International Journal for Multidisciplinary Research (IJFMR)

E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Enhancing Urban Resilience to Flood in Chennai: Strategies for Sustainable and Adaptive Cities

Ar. K. Dhiksha[1], Raja Ram C[2]

[1]Assistant Professor, Department of Architecture, School of Architecture and Planning, Anna University, Tamil Nadu, India
[2]Student, B.Arch Department of Architecture, School of Architecture and Planning , Anna University, Tamil Nadu, India

ABSTRACT

Chennai, the capital of Tamil Nadu is located in the South East of India and lies at a mere 6.7m above mean sea level and well developed and highly vulnerable city in India especially to floods.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 had a significant impact on the shoreline, and increasing urbanization together with the ground's declining natural drainage capacity as a result of encroachment on wetlands, marshes, and other ecologically delicate and permeable places have contributed to have more floods in the city. Canals and rivers that have been filtered through the Waste and informal settlements have made the situation worse. Organic and artificial water systems, such as those for collecting and storing monsoon water infrastructure like the reservoirs and tanks at Temple have been contaminated and have fallen into abuse. This dissertation involves the study of various geographical contexts that are similar to chennai context and to analyze urban flood resilience. The various case studies that are discussed and analyzed. The outputs can be recommended to city Chennai to become better urban resilience to floods.

Keyword: Chennai, Tamil Nadu, South East India, mean sea level, floods, vulnerability, storm surges, tropical cyclones, tsunami, urbanization, natural drainage capacity, wetlands, marshes, encroachment, canals, rivers, informal settlements, water infrastructure, reservoirs, tanks, urban flood resilience, geographical contexts, case studies, urban resilience.

3.7 LIST OF SYMBOLS, ABBREVIATIONS ANDNOMENCLATURE

1. Hydrometeorology - Hydrometeorology is a branch of meteorology and hydrology that studies the transfer of water and energy betweenthe land surface and the lower atmosphere.
2. Geomorphology - Geomorphology is the study of how landforms and sediments form on the Earth's surface.
3. NOAA - National Oceanic and Atmospheric Administration.
4. SLR - Sea level Rise
5. PPP - Public Private Partnership
6. MAOUDC - Metropolitan Area Outer Underground DischargeChannel

7. WSUB -Water Sensitive Urban Design
8. SUDS - Sustainable Urban Drainage systems
9. WRI - Water Resource Institute

CHAPTER 1: INTRODUCTION

1.1 GENERAL:

Chennai, the capital city of Tamil Nadu situated in the southeast of India, lies at 6.7 meters above mean sea level. Due to storm surges and tropical cyclones that cause annual floods and severe rains, Chennai is in a vulnerable position. 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.

1.2 AIM:

The main aim is to research how urban strategies can contribute to the prevention and mitigation of flooding in Chennai city through analyzing the case studies in the world which have the similar characteristics of the city chennai like the land, topography, climate, weather and so on.

1.3 OBJECTIVES :

2 To know the causes and impacts of flood in coastal regions with hot and humid climates like chennai.

3 To Examine the key elements and frameworks that constitute urbanresilience in the face of flooding.

4 To select and analyze the appropriate case studies and the suitable proposed strategies that can support the mitigation of flood in Chennai.

4.1 RESEARCH QUESTIONS :

A. 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?

B. Analyze successful strategies and interventions from diverse urban contexts that enhance cities' capacity to withstand, adapt to, and recover from flood

C. What ways can we use or enhance the cities’ natural features in urban resilience against floods in the future?

4.2 SCOPE OF THE STUDY :

The geography, types of flooding and its impacts,history of floods and its mitigation over the period of time.resilience factors that comes in the context of thechennai city which gives the the way of scope to the study for this research to recommend the appropriate strategies to the city in the given period of time.

4.3 LIMITATIONS OF THE STUDY:

The study 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 strategies maps are beyond the time scope of this study and can be carried out for further studies.

4.4 METHODOLOGY

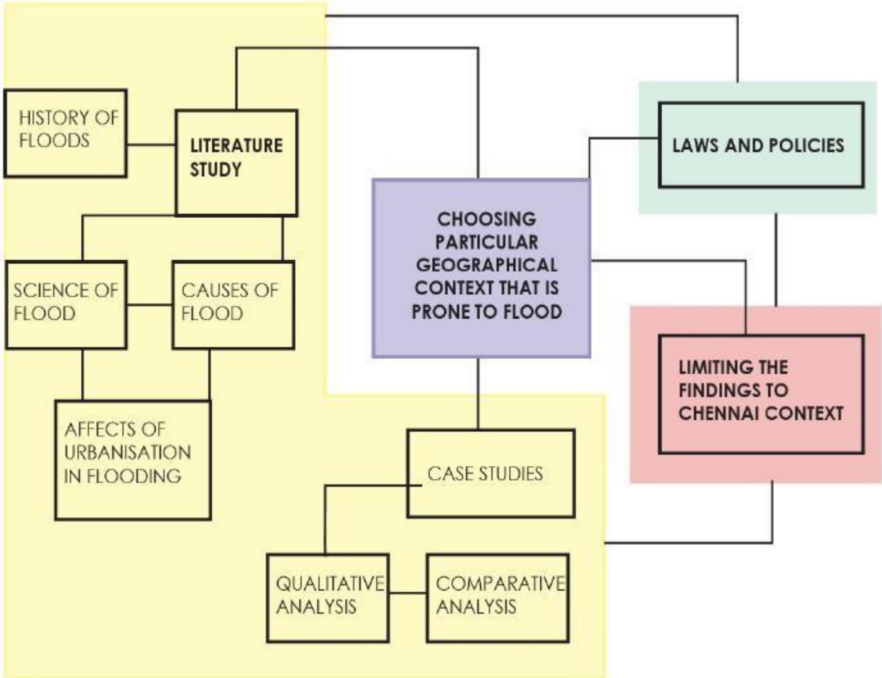


Fig 1: Methodology

4.5 SIGNIFICANCE OF THE STUDY :

The research can contribute by providing guidelines in the field of urban planning and urban design to design better cities that are resilient to flood.

CHAPTER 2 : LITERATURE REVIEW

2.1 INTRODUCTION TO FLOODS :

Sumerian cuneiform tablets contain the earliest known accounts of city flooding. An interpretive tablet from the 7th century BC is purportedly from Nineveh, whichis located in modern-day Iraq. It talks about a flood similar to the story of 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.

2.1.1 ETYMOLOGY:

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.

2.1.2 CAUSES OF FLOOD:

Floods happen when long-term precipitation, strong storms, or snowmelt release more water than rivers or land can hold without inflicting harm. As a result, the water overflows its banks and typically reaches low-lying nearby communities. Different kinds of floods might occur, each with its own origin and will be covered in due course. Floods are caused or contributed to by a variety of complex, sometimes unconnected events. They fall into two categories: anthropogenic (caused by humans) and ecological (caused by nature):

A) Ecological (Natural) Causes:

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

1. Hydro-meteorological factors: The core of these weather-related phenomena thatsignificantly impact floods are extended and intense rainfall, cyclones, typhoons, storms, tidal surges, precipitation, wind, sea level rise, tide levels, wave action, etc. A few examples of hydrological elements are ice and snow melt, impermeable surfaces, wet ground, etc.
2. 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, subsoil, relief and climate.

B) Anthropogenic (Manmade) Causes:

The destruction of natural ecosystems, such as marshes and wetlands, increased impervious surfaces, climate change, and change in land use, as well as unplanned flood control measures, deforestation, intensive agriculture, poor drainage and storm water management, clogging of river channels, socioeconomic and development activities, are examples of anthropogenic causes.

2.1.2 TYPES OF FLOOD:

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'sresources. 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 groundwater in the last century has compounded the risk of flooding.

B. Urban floods are also caused by improper land use planning. Growing populations and urbanization increase the need for land, causing areas to encroach. Laws and rules governing the construction of new infrastructure are frequently superseded by political and economic considerations. Plans to enhance the water's natural flow pathways are hampered by capacity and resource limitations.

C. Riverine floods: Though the consequences are gradual, this occurs as a result of significant downpours or obstructions in the rivers' natural flow path. Floodplains along the Yangtze River were reclaimed for agriculture in southern China, however this increased frequency of flooding has resulted in greater erosion. In order to prevent flooding, the flood plains could generally hold floodwater and release it back slowly. In order to reduce hazards in the future, the government has pledged to restore 14,000 square kilometers of natural wetlands by 2030.

