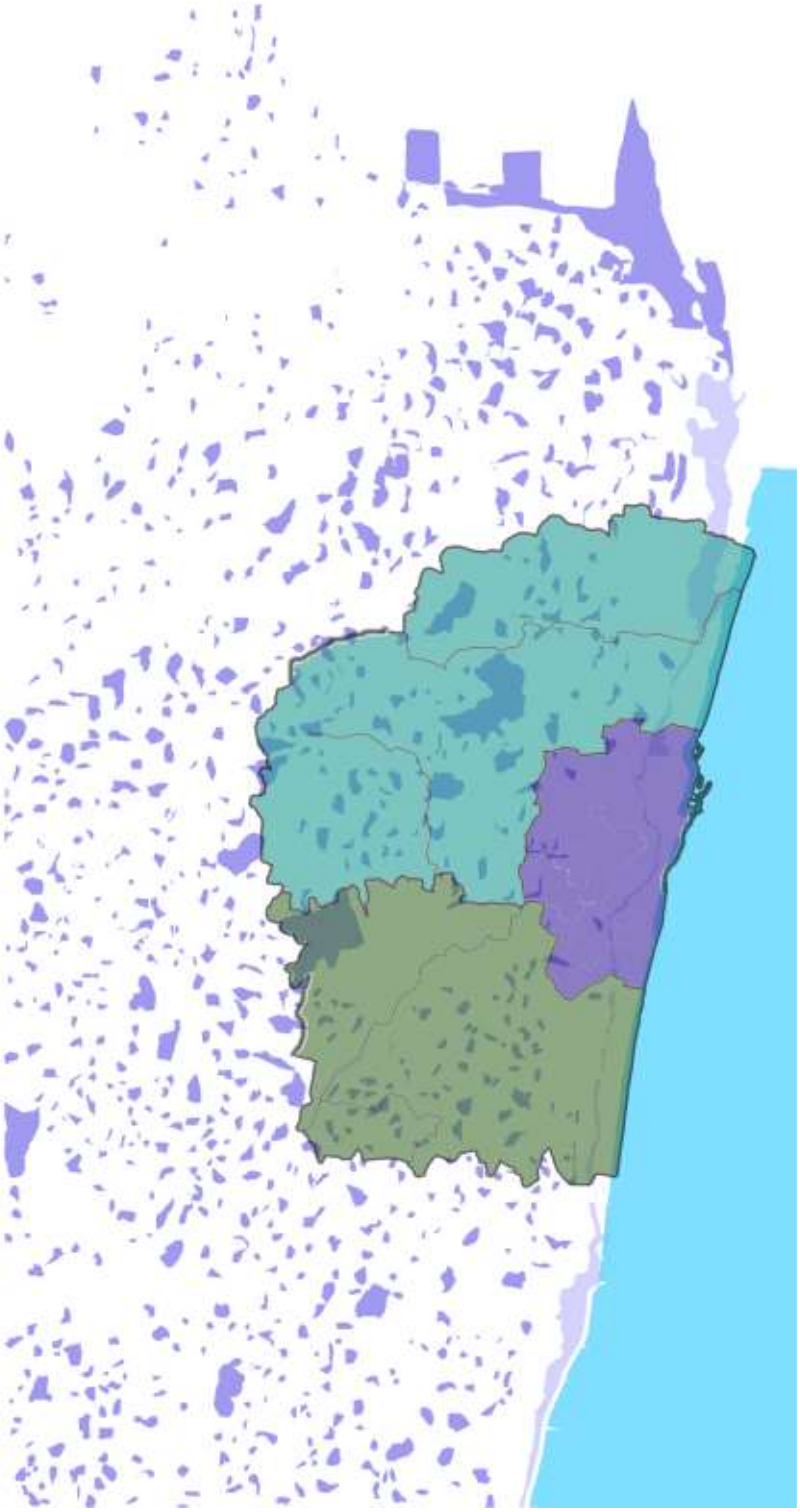




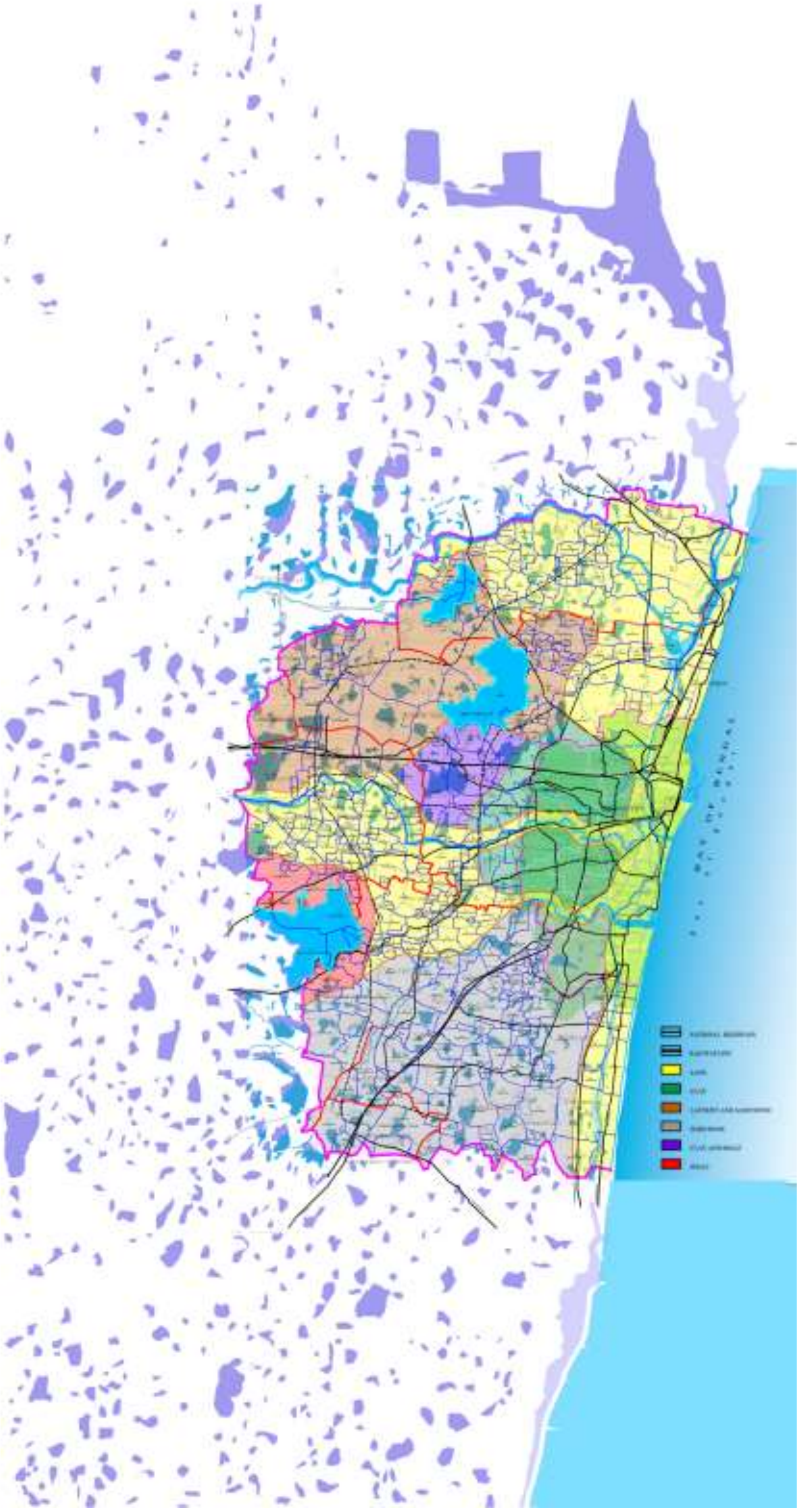


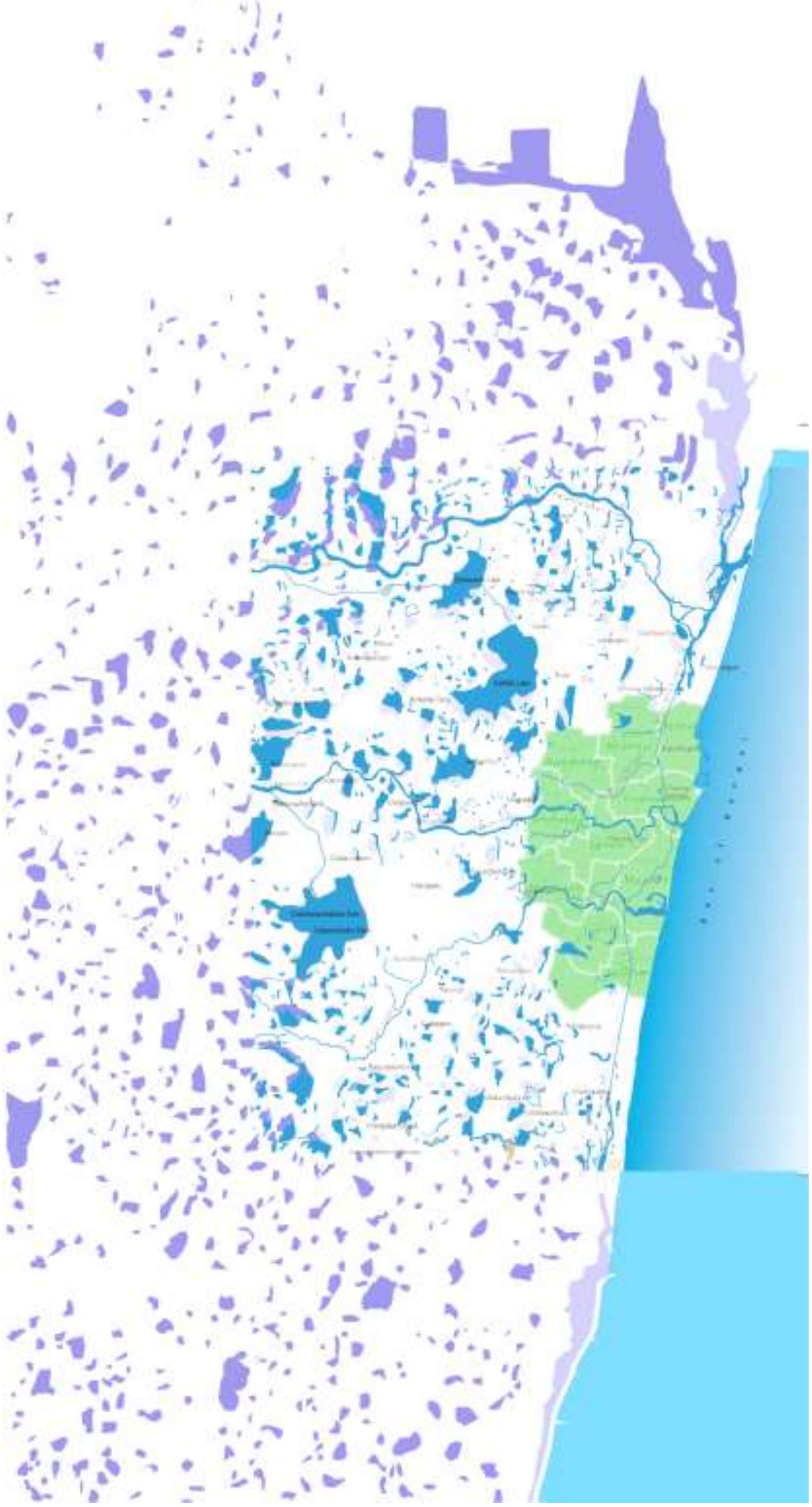
A PRADESH STATE
Gummidipundi
Ponneri
Kosasthalaiyur
Thiruvallur District
Ponneri
Ambattur
Thiruvallur
Chennai
Chennai District
Kanchipuram
Kanchipuram District
Tambaram
Chengalpattu
budur tank
Mamallapuram