D. **Pluvial or overland floods:** This is caused by rainfall not being absorbed into the land and flowing overland through non-permeable urban areas. Localized flooding clogs the drainage system and flows into urban areas which is a regular occurrence in tropical urban areas.
E. **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.
F. **Groundwater floods:** When ground water level of the water table of underlying aquifer reaches surface level or if the groundwater is rendered unusable due to pollution, the water level could rise and exceed the combined water and sewage volume.
G. **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 12 affected. Many levees along rivers to protect agricultural and residential land failed, thus flooding areas around the Mississippi and Missouri Rivers .
H. **Flash Floods:** They are caused by local convective thunderstorms and occur 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.
I. **Semi-permanent Flooding :** Urban areas lying below sea level or with water tables 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.

Since there are many factors that contribute to pluvial, groundwater, flash, and semi-permanent floods, it is challenging to estimate the likelihood of these events, even in the absence of historical data. Since floods are dependent on the erratic weather, it is impossible to predict or estimate when and where they may occur in the future.

2.1.3 IMPACTS OF FLOODING :

A. **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 13 risk of waterborne diseases which can include typhoid, cholera and many other diseases depending upon the location of the flood.

   It could be challenging to get emergency medical care or to organize relief to those in need if roads and other transportation facilities are damaged.

Generally speaking, flood waters submerge farmland, rendering it unusable and hindering the planting or harvesting of crops, which can result in a shortage of food for both people and farm animals. In severe flood situations, a nation may lose its whole harvest. Certain tree species might notbe able to withstand repeated flooding of their root systems.

B. **Secondary and long-term effects:** One common aftermath of significant floods is economic hardship, which can be caused by a temporary reduction in tourism, the cost of reconstruction, or shortages of food contributing to price hikes. When fatalities, severe injuries, and property loss occur, the effect on the affected parties may be very harmful psychologically. Chronically moist homes, which are associated with an increase in respiratory ailments and other diseases, might result from urban flooding. Significant economic ramifications result from urban floods for the impacted neighborhoods.
C. **Socio-economic impacts:** Compared to other natural disasters, floods have caused a considerable amount of human casualties. Human vulnerability andthe potential losses resulting from neglecting the situation or from extreme weather occurrences like hurricanes and cyclones have been made worse by variables like urbanization, population expansion, land use change, and climate change. Worldwide flooding is predicted to become more common and to have a greater impact; this is especially true in developing nations, where the majority of floods now occur. On the other hand, industrialized countries are equally at risk from Sea level Rise (SLR) brought on by global warming. The harm and death toll from future floods can be decreased by preparation and mitigation.
D. **Environmental impacts :** urbanization-related degradation of wetlands and marshes, as well as the eradication of mangroves, sand dunes, tidal flats, andestuaries along beaches that serve to absorb and moderate powerful waves and surges from the ocean. There are not enough options for storing and discharging water when tanks, ponds, and lakes are neglected by the city.The above-mentioned natural shock absorbers during extreme events have been disregarded. Large bodies of water like ponds, tanks, and marshes collect rainfall, preventing flooding during periods of high precipitation and replenishing groundwater.

2.2 WHY IS FLOODING IN COASTAL CITY LIKE CHENNAI IS SUCH APROBLEM?

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. 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. "

Flooding of coastal cities are considered the most dangerous and harmful of natural disasters. Large chunks of populations live along coastal cities. A study confirmed that 21% of the world’s population lives in coastal cities. 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 Hydrometeorological cycle.

A research published in **Nature Climate Change by Hallegatte, S., Green, C., Nicholls, R. J., & Corfee-Morlot, J. (2013)** reported a study comparing 136 citiesall over the world with populations 1 million to determine most flood prone coastalcities.This was accomplished by contrasting information

International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

on population distribution with the measures in place for flood protection. This was utilized in conjunction with predicted estimates of SLR, groundwater depletion and subsidence, as well as GDP and population growth forecasts. The depth of water that flooded a city was measured in order to determine the cost of damage. Both the best and worst case scenarios for SLR would result in losses of up to $1 trillion. Asia and North Africa are home to almost all of the cities that are most vulnerable to coastal flooding.

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. Shenzhen, 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.

2.3 THE CASE OF CHENNAI CITY :

Fig 2: Location map of Chennai

2.3.1 GENERAL:

Chennai Metropolitan Area (CMA) is 1189 sq kms comprising 8 districts includingthe Chennai District. The population of Chennai increased from 5.8 to 8.9 million in the decade between 2001 to 2011.

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.

The area around Chennai is prone to flooding. Natural elements include the land's physical features and the area's weather conditions contributed to the 2015 Chennai floods. A significant portion of the city was vulnerable to flooding and waterlogging. The Tamil Nadu State Disaster Management Authority has classified 306 areas in Chennai as flood-prone areas, of which 37 are considered as very highly vulnerable.

The floods in Chennai have been attributed to various factors such as inadequate capacity within the banks of the rivers to contain high flows brought down from the upper catchments due to heavy rainfall, encroachment of floodplains, and haphazard and unplanned growth of urban areas. Coastal areas of Tamil Nadu are also prone to cyclones, which are often accompanied by heavy rainfall leading to flooding. Overall, Chennai is a region that is vulnerable to floods, and there is a need for effective flood management strategies to minimize the impact of floods onthe region.

2.3.2 IMPORTANT FLOODS IN CHENNAI :

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. Additionally, floods have been regular from 2002 onward. In **2002**, residential areas resembled islands and all communication, transport and trade links were cut off. 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. The North zone along the coast was relatively protected due to the presence of shoreline erosion protection. Some areas along the coast suffered heavy erosion due to the pounding ocean waves. Coastal environment and livelihood was severely hit.

The year **2005** saw a deep depression over Bay of Bengal that brought up to 42 cm rainfall in around 40 h during the 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.

2.4 CONDITION OF WATER BODIES IN CHENNAI :

1. The city's numerous lakes and tanks were built during the Chola era. Ooranis were used to store drinking water, whereas ponds were utilized for general uses. Lakes and other bodies of water have not been properly maintained since the 1960s. The government did not act seriously. That resulted in deliberate intrusions, a shortage of resources, and accountability because of the allocation of water bodies to people, businesses, military, railroads, defense, the environment, and people with disabilities Departments of Fisheries, Corporation, and other government agencies, as well as local level organizations like Panchayats. About 60% of the water is owned by the PWD (Public Works Department). bodies in Tamil Nadu, with the various stakeholders cited sharing the remainder,
2. In the last two to three decades, the city has grown and residents have moved into places outside of Guindy. The city is vulnerable to both drought and floods. Without Veeranam Aeri's 157 water supplies to the city between 2001 and 2016, there would be a severe water scarcity. Due to a drought in the 1940s, when residents of the city had no access to water at all, it was abandoned.

Mismanagement of the city's water supply has also been caused by ineffective storm water drains, poorly utilized resources, and a lack of funding at the municipal level.

3. Ignore lakes as places to store water. An 'ayacut' (a location where water is redirected for irrigation) was present in the Muarasampet Lake, from which water was used for agriculture.However, because agricultural practices have declined, this area has been used for waste disposal for more than thirty years. Aadambakkam Aeri, which was formerly only 20 feet deep, is now home to over 15,000 homes. Alandur Lake was a portion of Medavakkam High Road.(Encroachments have occurred from every social group). Iron scrap workers have encroached on 2.4 acres of PWD-owned Maamkulam lake. This intrusion is difficult to stop and driven by politics.
4. There are over 330 acres of waste dump in the Perungudi swamp. The majority of the encroachments between the sections of Perumbakkam and Medavakkam are government structures that have emerged on delicate marshlands.192 lakes drained into the marsh, however these sites where water may have flowed into the marsh were blocked off due to neglect and encroachment from the inside out.Of the approximately 265 acres of Velachery Aeri, 165 acres were given to the Tamil Nadu Housing Board (TNHB).