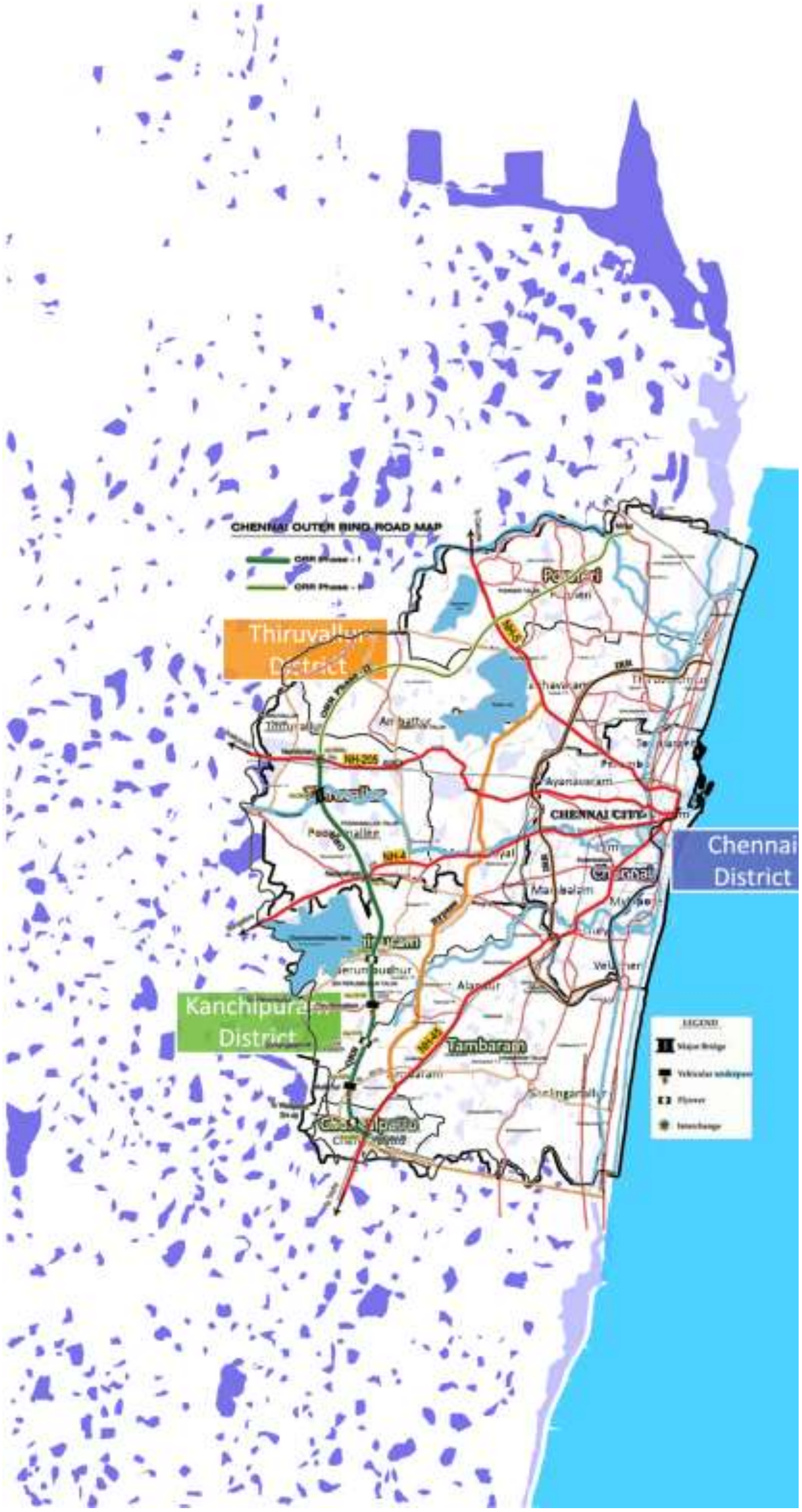
PANJETTY WELL FIELD
KANNIGAIPER WELL FIELD
FLOOD PLAINS WELL FIELDS
MINJUR WELL FEILD
CHOLAVARAM TANK
Ponneri
TAMARAPAKKAM WELL FEILD
District
POONDI WELL FEILD
Thiruvallur
Ambattur
REDHILLS RESERVOIR
Poonamallee
Kanchipuram District
Alandur
Tambaram
Shelinganallur
Chengalpattu



Ponneri
Thiruvallur District
Madhavaram
Thiruvottriyur
Thiruvallur
Ambattur
Ambattur
Tondiarpet
Perambur
Ayanavaram
Thiruvallur
Purasawalkam
Aminjikarai
Poonamallee
Egmore
Maduravoyal
Chennai District
Chennai
Mambalam
Mylapore
Guindy
Kanchipuram
Sriperumbudhur
Velacheri
Alandur
Kanchipuram District
Tambaram
Tambaram
Sholinganallur
Chengalpattu
Chengalpattu

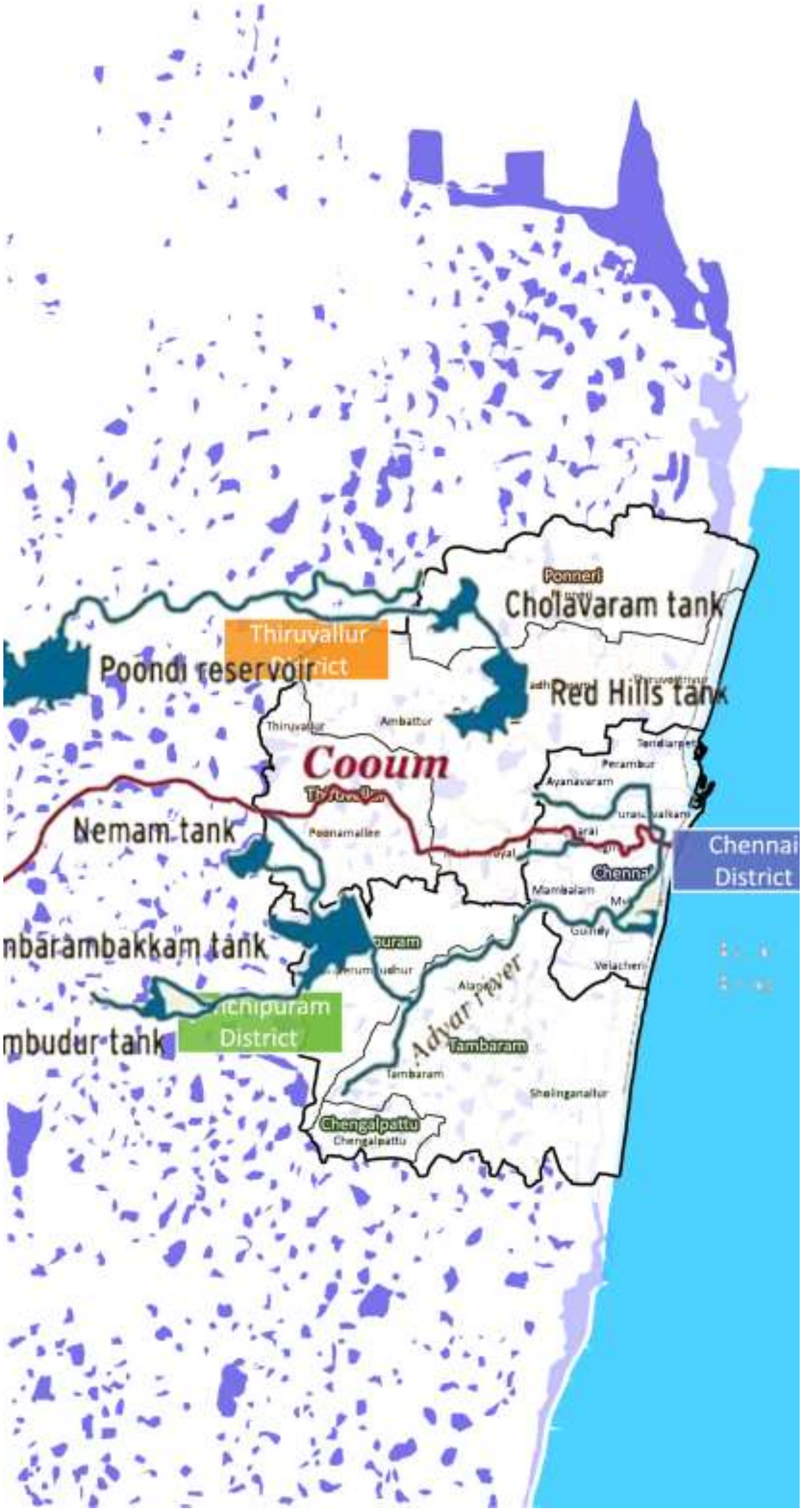




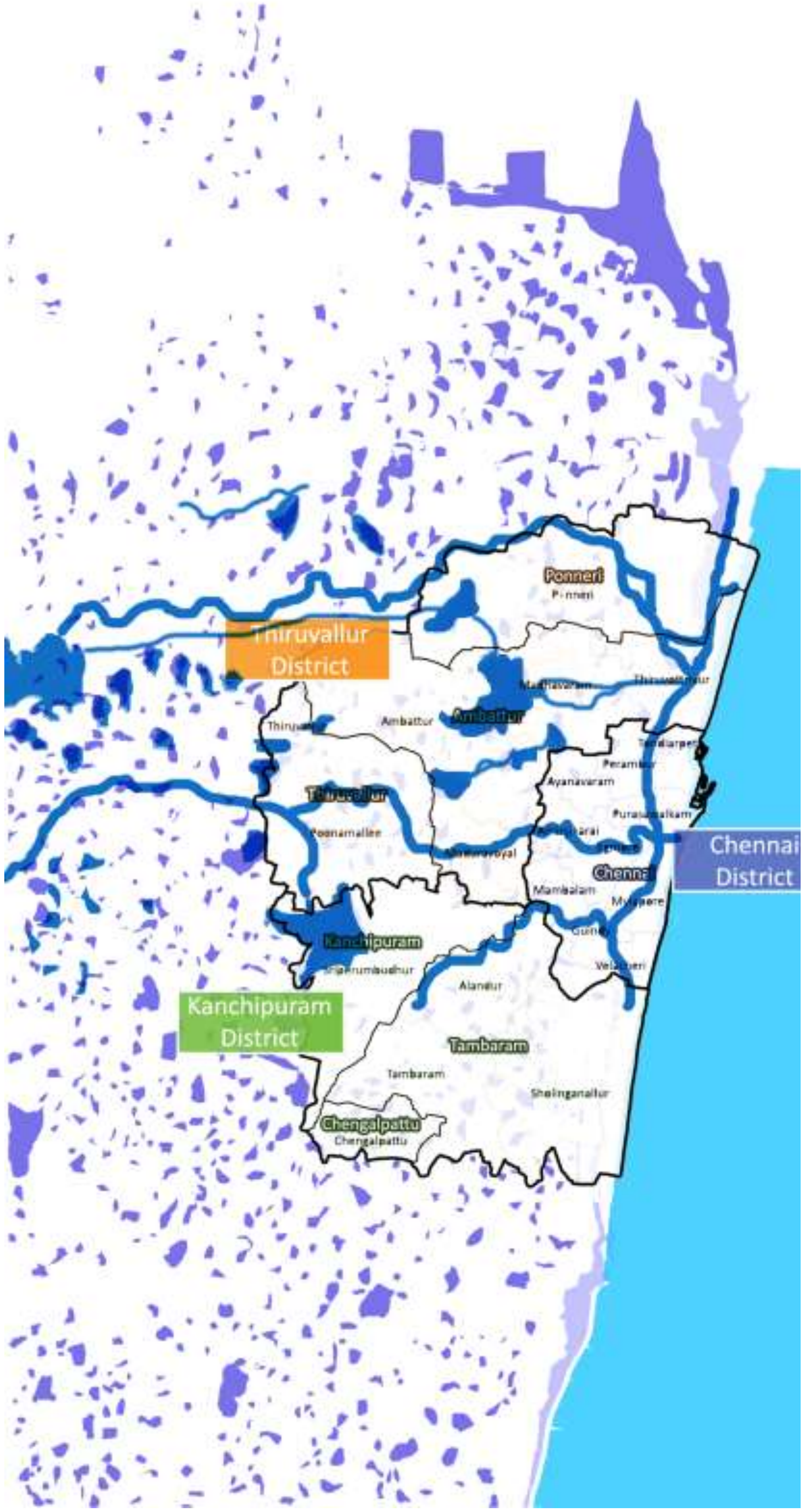


CHENNAI OUTER RING ROAD MAP
Thiruvallur District
Kanchipuram District
Chennai District
CHENNAI CITY
Tambaram
LEGEND

Water bodies and Road Networks in 2006



Ponneri
Cholavaram tank
Thiruvallur
Poondi reservoir
Red Hills tank
Thiruvallur
Ambattur
Cooum
Perambur
Ayanavaram
Poonamallee
Nemam tank
Chennai District
Mambalam
Guindy
Velachery
Advar river
Tambaram
Tambaram
Sholinganallur
Chengalpattu
Chengalpattu
District



Thiruvallur District
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Ambattur
Thiruvallur
Poonamallee
Chennai District
Chennai
Ayanavaram
Perambur
Mambalam
Mylapore
Guindy
Velachery
Kanchipuram
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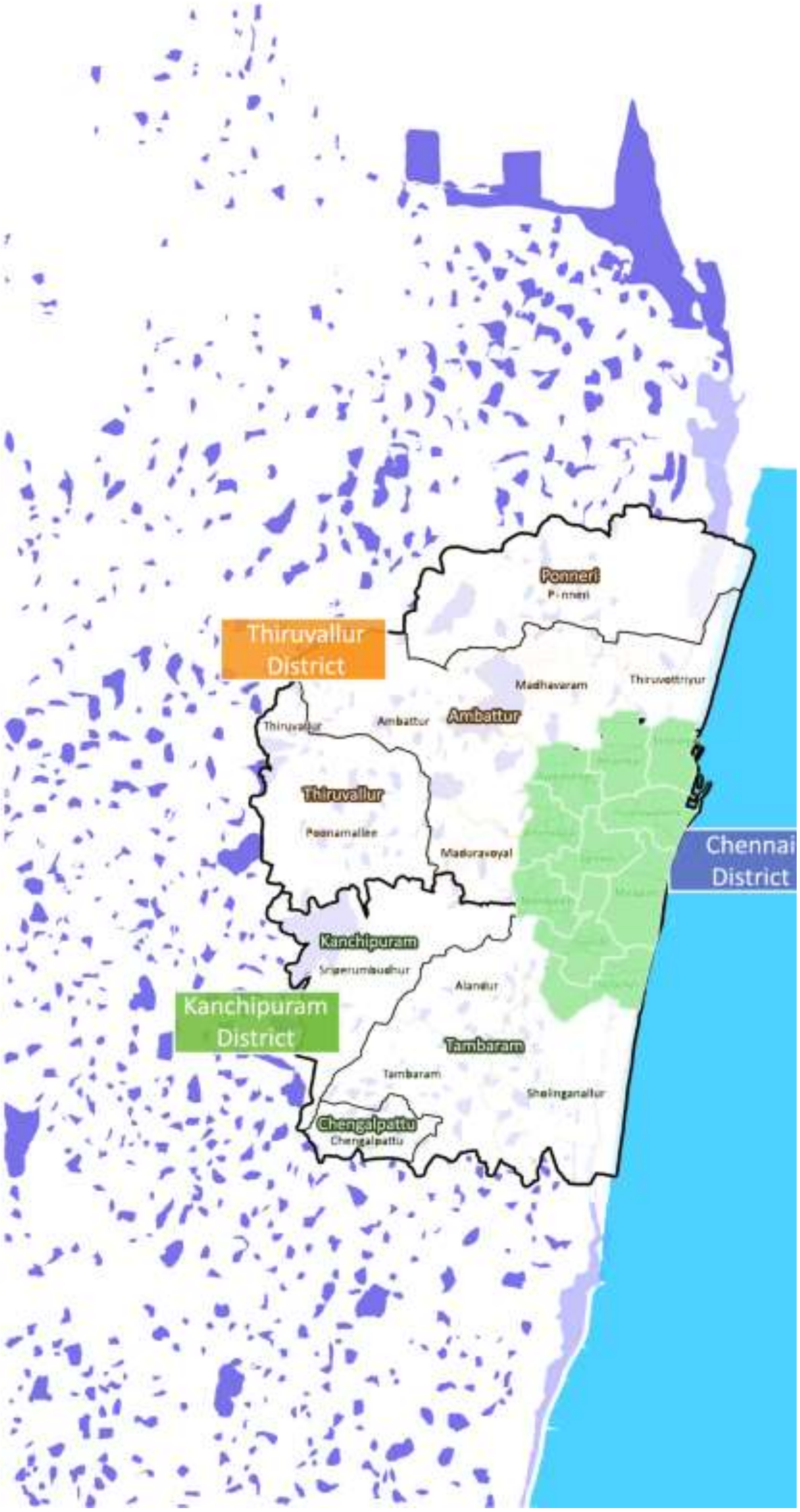
Alandur
Tambaram
Sholinganallur
Chengalpattu


THIRUVALLUR
CHENNAI
KANCHIPURAM



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Poonamallee
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Chennai District
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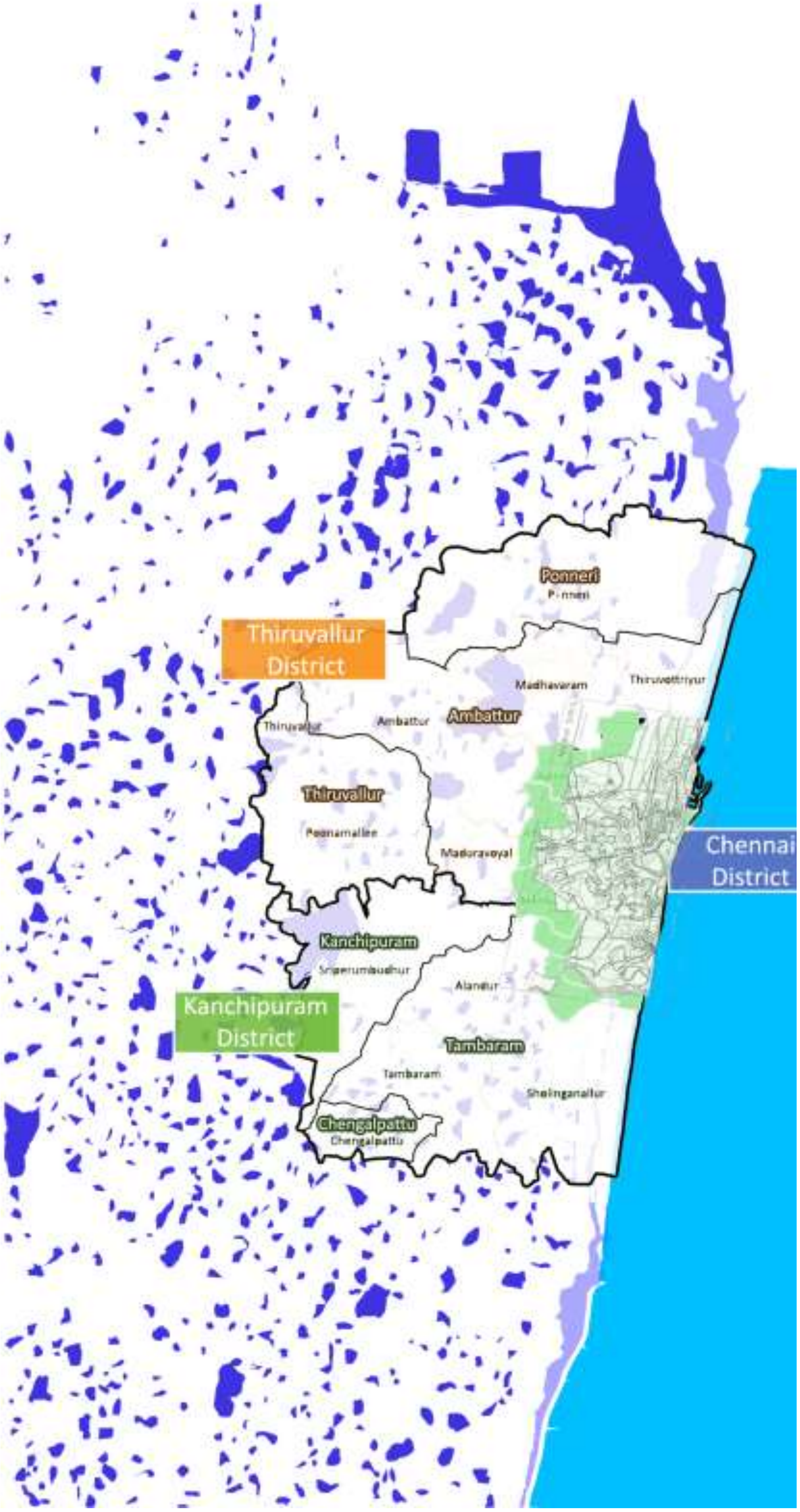
Ponneri
Thiruvallur District
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Sholinganallur
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Chengalpattu