2.5 2015 FLOOD MAPS OF CHENNAI :

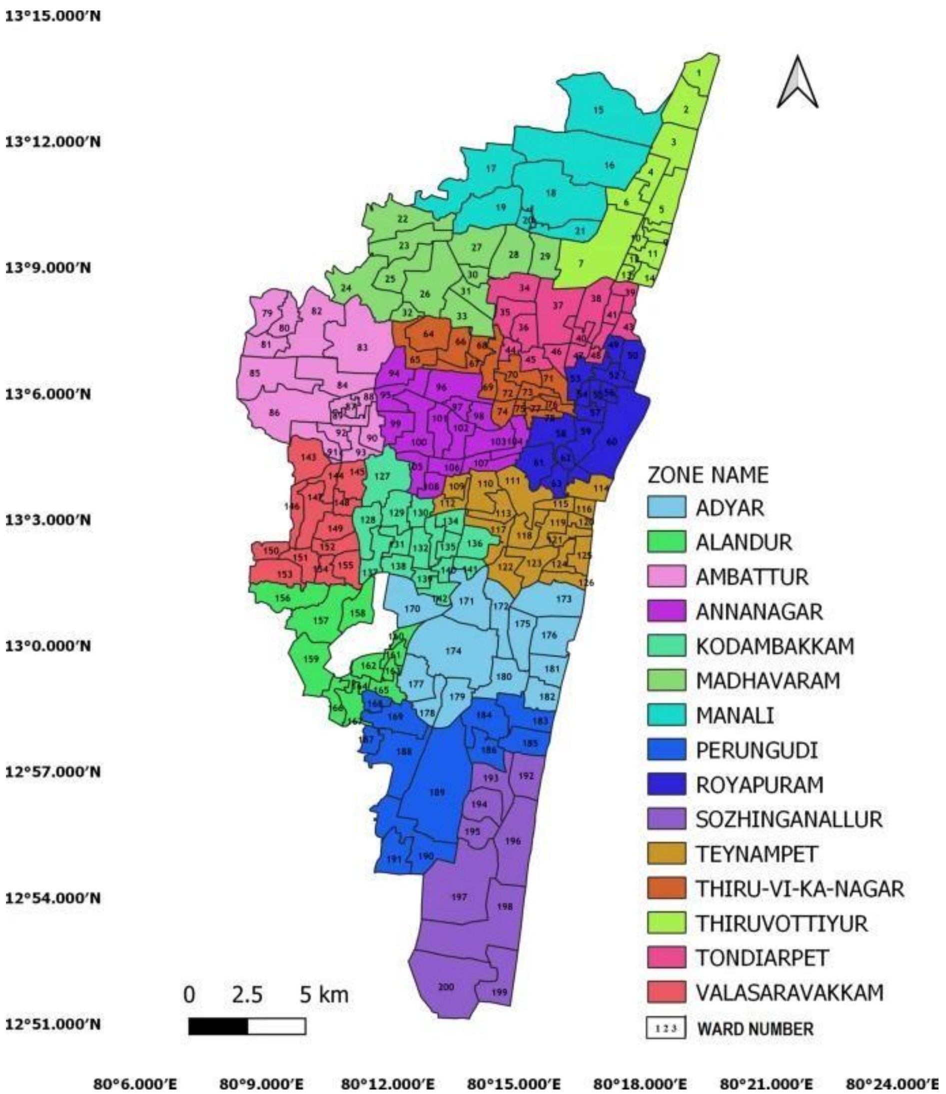


Fig 3: Ward map of Greater Chennai Corporation (source -geoenvironmental-disasters.springeropen)

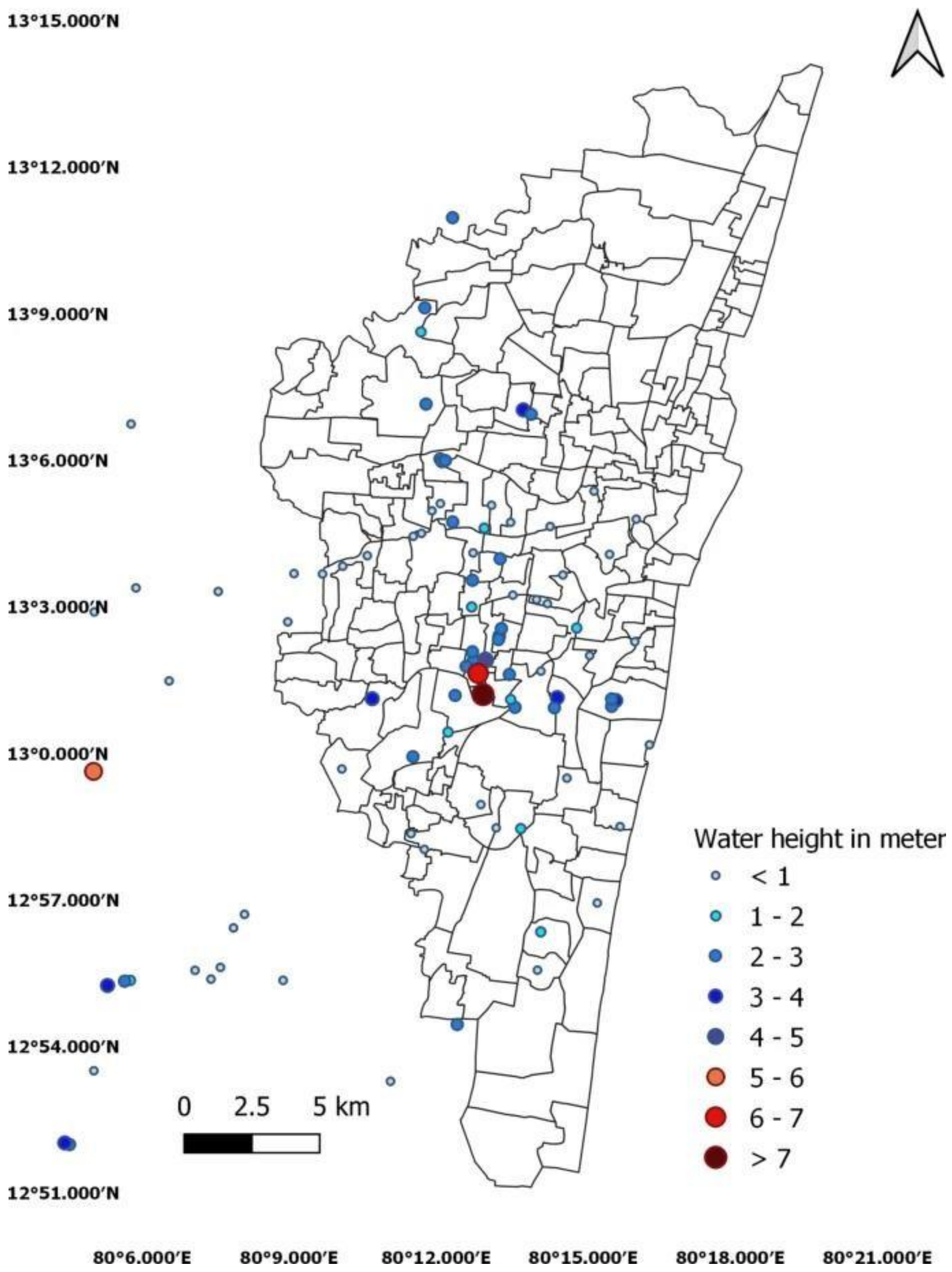


Fig 4 : Distribution of water height points (source -geoenvironmental-disasters.springeropen)