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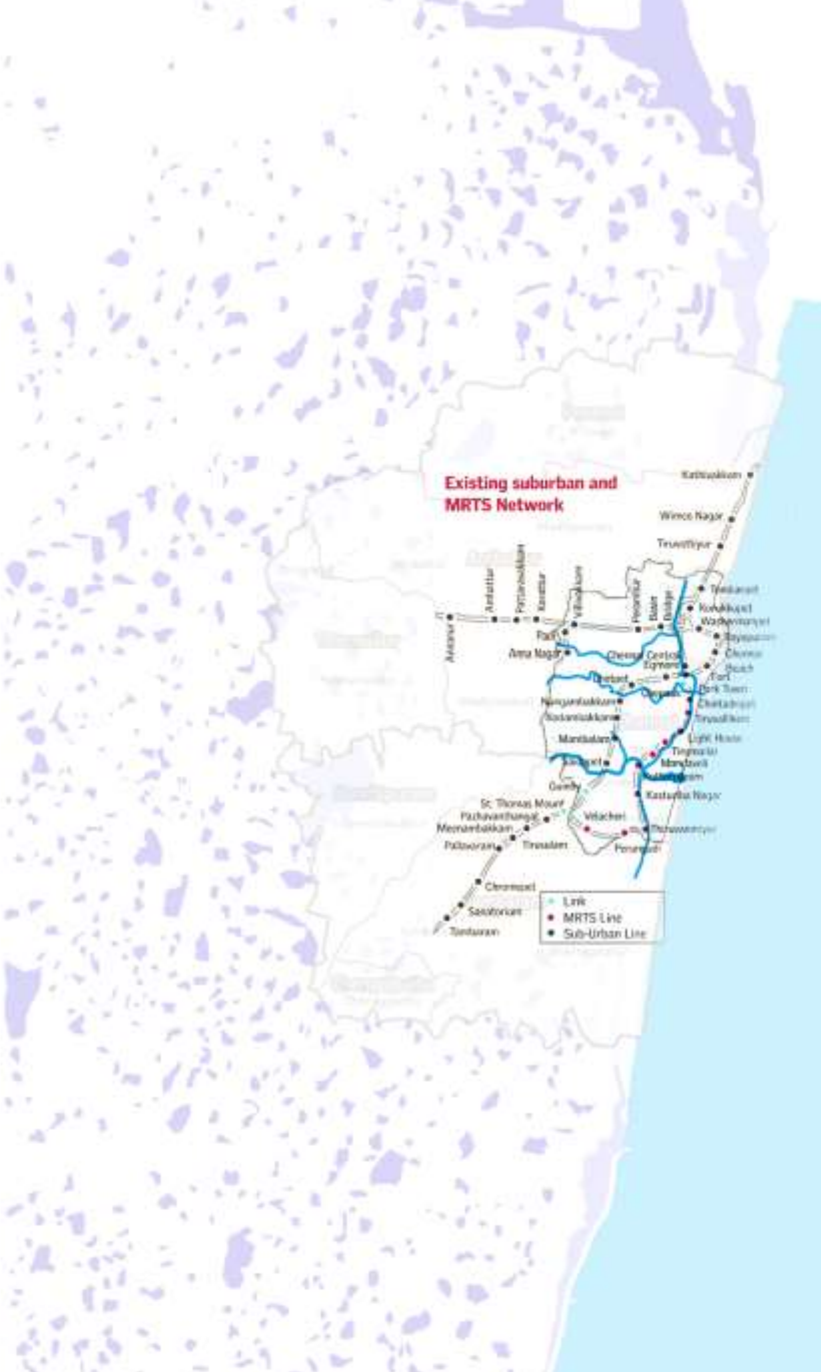
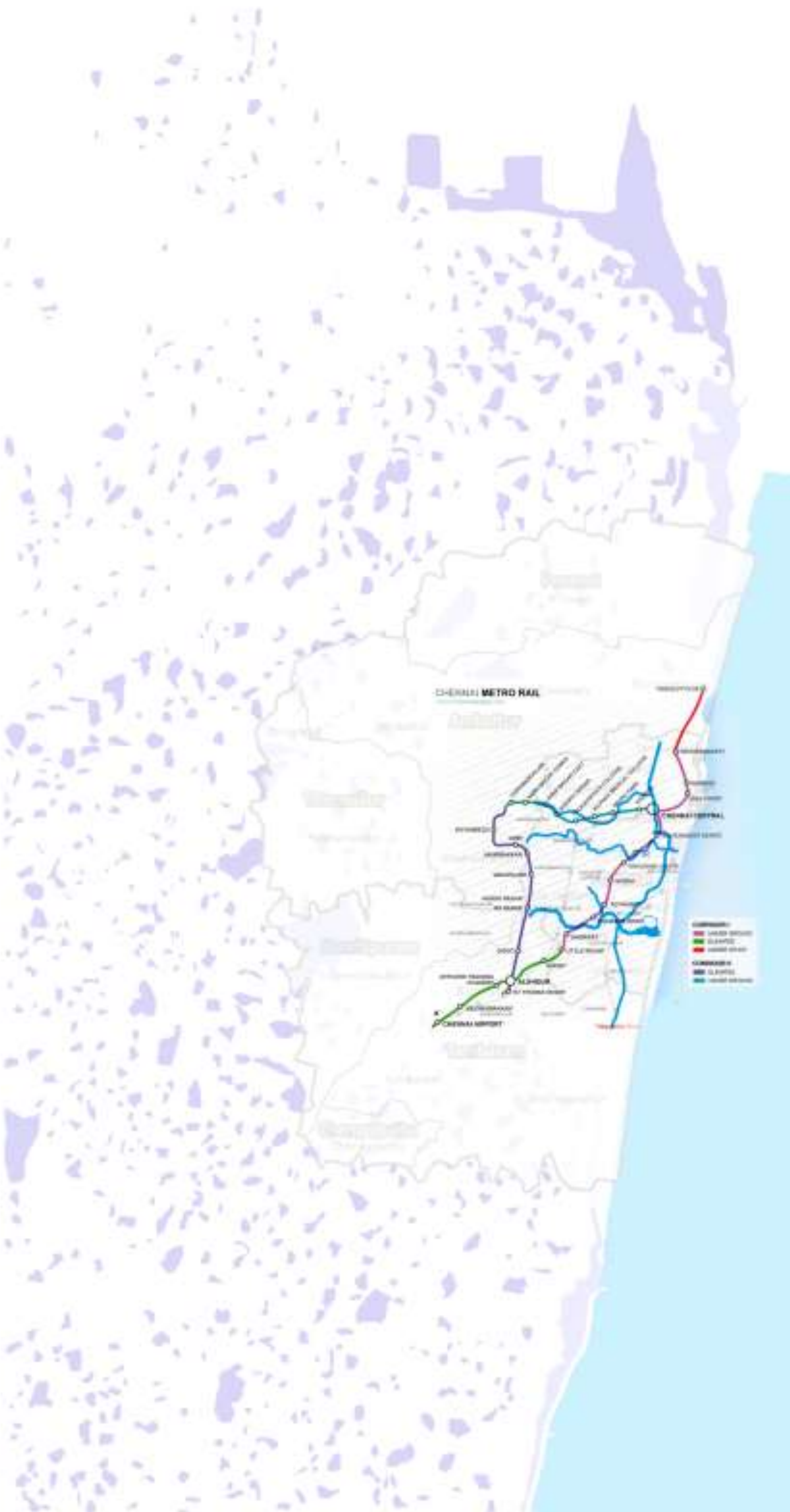
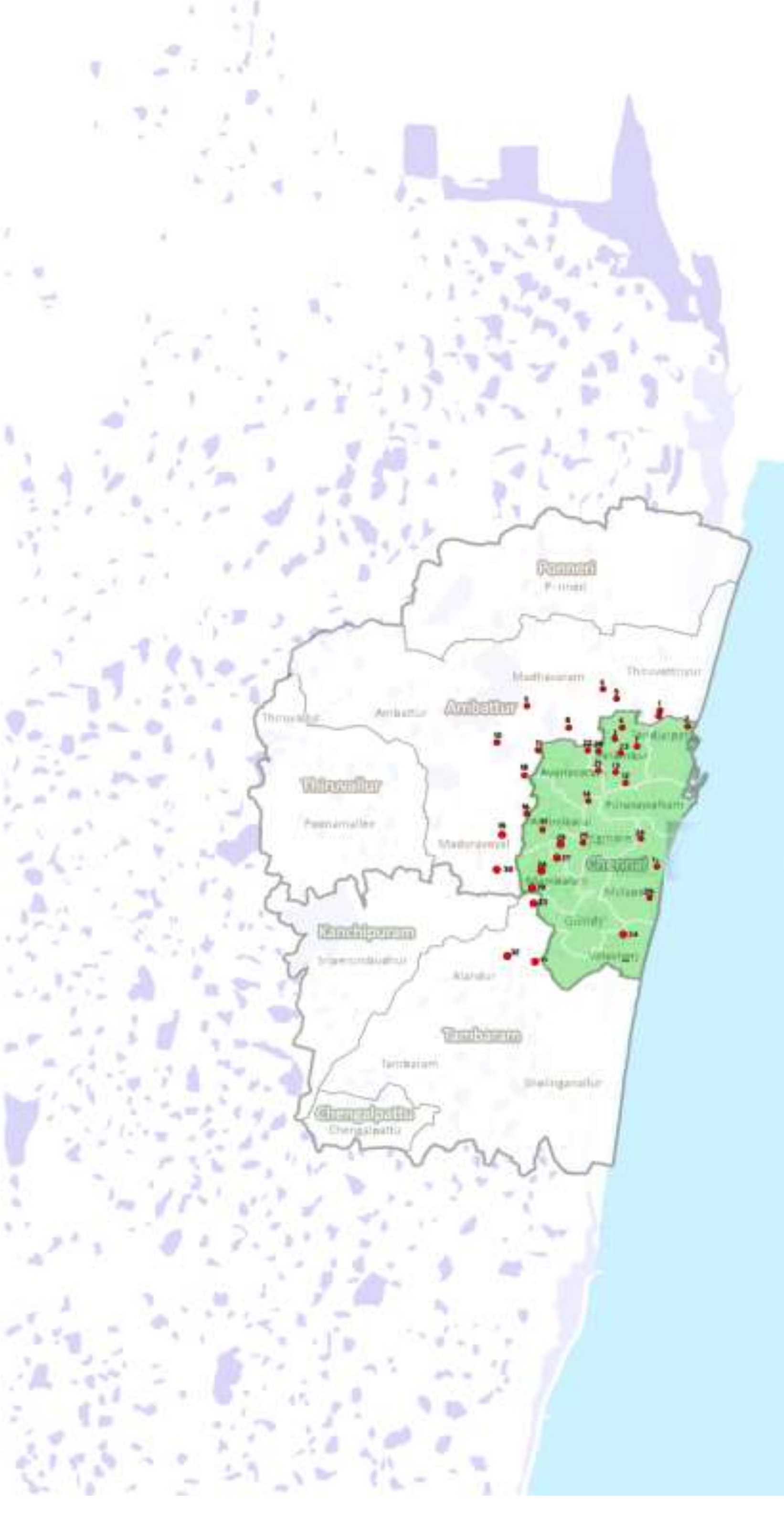

Existing suburban and MRTS Network
Wimco Nagar
Tiruvottiyur
Ambattur
Avadi
Anna Nagar
Light House
Tirusulam
Pallavaram
Chrompet
Tambaram
Velachery
St. Thomas Mount
Kasturba Nagar
Guindy
Link
MRTS Line
Sub-Urban Line


CHENNAI METRO RAIL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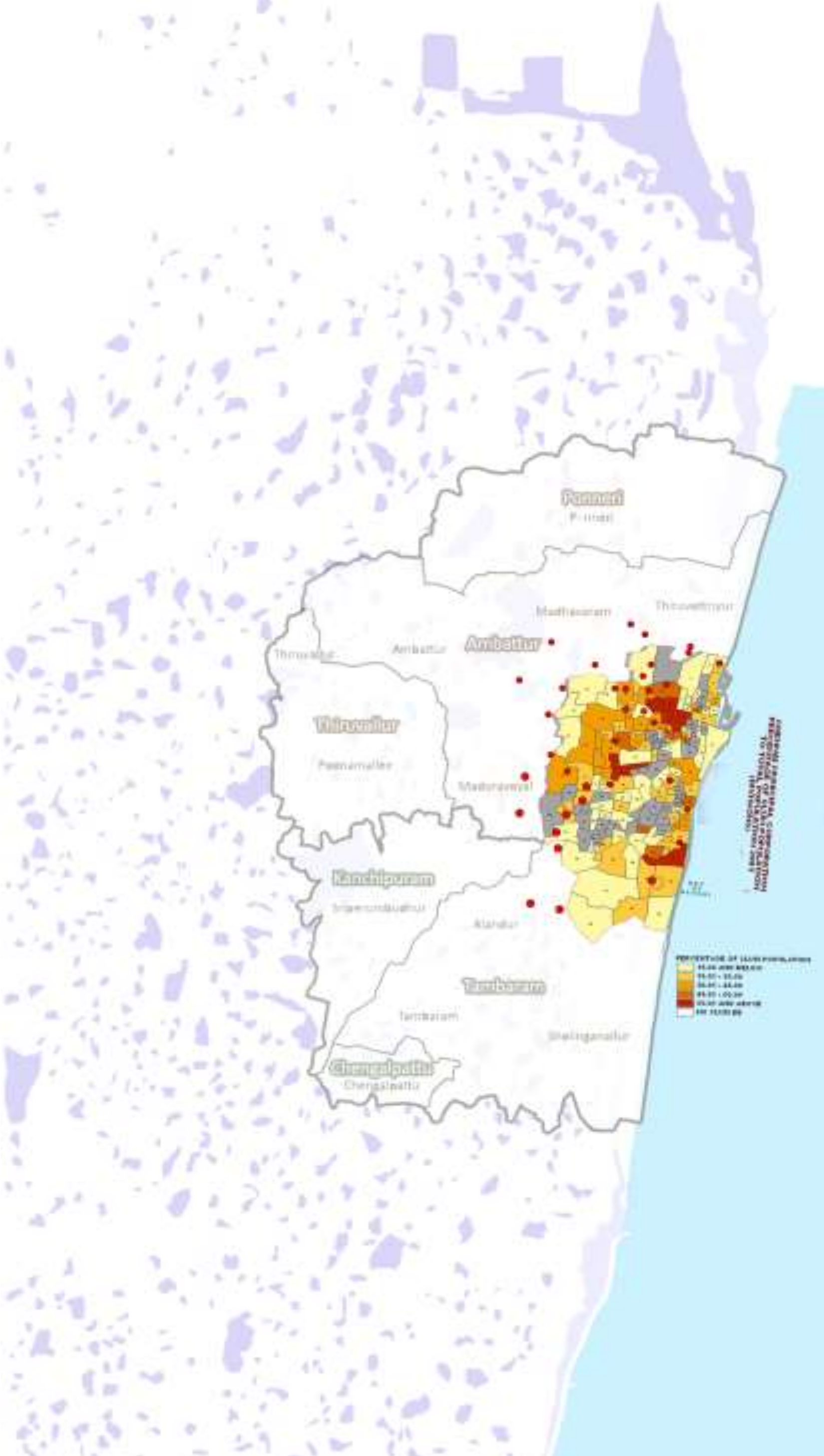
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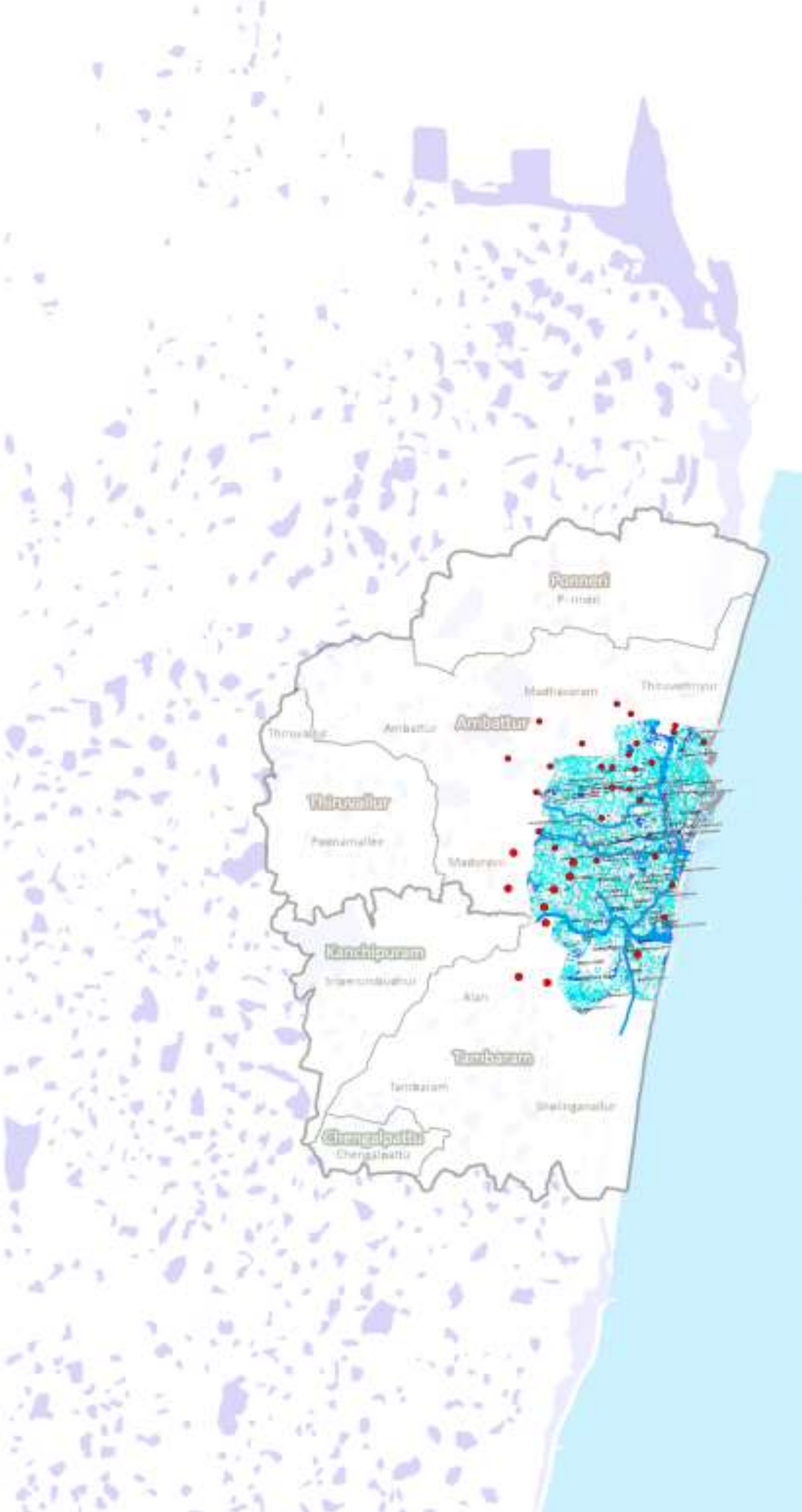
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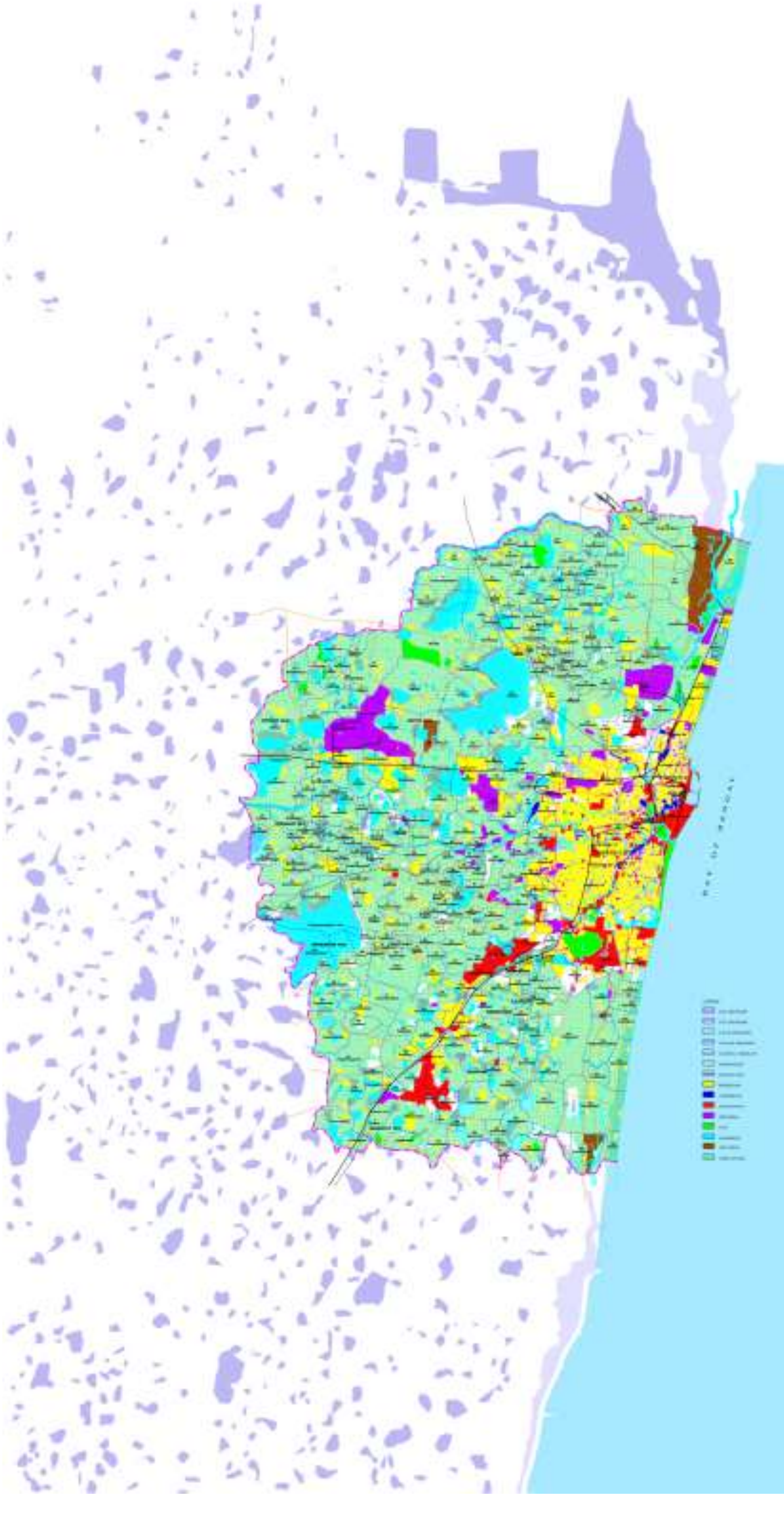
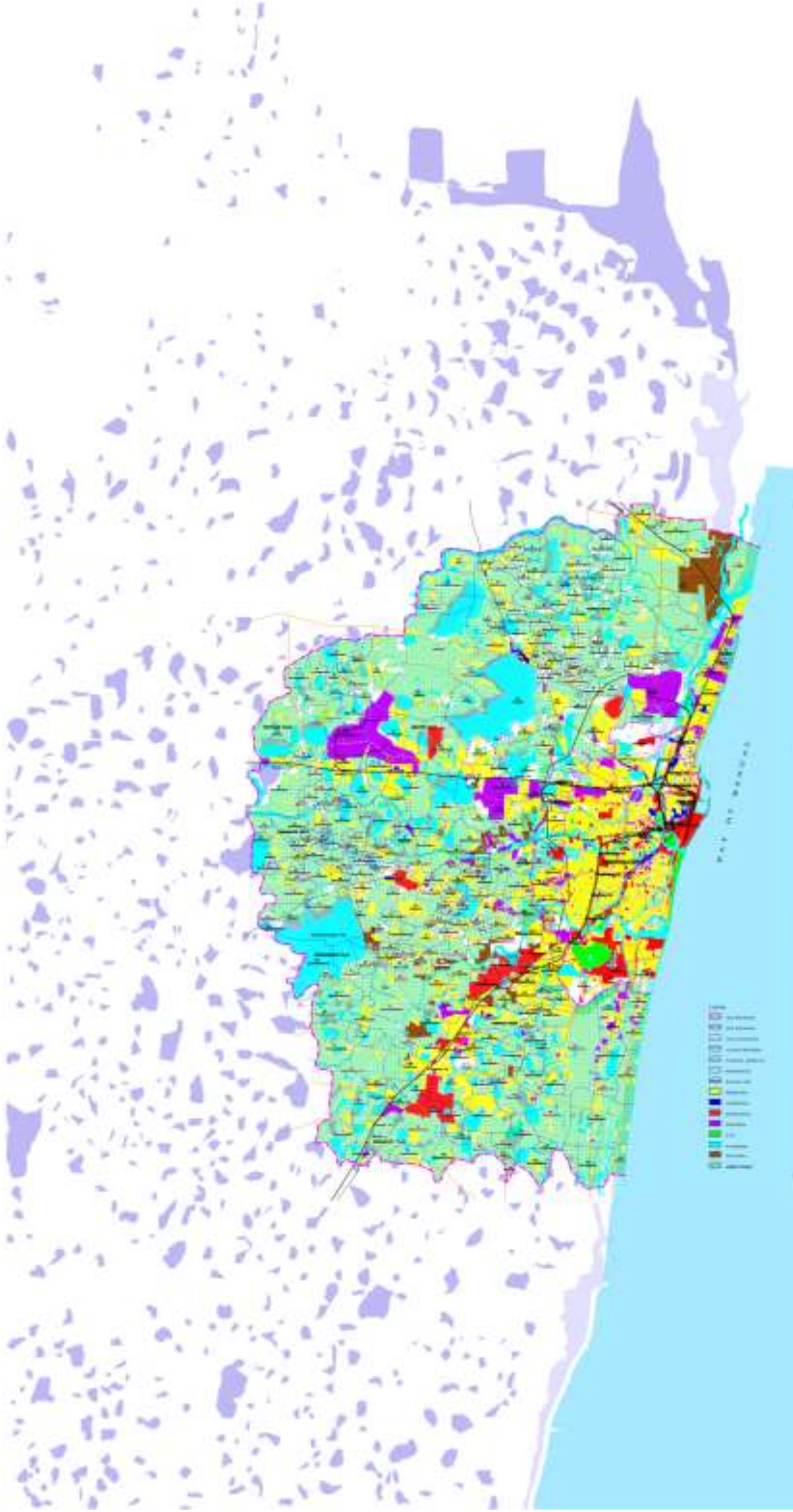
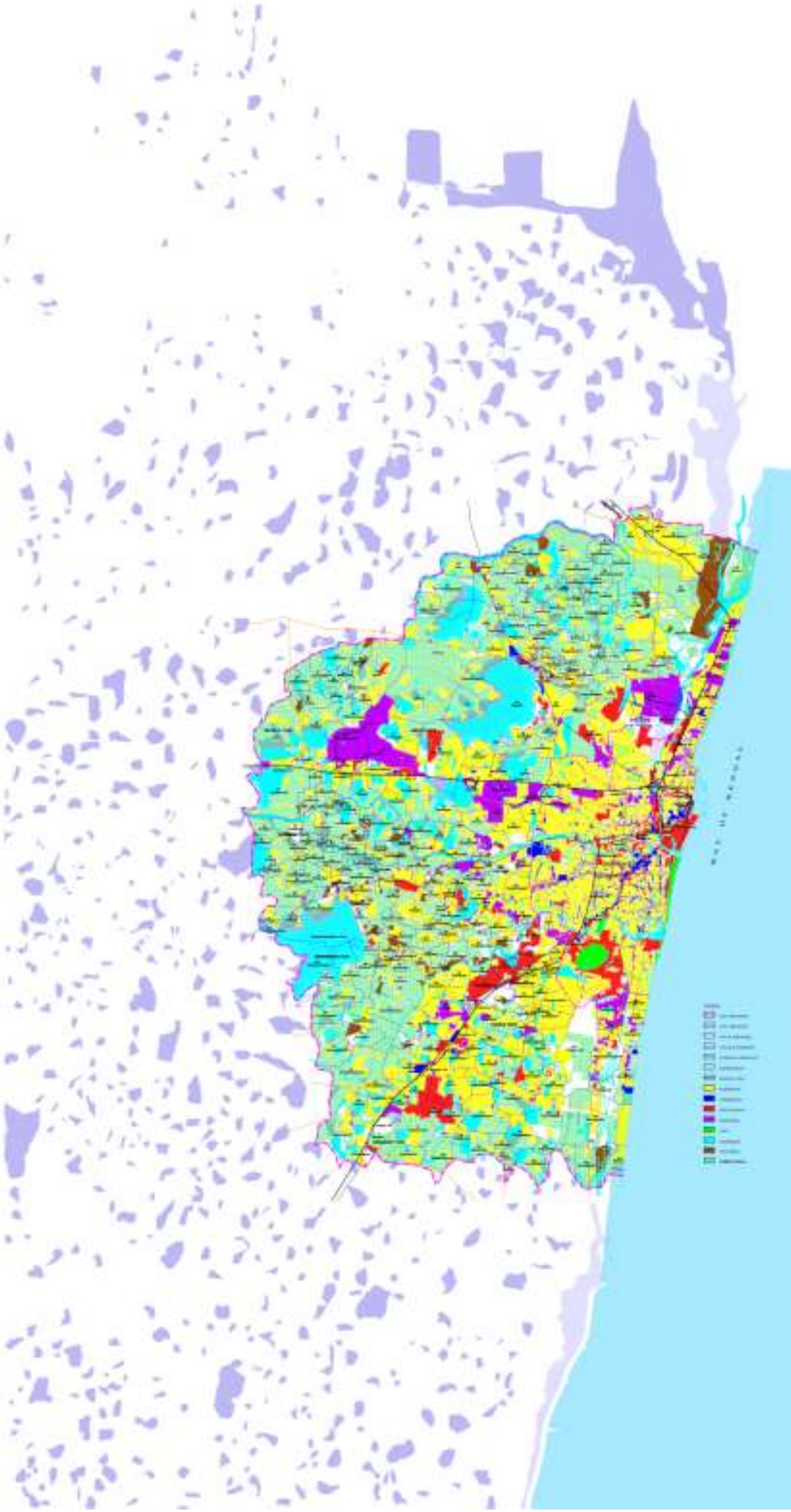
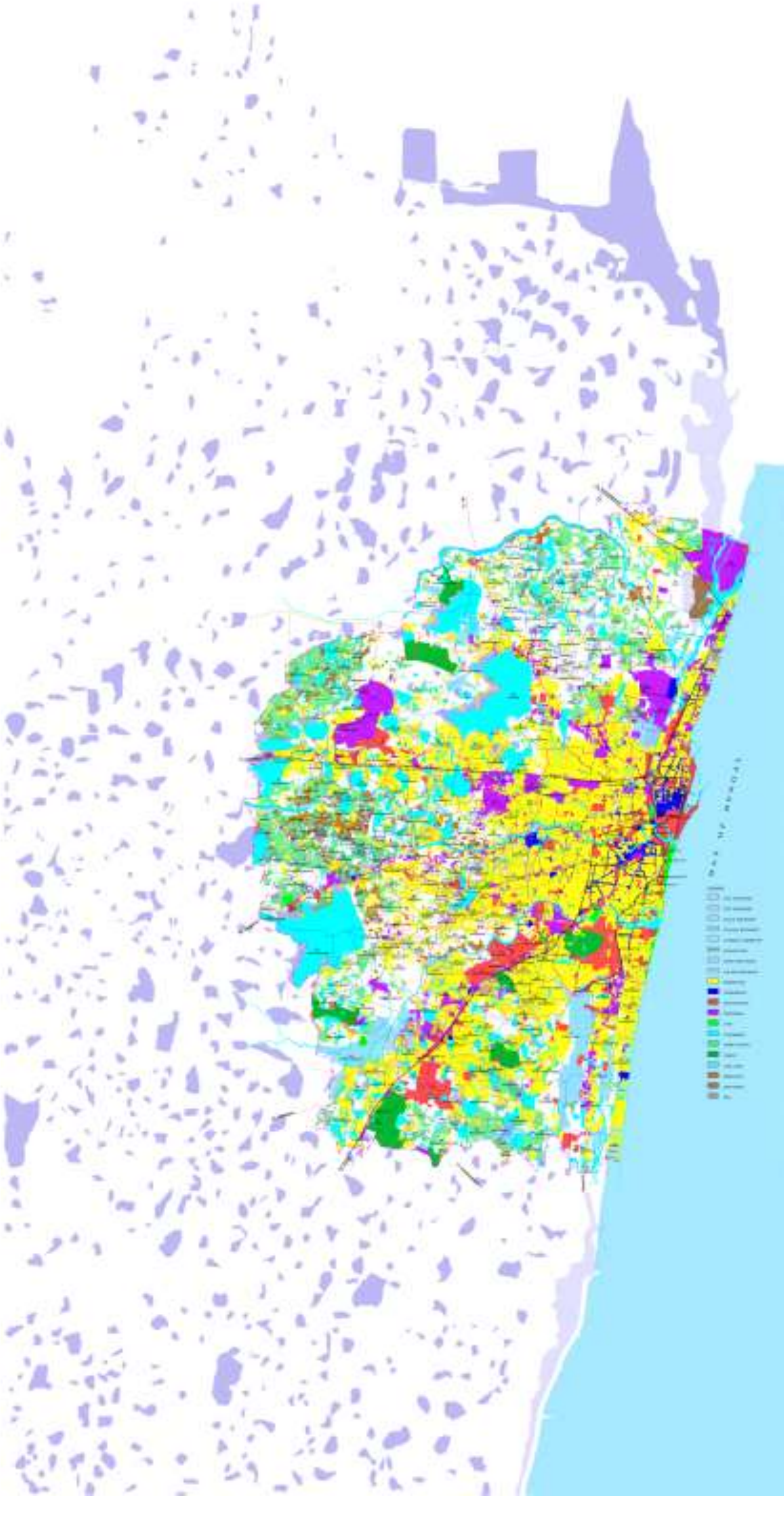