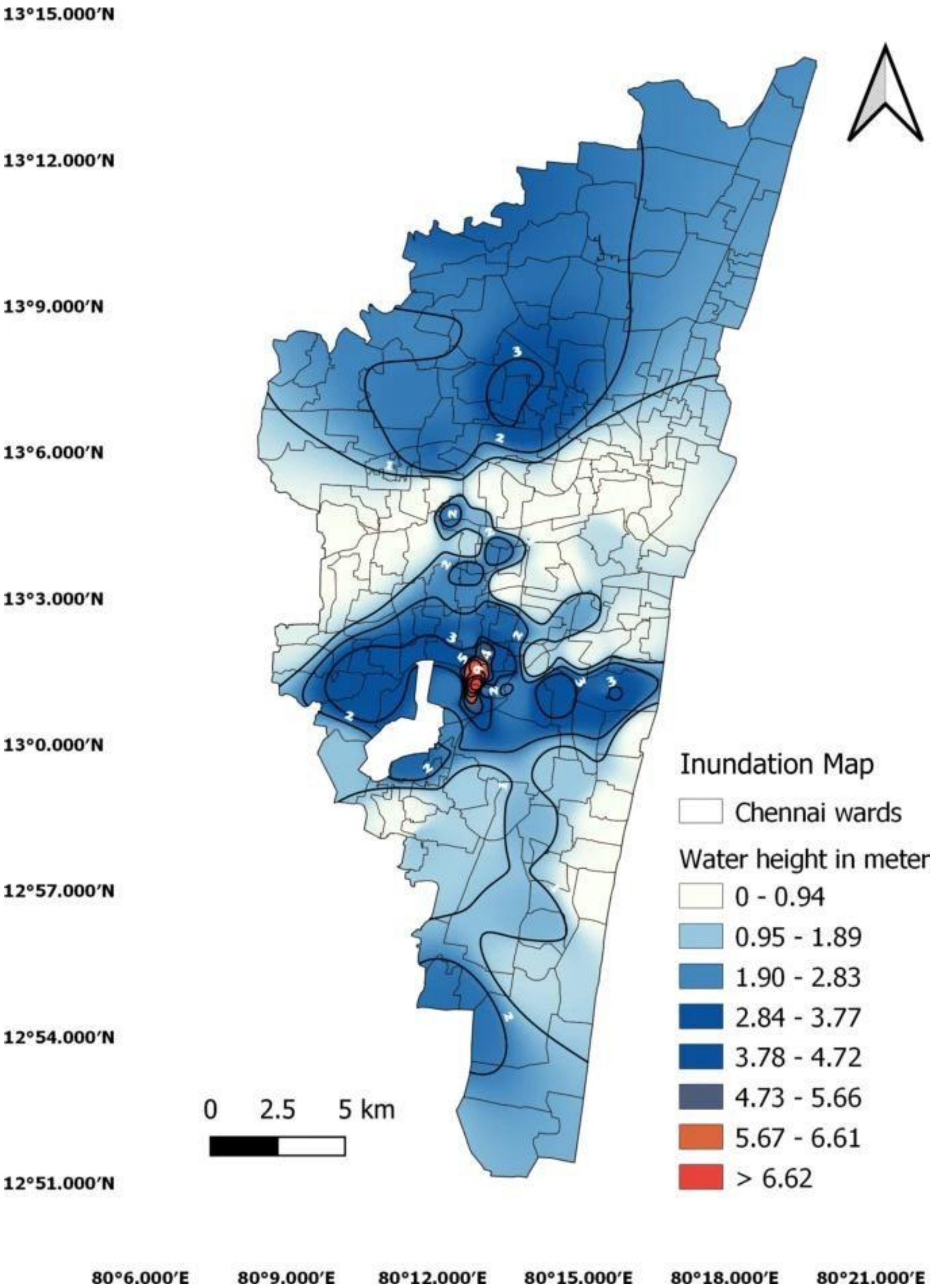


Fig 5 : Water inundation map after interpolation (source -geoenvironmental-disasters.springeropen)

2.6 : 2015 FLOOD ANALYSIS :

we found that the water depth of 4m is highest in the localities in saidapet, jafferkhanpet and ashok nagar, Chembarambakkam is an active tank that supplied water to city during the flood, breached due to unexpected heavy downpour,releasing thousands of cusecs of water in to adayar River.the areas around the adayar river that flows through the city lying close proximity to the adayar river were heavily inundated.That might be the reason for highest water depth in the above mentioned areas, as they were closely located to adayar river.

The interpolated map mentioned in the Fig 3, 4 and 5 also confirms that the areas round the adayar river had higher water depth.As per the results from the map aslo confirms that wards in kodambakkam (ward 141) and adayar (wars 171) zones had zones had water depth more than 6m.thes e both wards are located at the bank of the river. its also mentioned in the report as the worst affected areas in 2015 floods as (national remote sensing center).

2.5 TAMIL NADU FLOODS: LESSONS LEARNT AND BEST PRACTICES(NDMA)

2.5.1 :MEASURES TAKEN FOR BETTER PREPAREDNESS :

1. Master Plan 2030, drawing lessons from the 2015 deluge, is underpreparation. This will
2. result in an institutional framework to manage disasters of such magnitudeby way of a long term plan.
3. Long-term conservation and response plans are being drawn.
4. Regulation of tanks/reservoirs is being prepared.
5. Classification and subsequent mapping of both rural/urban areas to decide their vulnerability to flooding depending on inundation: 5ft. and above water high vulnerability; 2-3 ft. water - moderate vulnerability, less than 2 ft.water - low vulnerability.
6. Plans to deploy unmanned vehicles (drones) for aerial photography.
7. Proposal to equip SDRF with cranes of 100 tonnes capacity to removeblockages due to water hyacinths.
8. UAV photogrammetry of all rivers in rural areas.
9. Sea-side Storm Surge Modeling.
10. Study the designed discharge capacity of tanks as it may have cascadingeffects on breaching of tanks.
11. A compendium of water resources to be made public.
12. Constitute Inter-Departmental Teams with Team Leaders for pre-inspection and monitoring designated areas.
13. Identify escape routes to the nearest relief shelter on vulnerability maps.
14. Hospitals were asked to prepare their emergency plans.

2.5.2 :SPECIFIC RECOMMENDATIONS FOR GOVERNMENT OF TAMILNADU :

1. A high-level expert committee for Chennai city should be formed. This committee should be given adequate authority to take decisions on-site to appropriately regulate and release water from upstream lakes/tanks keeping in view hydrological and meteorological forecasts issued for the region. During heavy rainfall, this committee should have a fi nal say on releasing water from lakes/tanks/water bodies on the basis of reviewing the infl ow forecasts.

2. Chennai city should develop its own network of Automatic Weather Stations(AWS), say one station for every four sq. km., for effective monitoring of rainfall and issuing of warnings. These should be used in conjunction with satellite map animations, IMD warnings and flood forecasting software. It should address sudden thunderstorm flooding (20 mm/hr to 120 mm/hr), rapid moving weather disturbances, heavy rains due to various factors, etc.
3. Documentation of best practices and sharing the same in public domain so that other States may learn and mitigate risks of flooding based on Chennai's experience. This may also help other countries, especially the developing nations of Asia, plan flood rehabilitation efforts.

CHAPTER 3 : RESILIENCE STRATEGIES AND CASE STUDIES.

3.1 GENERAL :

Resilience is the ability of an individual, community, organization, or system to withstand, adapt to, recover from, and even grow stronger in the face of adversity, challenges, or unexpected events. Resilience is often associated with the capacity to bounce back from difficult situations, but it goes beyond mere recovery. It involves developing and maintaining the strength and flexibility to endure and thrive in the face of various stressors and disturbances.

When it comes to **urban resilience** against flooding, in the context of cities and urban planning, refers to the capacity of a city or urban area to withstand, adapt to, and recover from various shocks and stresses, while also maintaining or improving its essential functions, structures, and quality of life. Urban resilience encompassesthe ability of a city to respond effectively to a wide range of challenges, including natural disasters, climate change, economic fluctuations, public health crises, and social issues. It aims to make cities more adaptable, sustainable, and better prepared for uncertain and dynamic conditions.

In the urban paradigm, resilience is borrowed from understanding how ecological systems cope with external stressors.(Davic and Welsh 2004).

3.2 CASE STUDY 1 JAPAN-MAOUDC(METROPOLITAN AREA OUTERUNDERGROUND DISCHARGE CHANNEL)

Fig 6 : Location map of Japan

3.2.1 : INTRODUCTION:

Japan, an island country lying on the east coast of Asia. It consists of a great string of islands in a northeast-southwest arc that stretches for approximately 1,500 miles (2,400 km) through the western North Pacific Ocean. Nearly the entire land area is taken up by the country’s four main islands; from north to south these are Hokkaido (Hokkaidō), Honshu (Honshū), Shikoku, and Kyushu (Kyūshū). Honshuis the largest of the four, followed in size by Hokkaido, Kyushu, and Shikoku.

A. **CLIMATE :** Most regions of Japan, such as much of Honshu, Shikoku and Kyushu, belong to the temperate zone with humid subtropical climate (Köppen climate classification Cfa) characterized by four distinct seasons. However, its climate varies from cool humid continental climate that is almost similar to Indian climate conditions.

B. **POPULATION :** The population is primarily concentrated in lowland urbanareas, Particularly in those of the Kanto, Chubu, and Kinki districts along thePacific coast of Honshu. The census of 1991 pegged the population of Japan at about 123.6 million, the seventh largest population in the world following China, India, the former USSR, the USA, Indonesia and Brazil. Japan's population density, 327 persons/km2, is one of the heaviest in the world.