After analyzing all the parameters and proposing intervention remarks, as in tables and maps above,

Proposals were made combining

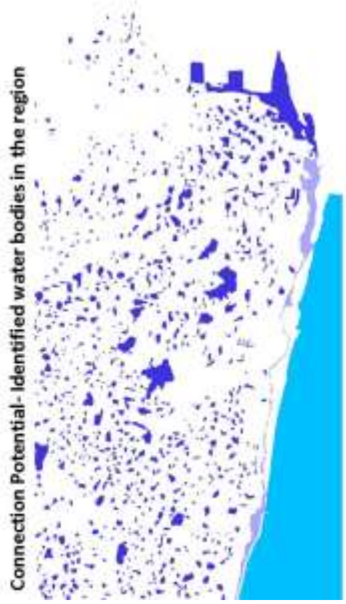
Literature and case study information

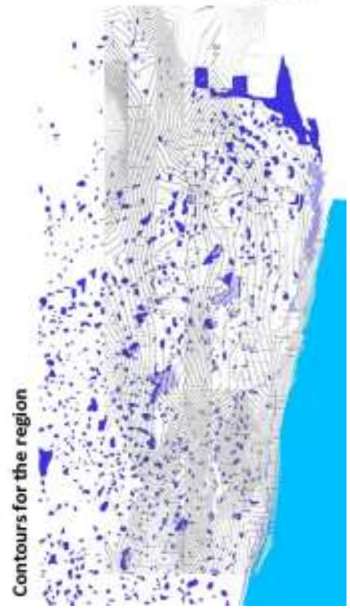
+

Analysis results

Giving suggestions to help solve the problem.

Regional





Regional Intervention

- Connect all water bodies to one another to maintain water levels.
- At sea, during flood, backflow preventors can prevent floods as it will only allow discharge. However if the system fails, intentional flooding can take place forming storm water lagoons.
- Connect the upper water reservoirs to one another and to the smaller neglected tanks around it, such that during overflow, water would go into these areas first .
- Create alternate discharge path – connect the reservoirs to Pulicat lake up north and muttukadu backwaters down south rather than having just 3 channels which pass through a crowded city.
- Integrated water and garden master plan

Overall water flows in the region

Region- Macro -Micro

Regional – Macro (Intermediate)

Water supply to Chennai city through the region and CMA

Macro level (CMA)

- Creating Macro(CMA) water master plan
- Survey and Connect all water bodies within CMA which are currently either encroached, lost or disconnected and connect them in the water master plan.
- Water master plan should include all levels of water governance.
- Create ecological intervention at sea and rivers
- Protected land around water bodies – fine zones
- Ownership of water bodies –Centralized for the whole region but maintained by zones and neighborhoods.
- Intervene in accretion and erosion zones by dredging river discharge mouths, ecological intervention to prevent erosion along with regular dumping of dredged sand to erosion areas and install conditional backflow preventors, and create city wide water and garden networks

Macro -CMA

Macro -CMA

Road network through CMA

Road and Major Water Bodies

Fragile Water flows through CMA

Region-Macro –Micro- Sea

Sub basin map for CMA

Tanks marshes and Lakes around CMA

Water supply Sources- reservoirs and groups of tanks around

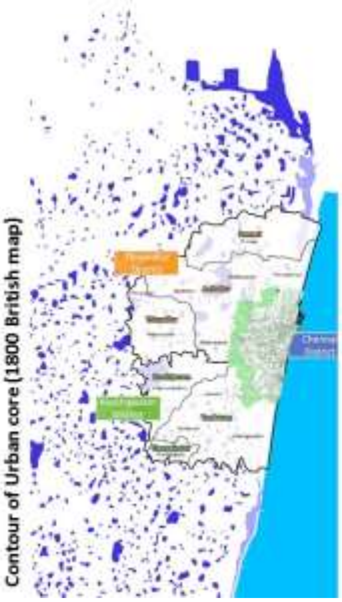
Micro level – Chennai district

- Creating Chennai city water master plan
- Tidal backflows that come up from sea through river channels can be used as storm water lagoons
- Buckingham canal eco park (Intentionally flooding)
- Marsh eco trail (Connect marshes and parks)
- Vertical gardens along transport corridors and infrastructure.
- Protected land around water bodies – fine zones
- Ownership of water bodies –Centralized for the whole region but maintained by zones and neighborhoods.
- Neighborhood parks and tanks(Sub macro) in series.
- Prevent dumping of garbage and encroachments - punishable offense
- Mobilize Governo-Citizen groups
- Accountability across all levels through monthly meeting of ALL stakeholders.

Micro – Chennai District

Urban core of Chennai city

Contour of Urban core (1800 British map)



River and Canal water flows through Chennai city

Micro – Chennai District

Waste water map- Showing flows of waste

Suburban and MRTS rail networks

Chennai Metro lines

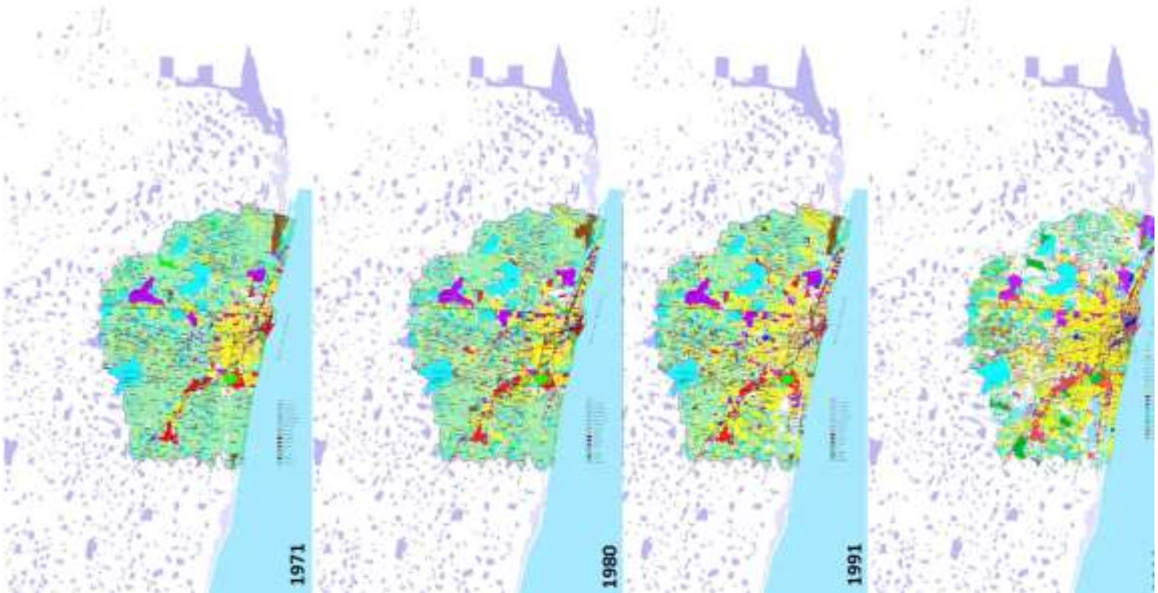
Micro – Chennai District

Flood risk Hotspots -36 as highlighted by corporation

Slum areas and Flood hotspots

Inundation prone area- literally the whole city

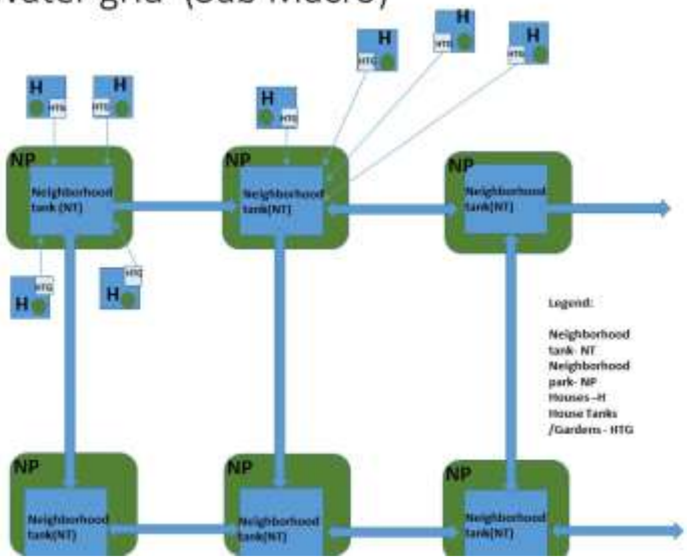
CMA Land use changes -1971,1980,1991,2006



RECOMMENDATIONS

Location	What can be done(system) /Proposal
Along the sea coast	Ecological engineering for coastal marshes backflow preventers to be installed.
Along the rivers	Ecological engineering and backflow preventers and sewage outfall preventers to be installed.
Lakes	Connect lakes to each other and storage areas , additionally create lake ponds for storage.
Reservoir	Redirect reservoir discharges to Pulicat creek and Muttukadu creek rather than all the volume of excess water coming down to the city. Creating a regional water grid.
Pallikarnai marsh	Connect the marsh to all local and neighborhood parks and create marsh eco trail.
Along Buckingham canal	Buckingham canal park (By intentionally flooding it from tidal backflows)
Dense Urban Neighborhoods	Roof gardens Waffle gardens and water grid systems to maintain water balance
Roads and transport corridors	Vertical gardens Mexico street level
Obstructed drainage routes	Drain filters/ blockers to be installed , backflow preventers and sewage outfall preventers to be installed.
Water drainage in Sewage contamination areas	Water treatment and further prevention of waste being dumped.