C. HISTORY OF FLOODS IN JAPAN

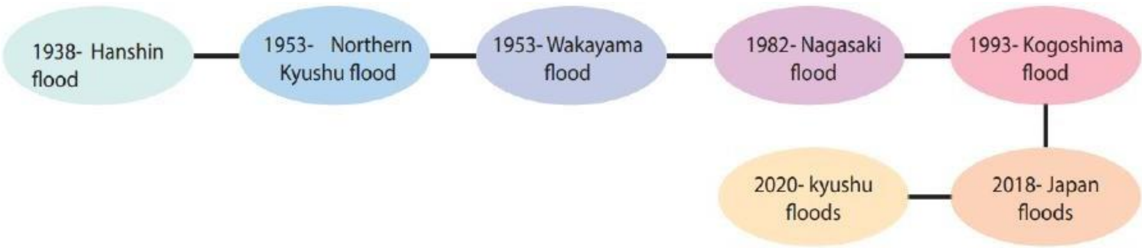


FIG 7 : HISTORY OF FLOODS IN JAPAN

D. TOPOGRAPHY MAP OF JAPAN

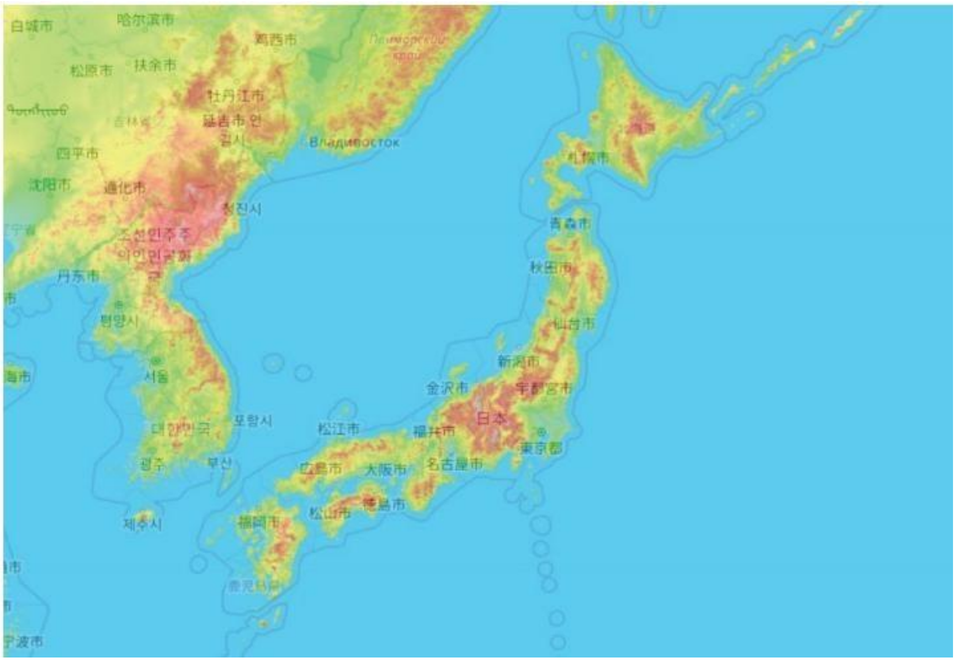


Fig 8: Topography map of Japan

Topography of Japan is basically spinal higher grounds and surrounding are lower grounds where kasukabe city in saitama prefecture has the major areas in lower grounds which are highly prone to floods where they came up with underground channels to drain the storm water. In particular, due to the remarkable shift of population and social assets into urban areas since the period of high economic growth began in the 1960's, urbanization has progressed in the areas with a high risk of disasters near lowland marshes, alluvial fans and clis. Today, 48.7% of the population and 75% of holdings are located within the ood-prone areas of rivers (1985).

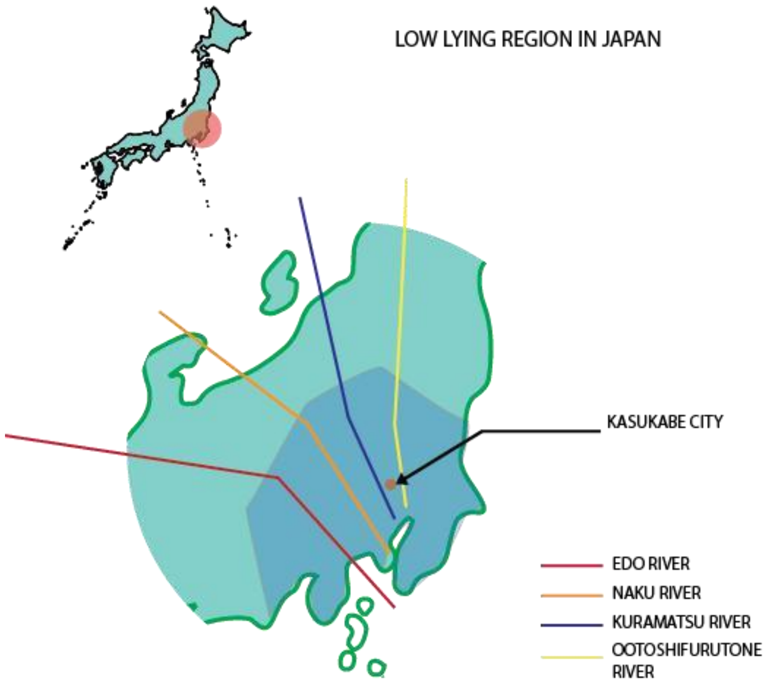


FIG 9 : Proposed zone for underground channels in japan

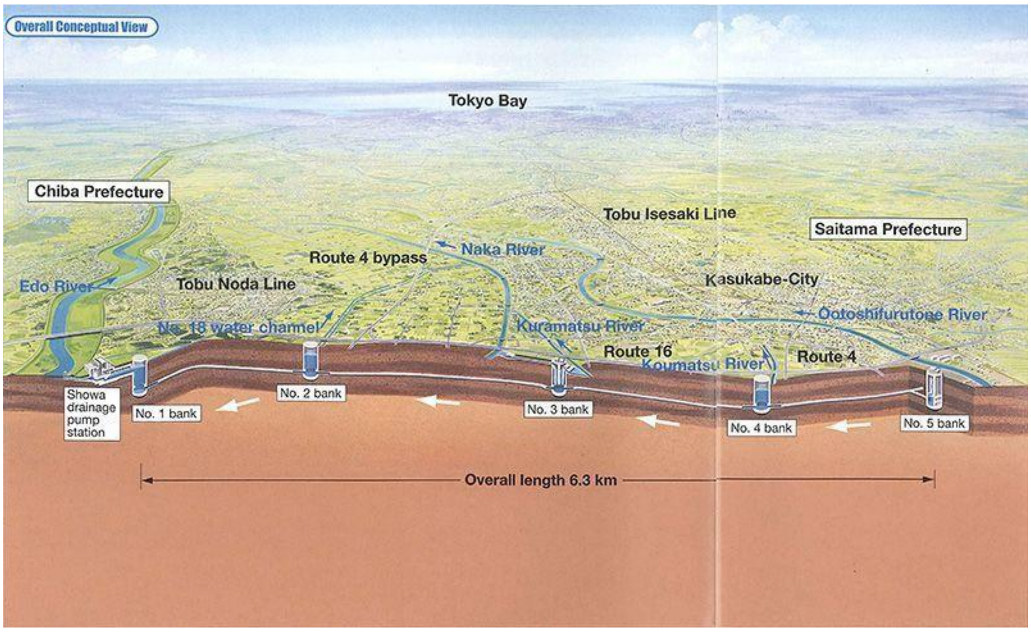


Fig 10: Overall view of the Metropolitan Area Outer Underground DischargeChannel.

3.2.2 ABOUT THE UNDERGROUND DISCHARGE CHANNEL:

World-class underground discharge channel has been constructed on the outskirts of Tokyo, the capital of Japan. The tunnel, dug about 50 meters below ground, extends 6.3 km in total. The underground construction, comprising vertical shaftsto store goodwater – which look more like gigantic tanks – and a mammoth water tank supported by towering pillars weighing 500 tons each, is far beyond anyone's wildest imagination. It was planned as an anti-ood scheme for local residents and completed in 2006. The underground discharge channel, having employed a varietyof new technologies, is the very best of Japan's state-of-the-art civil engineering technology.

3.2.3 GIGANTIC UNDERGROUND SHAFT :

A. Japan is a long ribbon of islands stretching north to south, divided by a spine of steep mountains occupying 75% of the land. Steep rivers owing into the ocean easily overflow when heavy rain falls. So, Japan's export to develop good-control technology dates back to the ancient past. The Metropolitan Area Outer Underground Discharge Channel, an underground discharge channel constructed in Saitama Prefecture adjacent to Tokyo, represents technological innovations accumulated over many centuries.
B. The discharge channel is a mechanism to drain water from flooded residential areas into ve gigantic vertical shafts built below ground and then discharge it into rivers through an underground tunnel connecting the shafts.

3.2.4 SPECIFICATION OF UNDERGROUND SHAFT :

The cylindrical shafts are about 70 meters tall. The large shafts measure about 30 meters in diameter, spacious enough to park a space shuttle.

The connecting tunnel 50 meters below ground measures about 10 meters in diameter. The tunnel stretches for 6.3 km, including a sharp curved line witha minimum radius of 250 meters.

The tank is designed to perform multiple functions, including abating the force of running water and adjusting water pressure that could change sharply if a water pump breaks down. Measuring 177 meters long and 78 meters wide, and lying about 22 meters below ground, the water tank is larger than a soccer pitch. The ceiling of the water tank is supported by 59 pillars which are 18 meters tall and weigh 500 tons each. An inside look at the tank structure conjures up the image of a “temple” below ground.