Intervention Ideas – Neighborhood Water grid (Sub Macro)



Every house to store water within site (roof tanks/gardens etc)
Roof gardens will have downspouts that connect to pervious gardens and walls in ground floor.
Excess drains off to join neighborhood tank connected in series to one another.

House tanks can only flow toward neighborhood tanks and will be protected by backflow preventers. Which means that water cant flow back into the house/street

Neighborhood tanks will maintain levels in each neighborhood and pass surplus to other water deficient tanks But will not flow back to the houses due to level difference.

Neighborhood tanks will act as retention basins and will be connected to gardens on an upper level. The gardens are connected to other ecological areas such as marshes through a network

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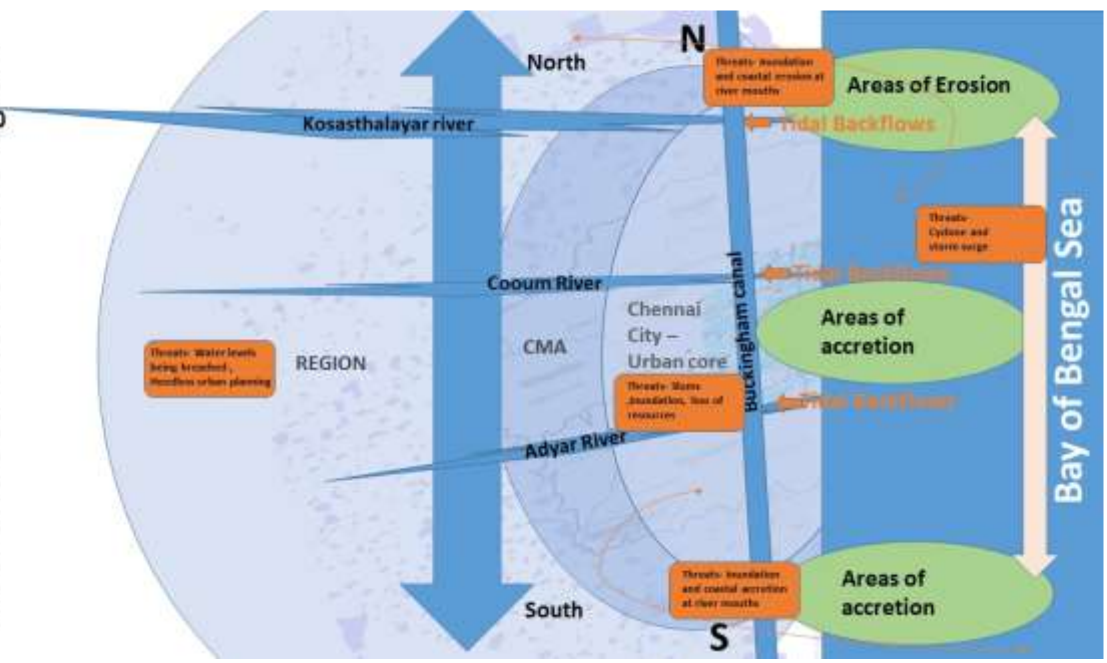
River and Sea Intervention Diagram



Intervention map

Intervention at the Reservoirs:

- Connect them to Pulicat in the North and Muttukadu in South.
- Create regional water grid

Intervention at the Coast:

- Ecological intervention for erosion
- Storm surge prevention - Oyster bays
- Increase marsh cover
- Tidal backflow preventers at discharge mouths

Intervention at Buckingham canal:

- Intentional flooding from tidal backflow.
- Protected zones – fine for litter
- Garbage traps to prevent waste in rivers
- Sewage outfall preventers
- Eco park trail

Intervention map

Intervention at the Lakes:

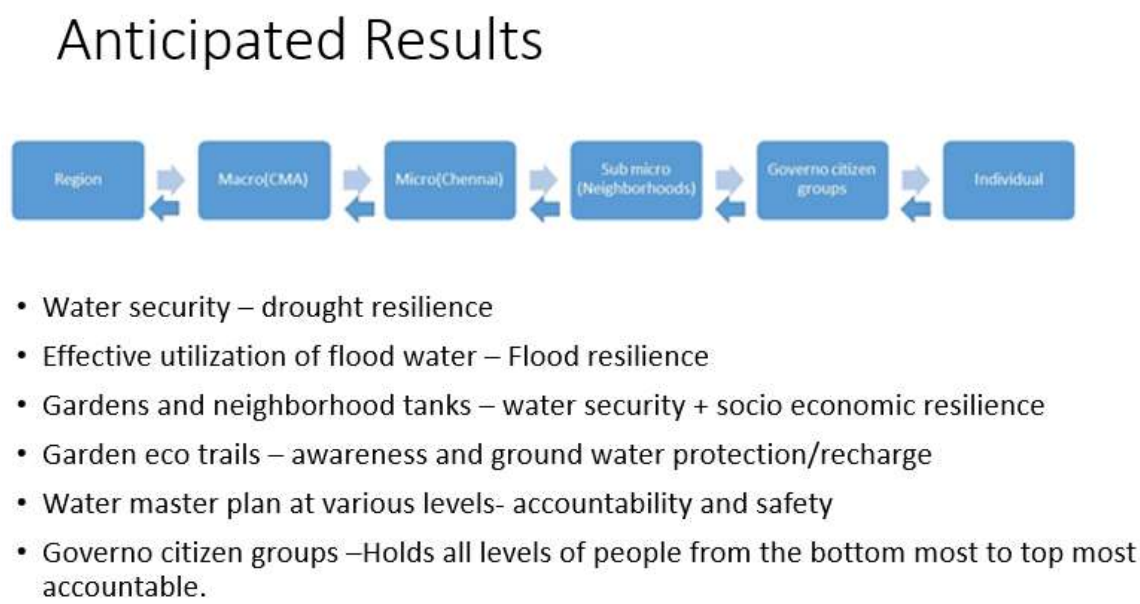
- Connect them
- Increase storage (Lake ponds?)

Intervention at the Marsh:

- Connect them to gardens in neighborhoods
- Marsh eco trail

Intervention at the Rivers:

- Protected zones – fine for litter
- Garbage traps to prevent waste in rivers
- Sewage outfall preventers
- Eco park trail
- Tidal backflow preventers at discharge mouths
- Back up system- Storm water lagoon park at Buckingham canal.



6.1.3 Chennai City area flood solution

Location	**What can be done(system) /Proposal?**
Along the sea coast	Ecological engineering for coastal marshes backflow preventers to be installed.
Along the rivers	Ecological engineering and backflow preventers and sewage outfall preventers to be installed.
Lakes	Connect lakes to each other and storage areas , additionally create lake ponds for storage.
Reservoir	Redirect reservoir discharges to Pulicat creek and Muttukadu creek rather than all the volume of excess water coming down to the city. Creating a regional water grid.
Pallikarnai marsh	Connect the marsh to all local and neighborhood parks and create marsh eco trail.
Along Buckingham canal	Buckingham canal park (By intentionally flooding it from tidal backflows)
Dense Urban	Roof gardens
Neighborhoods	Waffle gardens and water grid systems to maintain water balance
Roads and transport	Vertical gardens
corridors	Mexico street level
Obstructed drainage routes	Drain filters/ blockers to be installed , backflow preventers and sewage outfall preventers to be installed.
Water drainage in Sewage contamination areas	Water treatment and further prevention of waste being dumped.

Table 16- Application of resilient solutions along corridors of flood. Source- Author.

6.2 Discussion and Further Recommendations

This section discusses the interventions suggested and outlines the recommendations suggested by the author after interventions mapped by this study for micro and macro levels of water management as well as lists out the limitations of the study and scope for further studies.

6.2.1 Discussion

Soil and terrain of Chennai suggests that it had always been a flood plain. Accretion and erosion along coast have been occurring for centuries and has in part contributed to the sandy stretches of Marina beach. However, the river mouths, when clogged would prevent water from flowing into the Sea, So there is a need for connecting and creating a balance in the water bodies within the city. This is attempted through the water master plan proposed by this thesis. Additionally, Due to tidal backflows at the river mouths, it is important to have backflow preventers in the discharge mouths of the river meeting the sea.

Ecological interventions such as Oyster reefs, planting of marshes and established techniques can be implemented in the North, where there is significant erosion of the coast. In the south, accretions should not be encroached upon and a significant protection plan should exist for the coast. Building of groynes and barriers usually causes more damage in the long run as it has a finite measure beyond which it would fail. It is thus encouraged to follow ecological resilience along all concerned corridors that lead to floods- the rivers, the lakes and marshes as well as the coast. Ecological master plan would aim to connect the marshes with all parks and wetlands in the area. Parks need to be mandated for every neighborhood and the water storage facility suggested at the neighborhood level could be under these community parks if feasible. Flood retarding basins are to be built in areas that are the lowest points in Chennai to safely channel water that can further flow into the marshes.

Policy regulations as suggested in the recommendations are imperative to stop encroachment and would need strict policing by local neighborhood groups that comprise of government officials, NGO, local population of all classes of society including the disabled and underprivileged to hear the views of all factions of the society. Periodic inspection, educational sessions and workshops along with clean up drives should be held by this group. They should also keep any proposed developments accountable to do an environmental impact study to understand the impact of their project on the ecological master plan and water master plan. They should also provide for local water storage within the property as well as provide connections to the neighborhood tanks that are proposed in every neighborhood. The water flow would thus be regulated after individual storage to community storage to zonal storage and extra can be stored at the discharge mouths of the lagoons to be discharged appropriately thus preventing any accumulation of water within the city. The connections should be such that waste and treated waste cannot enter the system and backflow is prevented. Thus providing the city with a measure against flood as well as against droughts when monsoons fail.

6.2.2 Recommendations

1. Centralized management of water bodies in the 3 districts –Macro/Regional master plan
2. Flood Disaster reduction policies and measures to be devised at individual level, street level, neighborhood level - The Policy should strengthen societies and prevent any development that can increase vulnerability to the hazard.
3. Relocate slums and create Flood Buffer zones - Areas on both sides of the rivers need to be cleared of encroachments, .law should be mandated for the

same. Vulnerable Populations, infrastructure and housing need to be relocated but within reach of jobs and not in outskirts.

4. Law to Prevent dumping of garbage and encroachment of water bodies and natural drain paths through policy regulation, court orders and eviction where required. Regularization should not be permitted at any cost, and this should be made a non bail able, punishable offense.
5. Form a government recognized organization that unites all stakeholders- NGO'S, individuals, Governmental organizations to partake in maintenance and accountability.
6. Decentralize maintenance of water bodies through Citizen Partnership – Empower citizens to organize into water body protection committees at neighborhood level with government and NGO members.
7. Centralized inventory and management plan of all water bodies in Chennai, Tiruvallur and Kancheepuram districts through a water master plan which will bring all water bodies –Rivers, tanks, lakes, marshes etc to be under one body rather than under different factions of government and individual and institutional control.
8. Strong local leadership, citizen empowerment to make decisions with stakeholders - Various groups of engineers, urban and landscape planners, designers, architects, NGO's ,governmental authorities and local population of all strata of society need to work together in decentralized groups, reporting to a central body comprising all these stakeholders so as to hold both ends responsible back and forth thus preventing corruption and vested interests.