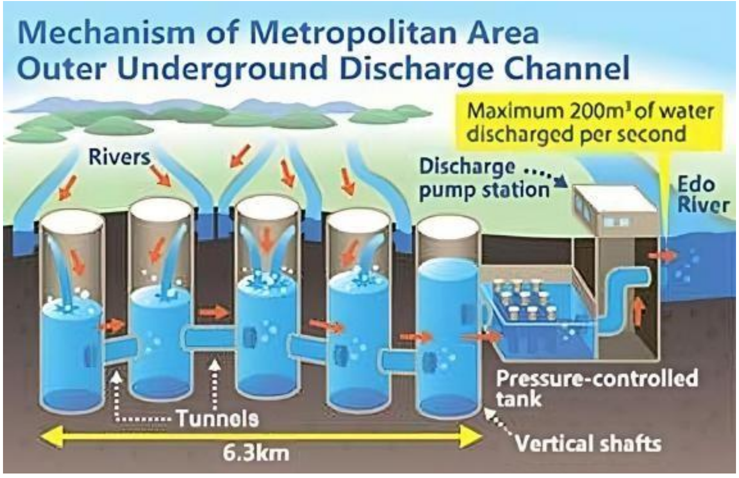


FIG 11: A schematic of the Metropolitan Area Outer Underground Discharge Channel that drains Flood water below ground, stores it and eventually dischargesit.

3.2.5 PROJECT IMAGES :

Fig 12: before and after the Discharge Tunnel was opened in 2004 right side and2000 left side at saitama prefecture

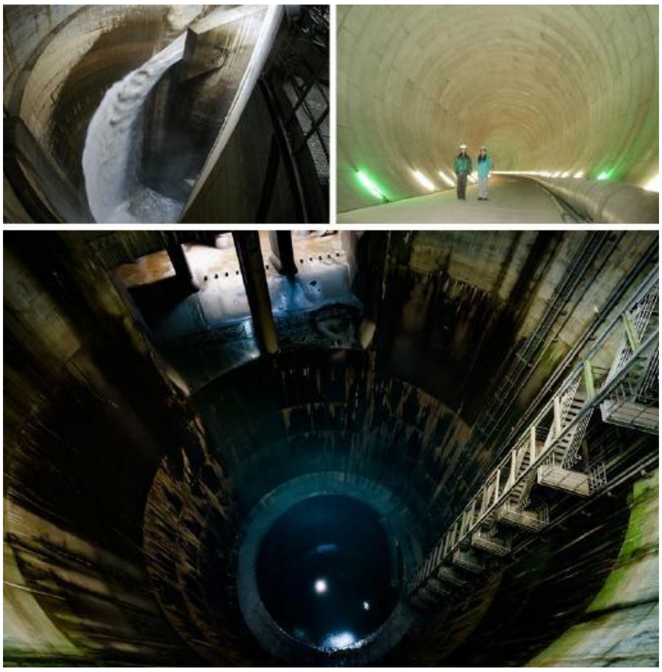


Fig 12: Water flowing into a containment silo. Upper right: Inside the huge, 10-meter diameter underground tunnel. Bottom: Looking down into silo No. 1,which could easily house the space shuttle.

3.3 CASE STUDY 2 CHINA - QUNLI STORMWATER PARK HAERBINCITY, HEILONGJIANG PROVINCE

3.3.1 : INTRODUCTION:

The Qunli Stormwater Park in Haerbin City, Heilongjiang Province, China isan example of an innovative strategy to make a city more resilient to floods. The park is a former wetland that was transformed into an urban stormwater park, which provides multiple ecosystem services for the new community. The park acts as a green sponge, cleansing and storing urban stormwater and can be integrated with other ecosystem services including the protection of native habitats, aquifer recharge, recreational use, and aesthetic experience, in all these ways fostering urban development. The park has been listed as a National Urban Wetland and has become a popular urban amenity. The park's design illustrates the principle that cities need to 'make friends with the flood'. The park's design strategies are multifaceted and multi-layered, including nature-based solutions, early warning systems, emergency evacuation strategies, spatial planning, and green infrastructure.

Fig 12 : sponge cities in china

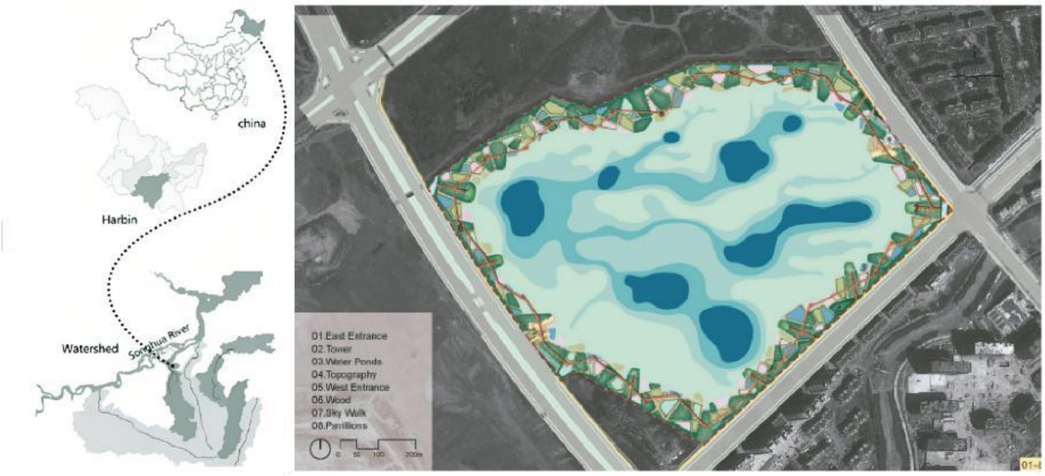


FIG 12 : Location map of the project

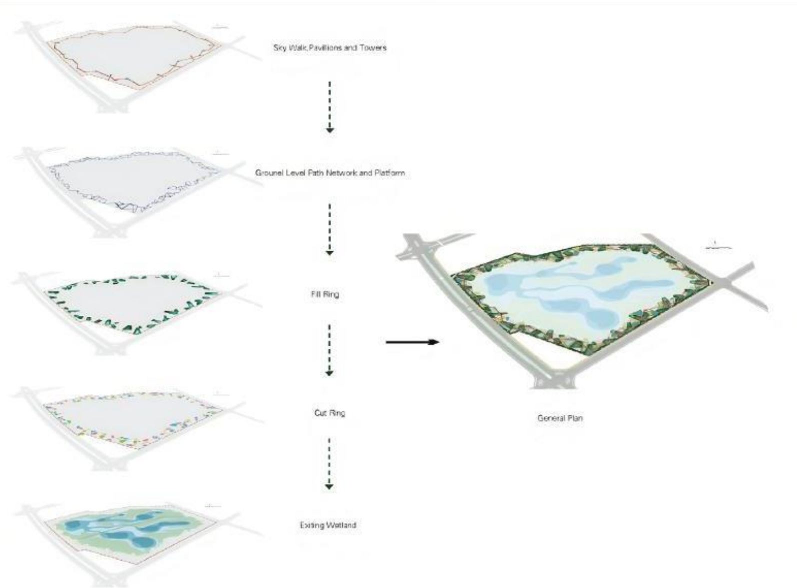


Fig 13: Design strategies in layers

International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

3.3.2 :DESIGN CONCEPT AND STRATEGIES :

1. Leave the nature core alone: The central part of the existing wetland is untouched and left alone for the natural process to domain for evolution and transforming.
2. Cut-and-fill strategy to create an outer ring. The next strategy was to createa necklace of ponds-and-mounds surrounding the former wetland using simple cut-and-fill technique. This pond-and-mound peripheral ring surrounding creates a stormwater filtration and cleansing buffer zone for the core wetland, and a welcoming landscape filter between nature and city. Stormwater from the newly built urban area is collected into a pipe around the circumference of the wetland, and then released evenly into the wetland after being filtered and deposited through the ponds. Native wetland grasses and meadows are grown in the ponds of various depths and the natural evolution process is initiated. Groves of native silver birch trees (Betula) are grown on the mounds of various heights that create a dense forest setting.
3. The path and platforms: On the ground level, following the cut-and-fill water filtration land form, a network of paths are built into the pond-and-mound ring allowing visitors to have a walk- through-forest experience. Seats are put into the ponds to allow people to have close contact with nature.
4. The upper layer above the natural landscape: A skywalk links scattered mounds allowing surrounding residents to have an above-the-wetland and in-the canopy experience. Platforms, pavilions and viewing towers are set on the mounds and are connected by the skywalk to allow visitors to have distant views and observe the nature in the center. Through the transformation of this dying wetland, stormwater that frequently causes flooding has now become a positive environmental amenity in the city. The Stormwater Park now has been listed as a national urban wetland park. This project demonstrates an ecosystem services oriented methodology to urban park design, and is a showcase for this water urbanism approach.