9. All water bodies, marshes and wetlands to mandate periodic clean up every 6 months to prepare. Periodic dredging of sand at the river discharge mouths.
10. Create ecological resilience at the Sea coast and rivers.
11. Storage reservoirs at neighborhood level where water can flow during a flood.
12. Prevent dumping waste in rivers and marshes. Separate water flows- waste and potable water flows need to be separated before any clean up is undertaken. -
13. Creating maintenance and sewerage infrastructure should be made the primary Requirement
14. Due to stagnation, Buckingham Canal , Caption canal and Mambalam Drain waterways are more polluted than the Adyar and Cooum River, due to insufficient freshwater flow and continuous dumping of waste into them.
15. Grey water in the house should be reused within the house by making waffle gardens and planting in the periphery rather than concreting/paving.
16. Setting a minimum unpaved surface around the house that connects to invidual as well as community water storage
17. If paving is to be done ,policy should mandate pervious pavements and neighborhood roads.
18. The dumping of waste from STP's should be completely stopped along with ensuring that industrial, commercial and household wastes don't land in them. This should be a punishable offence.
19. Sewage arresters need to be provided at the river edges which will ensure that river mouths remain clean. The flow of water needs to be contained to flow

from reservoir overflow to the sea.

20. Sewage non return valves should be installed in households that lie in flood prone areas.
21. All drains currently connected to the river systems need to be documented and removed from the cycle and appropriate diversion needs to be undertaken by CMWSSB to provide proper drainage systems.
22. Houses and infrastructure provided by Tamil nadu housing board and tamil nadu slum clearance,along with any other governmental or nongovernmental entity of low lying marshes,and water bodies should be stopped.
23. Vertical gardens need to be mandated under all flyovers and main roads which would have ‘green walls’ that will clean the environment and reduce the heat island effect as well as act as rain water collectors during intense rains.
24. Buckingham canal can accommodate tidal backflow waters thus the water in the canal can be flushed out and will create a landscape for people e gradual and remain steady with fresh sea water
25. Topography and drainage must be considered before any approvals are given and people should be forced to adhere to local and regional master plan.
26. Natural Geography –Pay regard to topography while building even though minimal as water flow direction and closest storage point should be assessed.
27. Ponds and Pavement- Make new proposal roads, parking’s, etc pervious, older ones need to be refurbished. Green walls should be along the entire infrastructure above the water bodies.
28. Pallikaranai Marsh Land – seize all building activity with immediate effect

and declare as protected land. Connect with nearby systems and increase capacity of the marsh.

29. Additionally, transportation tunnels in the city can act as storm water carriers and in the event of a flood, tunnels need to be closable and should be capable of shutting the loop.
30. During the flood season, households and neighborhoods should consider stockpiling food ,and also have important documents etc ready for safekeeping to prevent loss of valuable documents due to floods.
31. Using social media and sms facility of mobiles to inform in advance about weather predictions and warnings.
32. Flood Disaster management training to be offered in schools along with educating on the importance of the water resources.
33. The best way recommended to protect a dwelling is to raise it by atleast 1 foot above the 100 year flood mark. The plinth should safeguard against erosion.

6.2.3 Limitations

This study only starts the process of an extensive list of further studies that need to be done for Chennai by starting with the origin of the problem. Due to the extensive nature of the topic, only diagrammatic mapping is done as it is beyond the time scope of the thesis to map out the details for the city. The map proposal drawn out by the author for the purpose of this thesis is just an immediate suggestion to contain floods and prevent neighborhoods and infrastructure from being flooded and additionally offer water security. The sample size is quite insignificant to cross tabulate data and only served in the first stage of informing the author about the citizens feedback and contribution.

Further detailed studies as well as pilot studies in select areas with a significant population size still needs to be considered.This is beyond the ability of a single person and would need groups of people to do this work at the various scales.The term ‘Governo-citizen’ group is coined by the author to identify a body of people from all sectors and representing all stake holders-that unites governments,NGO’s as well as common man from all walks of life to maintain accountability.But this is possible only if such a group can exist without political influence. The suggestions are aimed at a micro level (water protection) and macro level (flood prevention) to enable neighborhoods, communities, households as well as other stakeholders to be able to partake in minimizing flood events and vulnerability in the future.

This study only aims to create a map to link the rivers and lagoons and connect the water bodies to create a balance when floods occur, in terms of having a water master plan and an ecological master plan that would connect all parks and marshes in the area.Specific areas are not surveyed as this is a problem that affects the whole city in a generic sense. Other aspects, such as groundwater recharge, Prevention of saltwater intrusion into ground water systems, waste disposal systems, water supply systems etc that would need further elaborate studies are not considered for the purpose of the study.Also omitted is zonal proposal map and all other local maps. There is also no reference to encroached areas or areas where rivers have been narrowed and intervention suggestions are given on a generic basis for such areas. Due to time and location constraints, the author has not been able to do extensive observational studies. This may be taken up in the future for further studies.

6.2.4 Future Outlook

Extensive studies would need to be conducted to understand feasibility and implications of the proposal before implementing. Also, GIS mapping may be required to understand where the areas of connection would be to work the proposal. Area wide analysis, as well as zone wise and various other questionnaires and surveys would be required. The proposal would need to be evaluated by teams of experts from various disciplines including urban and landscape design and planning, drainage engineers, geographers, and analysts from other departments to develop a holistic development plan. Future studies will need to include area analysis as well as physical on site surveys which is beyond the scope of this extensive topic at this level.

CHAPTER 7- CONCLUSION

Urban and Landscape design when integrated provide resilient systems that work well and are less likely to fail when compared to hard engineering options that are imposed on cities by successes elsewhere. Every city is different and has different parameters to address. So it is imperative to create a customized solution after extensive analysis of historic factors that have formed the city. Resilience of vernacular systems to calamities is established in the logical sequence as it emerged in the past by learning from nature.

Planners and local bodies need to consider water infrastructure and not just land. Urban and Landscape urbanism need to be integrated beyond just greening pathways along roads. A century ago, water scarcity was unheard of as each village was self sufficient and had its own tank, lake and water supply. Shrinking water bodies additionally can also lead to sea intrusion, low groundwater levels and increased flooding, hence the need to integrate them into a system.

The Government and Development authority are to be advised to take an immediate inventory of the condition of the areas of water bodies and marshes remaining after encroachments and to evict settlements and people with money or by force if required. Further approvals for development in the city need to follow stringent laws that would make it mandatory to adhere in strict accordance with the proposed water master plan, ecological master plan as well as neighborhood and zonal master plans that are proposed for water security. The modernized maps which would be an adaptation from the 'eri concept' of monsoon water harvesting would provide as a buffer against water scarcity as well as protect against floods. Additionally ground water sources may also be recharged.

As Chennai Metropolitan Area, continues to extend government approved plans that have not considered drainage of water or the water infrastructure continue to emerge. If immediate measures are not taken to contain this, Chennai would flood more and would suffer great damages to infrastructure and economy. Sub urban and rural areas into which the CMA is extending, still have the ability to make changes and re-assess their preparedness to adapt.

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APPENDICES:

Appendix I. Questionnaire for Professionals/engineers and experts :

This survey is completely voluntary. By responding, you agree to participate in this research project. No personal data will be gathered. We are trying to produce a flood mitigation system for Chennai city. Please take the time to complete these questions. You responses will remain confidential but will prove valuable for the proposal.
If you have any question, you may contact :
Alifa Muneerudeen, on +974-66497860 or am1304589@qu.edu.qa

1. Are floods considered during inception of an urban project?

2. Does current urban planning and design address the increasing global calamities or just cater to infrastructure requirement?

3. Is there a growing need for flood prevention mechanisms in the coming years? How do you think this can be achieved?

4. What new approaches exist in the field that can help solve the problem of flooding?

5. What percentage of a big infrastructure project is channeled into looking at impacts of flooding? Are the contractors educated about the problems or do they just build?

6. How much of support does the government offer to suggested approaches by the engineers?-Are they frequently dismissed or accepted and considered well before land allocation? What kind of systems have worked well?

7. Which systems work better- Soft engineering vs. hard and what is being implemented more?

8. What are the challenges faced on ground for implementing flood mitigation systems in urbanized areas prone to flooding?

9. What is being done to improve public opinions, attitudes and involvement?

10. Any high risk practices by general public or government that affect the resilience of the city toward disasters?

Appendix II - Government officials/Development authority

This survey is completely voluntary. By responding, you agree to participate in this research project. No personal data will be gathered. We are trying to produce a flood mitigation system for Chennai city. Please take the time to complete these questions. You responses will remain confidential.
If you have any question, you may contact :
Alifa Muneerudeen, on +974-66497860 or am1304589@qu.edu.qa

1. What areas currently are at greatest risk of flooding in the city and at the coast?

2. What remediation and mitigation interventions are being carried out currently

3. Is there a lacuna –Why are we not able to handle the floods-is it human or economic capacity, infrastructure or attitude?

4. In what areas are there additional factors that add to the risk?

5. Where are vulnerable populations, infrastructure, and sectors in relation to the flooding risk areas?

6. Are there any laws in place for eviction or removal of urban areas that have fringed upon the water body areas? What are they

7. To what extent is ecological engineering being implemented to increase resilience against flooding- rejuvenating mangroves etc?

8. Is there a clear segregation between the waste water and rain/storm water outflow or does contaminations occur? Is there a strategy to capture storm water to prevent it from flooding the streets – at residential, neighborhood, city scale?

9. Is the ground water increasing in salinity? Any efforts to control them?

10. Is there a way we can deal with the flooding in the coming years?

11. Are there any existing or future plans to quantify the current and future potential impacts of the recurrent floods-

12. Is there any data on the expected droughts/continued flooding in the coming years?Who is responsible for looking at this?

13. What is the current function of Buckingham canal and rivers Arani, Adyar, Kosasthalayar and Cooum? What are the future plans

14. Do the rivers flood the embankment areas during rains -How severe?

APPENDIX III- Questionairre - coastal communities and those near the rivers

This survey is completely voluntary. By responding, you agree to participate in this research project. No personal data will be gathered. We are trying to produce a flood mitigation system for Chennai city. Please take the time to complete these questions. You responses will remain confidential . If you have any question, you may contact : Alifa Muneerudeen, on +974-66497860 or am1304589@qu.edu.qa

1. Which locality do you live in?

2. Age, gender ,level of education

3. How has this area changed in the past decades?

4. What is the current problem related to flooding here?

5. Is there adequate water supply and drainage infrastructure

6. What areas currently are at greatest risk of flooding in your locality?

7. In what areas are there additional factors that add to the risk?

8. Where are vulnerable populations, infrastructure, and sectors in relation to the flooding risk areas?

9. Are there any local prevention measures that are taken by the community during a flood?

10. What governmental interventions have taken place after the floods

11. Are there any temple tanks or any other water collection systems in the area-are they being used or have they fallen into disuse? Are there any steps being taken to rejuvenate them?

12. Who maintains the water bodies in this area? Do they address concerns by the residents?

APPENDIX IV- Questions for Local residents

This survey is completely voluntary. By clicking on the link you agree to participate in this research project. No personal data will be gathered. We are trying to produce a flood mitigation system for Chennai city. Please take the time to complete these questions. You responses will remain confidential.
If you have any question, you may contact :
Alifa Muneerudeen, on +974-66497860 or am1304589@qu.edu.qa

1. What area do you live in?

2. How many years have you been a resident of Chennai for?

3. Do you live in a flood prone area? Are you affected by floods? Which areas?

4. Why do you think your area floods?

5. Does your apartment/house/ neighborhood store rain water?

6. How can we improve the condition of water infrastructure and drainage in Chennai city?

7. What can be done in the landscape to stop flooding?

8. What can be done at the building level?

9. Are there any historical ways to mitigate floods?

10. What can be done now in the areas that shouldn't have been constructed on?

11. Were there any measures that were employed traditionally by the previous generations to prevent floods that you are aware of?

12. Do you see a growing need for flood prevention mechanisms in the coming years?

13. In your opinion, how can floods in Chennai be dealt with?

14. Where does the waste from your house go? Are there any dumping grounds in your area?

APPENDIX V -QU IRB Exemption

April 9, 2017

Ms. Alifa Muneerudeen
Graduate Student
College of Engineering
Qatar University
Tel.: 66497860
Email: am1304589@qu.edu.qa

Dear Ms. Alifa Muneerudeen,

Sub.: **Research Ethics Review Exemption / CENG Graduate Student Project**
Ref.: **Project titled, "Urban and Landscape Design Strategies for Flood Resilience in Chennai City"**

We would like to inform you that your application along with the supporting documents provided for the above proposal, is reviewed and having met all the requirements, has been exempted from the full ethics review.

Please note that any changes/modification or additions to the original submitted protocol should be reported to the committee to seek approval prior to continuation.

Your Research Ethics Approval No. is: **QU-IRB 765-E/17**

Kindly refer to this number in all your future correspondence pertaining to this project.

Best wishes,

K. Alali

Dr. Khalid Al-Ali
Chairperson, QU-IRB

Institutional Review Board
(IRB)
Office Of Academic Research