3.3.2: SPONGE SYSTEM :

Fig 14: Sponge system

The resulting Qunli StormWater Park has diverse habitats and acts as an urban parkthat collects storm water from the new urban district being built around it. Storm water services by gathering, cleaning, and storing it,entering an aquifer, defending it, and recovering native species habitats, as well as assisting with flood mitigation.Qunli is one of the Sponge Cities promoted by the Central Government of China to innovate an old sewer system for draining rain water with the aim to meet the target of 80% of urban areas collecting 70% of the rainwater by 2030.

3.2.4 PROJECT IMAGES :

Fig 14: the various pavilion and levels in the project

Qunli is one of the Sponge Cities promoted by the Central Government of China to innovate an old sewer system for draining rain water with the aim to meet the target of 80% of urban areas collecting 70% of the rainwater by 2030. Urban floods brought on by storm water have become a global problem due to the growth of urbanization and the unpredictable precipitation brought on by climate change. As a result, the multifunctional strategy utilized with storm water parks for the management of wetlands is becoming more and more popular internationally.

3.4 CASE STUDY 3: MUMBAI

3.4.1 : INTRODUCTION:

With a population of 20.7 million, Mumbai is currently the sixth-largest metropolitan agglomeration in the world. With a significant commercial and trading basis, the city serves as India's financial capital. The city is an essential portof entry and strategic from a defensive standpoint. Mumbai can be found on the originally a group of seven islands, the Arabian Sea located on the western coast of India. These islands have been connected since the 17th century by reclamation and draining the development of causeways and breakwaters to create the present-day landmass.

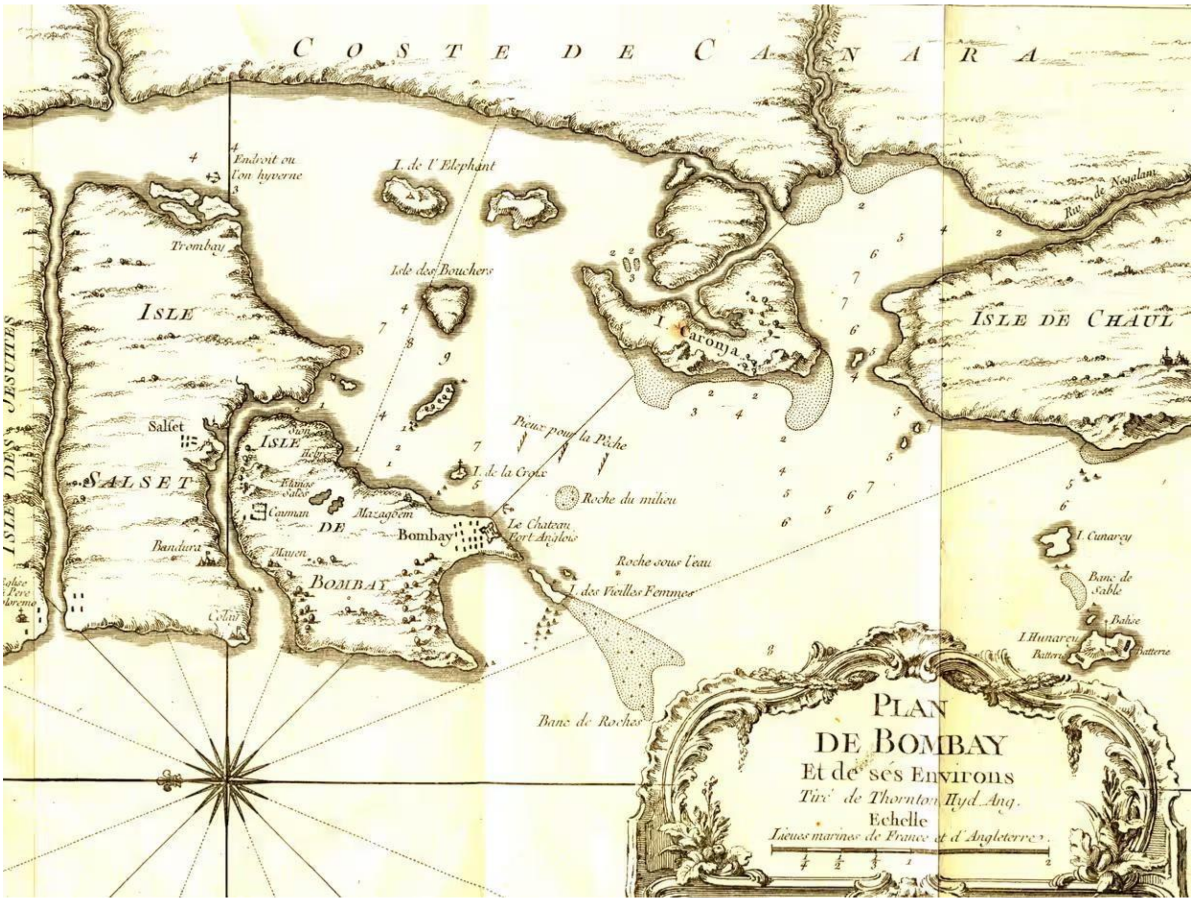
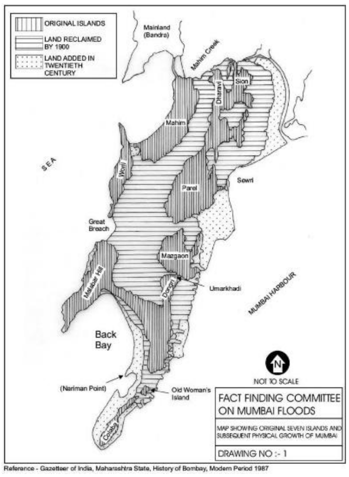


Fig: Map of bombay before the reclamation.

1. RAINFALL:

The average annual rainfall of Mumbai City as recorded by the Colaba meteorological station of IMD located at the southernmost tip of the city while that for the suburbs is 2300 mm as recorded at Santa Cruz, located 27 km away to the north. Monsoon rainfall occurs primarily from June to October, and about 70 % of the average annual rainfall occurs in Julyand August, and 50 % of this occurs in just 2 or 3 events. During these 2-3 events, it usually rains uniformly over the city, and severe flooding occurs in many parts.

2. ISLANDS OF MUMBAI AND LAND RECLAMATION:



B. Fig : Reclamation map of mumbai

Mumbai is divided into two revenue districts: Mumbai city district, which has been managed by the Municipal Corporation of Greater Mumbai, and created as a result of the union of seven islands through extensive reclamation from the sea between 1784 and 1845). These seven islands wereformerly given to King Charles II of England as a dowry from the Portuguese in 1661. The islands were in 1668 Tenanted for £10 to the East India Company. 1877 saw the transfer of power to the throne of Britain. Due to ongoing land reclamation, the former island of Salsette and the former Trombay Island were combined to establish the Mumbai suburban district in 1961. That being said, the Thane Municipal Corporation owns a tiny portion of Salsette Island's northern region. Mumbai and the Indian mainland are divided by the Thane and Salsette-Mumbai creeks. Consequently, the Arabian Sea and Thane Creek encircle Mumbai.

3. POPULATION DENSITY : The average population density is 27,209 persons per sq km while some areas, for example Ward 'A' has a daytime (floating) population density as much as 394,390 persons per sq km and the night-time population is 200,000 persons with a density of 17,528 persons per sq km. There are a large number of vulnerable informal settlements, many of them located on the flood plains of the Mithi River and the open storm water drains. About 65% of the Mumbaites live in informal settlements and over 2,768,910 structures - residential, commercial and industrial are listed with the Municipal Corporation of Greater Mumbai (MCGM). The Mumbai population is projected to reach 25 million before 2025.

3.4.2 : FLOOD MAP ANALYSIS:

International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

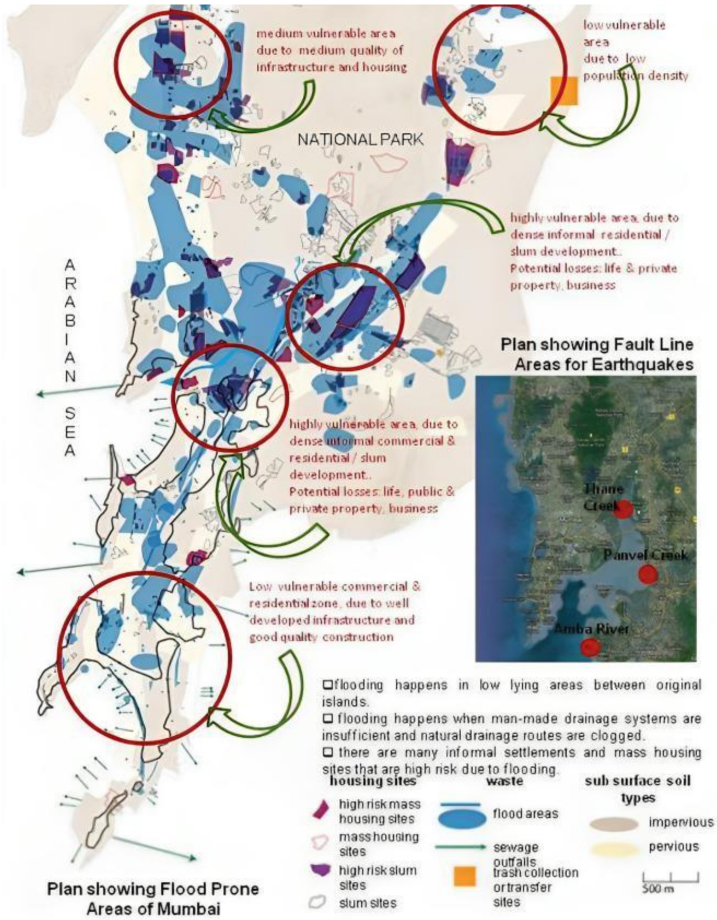


Fig : Flood risk map of mumbai

3.4.3 : FLOOD MITIGATIONS:

A. INSTITUTIONAL MECHANISMS:

Several institutional mechanisms have been strengthened - the Mumbai Disaster Management Committee headed by a very senior bureaucrat, the MCGM Disaster Management Committee headed by the Municipal commissioner and the Ward Disaster Management Plan headed by the Assistant Commissioner of the ward. Rainwater harvesting has been made compulsory for development on areas greater than 1000 sq. m. - this would ensure that no additional runoff reaches the drains from new developments.

B. EMERGENCY CONTROL CENTRE:

There are multiple conference rooms, press rooms, networked computers with disaster management software, televisions connected to major news stations, and a plethora of communications technologies. A backup generator, an uninterruptible power supply, and emergency water and ration supplies are also available.

C. AUTOMATIC WEATHER STATION:

in order to maintain the security of the instrument (protection from vandals) and the first responders status of the re and rescue services, the weather stations have been positioned atop there stations at each site. The locations of the remaining weather stations are at the MCGM headquarters, which houses the emergency control center, and the catchments of Tulsi Lake, Vihar Lake, and Powai Lake (at IIT Bombay).

D. REMOVAL OF SOLID WASTE FROM STORMWATER

E. RESPONSE MECHANISMS

3.5 STRATEGIES FOR URBAN FLOOD RESILIENCE:3.5.1: WATER SENSITIVE URBAN DESIGN (WRI)

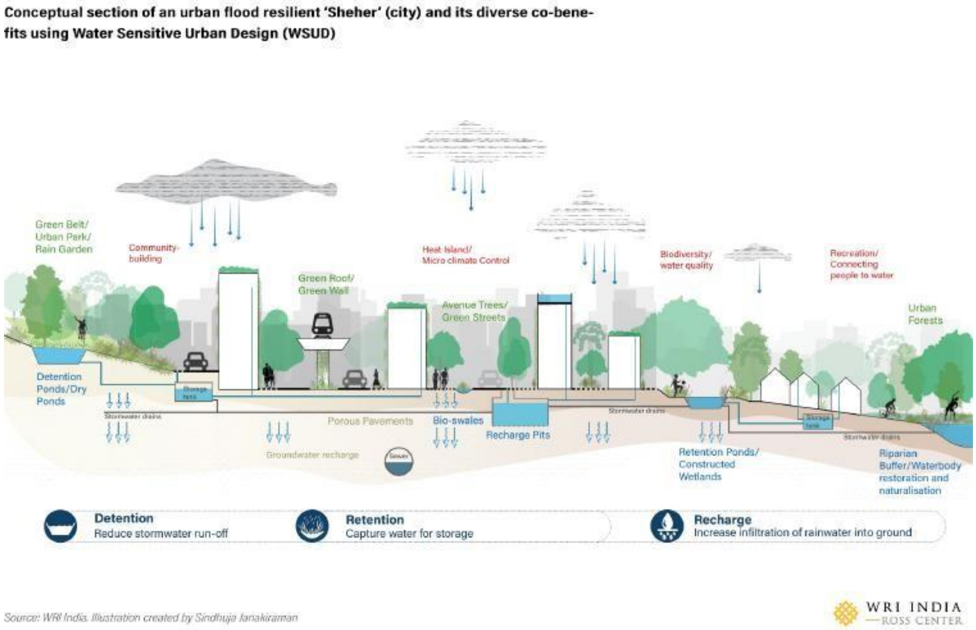


Fig: conceptual sketch for urban flood resilience

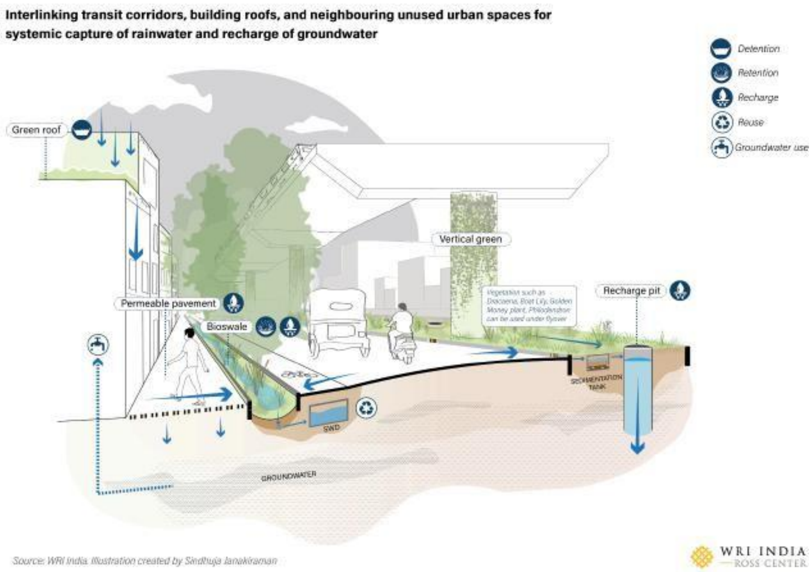


Fig: conceptual sketch for multiple tactics to control flood

3.4.3: URBAN BLUE-GREEN ACUPUNCTURES:

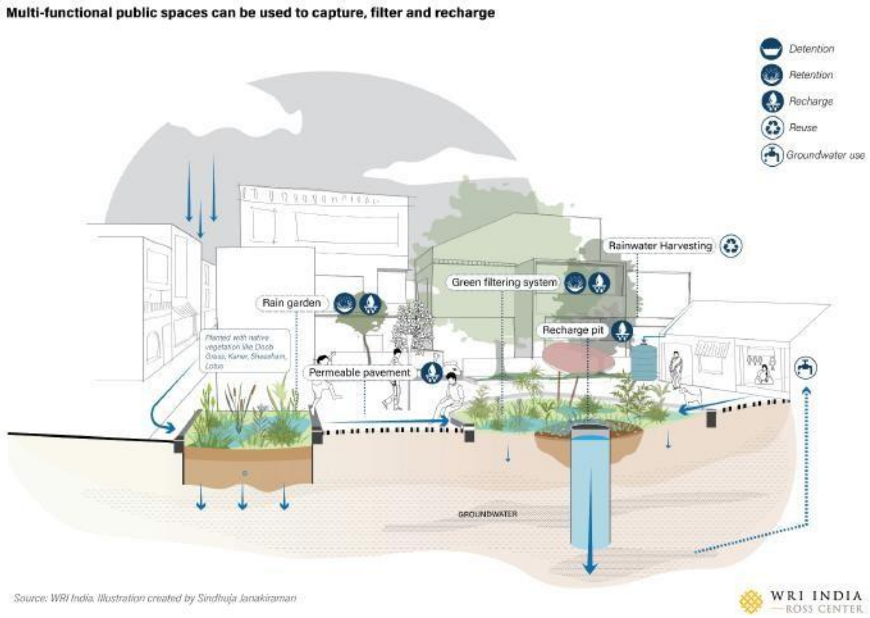


Fig : Multifunctional public space can be used to capture, filter and recharge.

The DRR concept can be applied to areas with high levels of public activity, such as parking lots, market places, sports venues, transit hubs, etc. These public areas can also take advantage of the surrounding neighborhood parks, corner greens, and buffers to create blue-green acupunctures on different sizes by developing them holistically. It is also possible to combine multiple acupunctures into one design.
Recharge wells, for instance, could be a feature of a stormwater park that enhances the area's general quality of life. If the local groundwater table is short, native plants can be used to purify the water collected in these wells; if the table is deep, the water can simply be let to naturally retain and replenish.

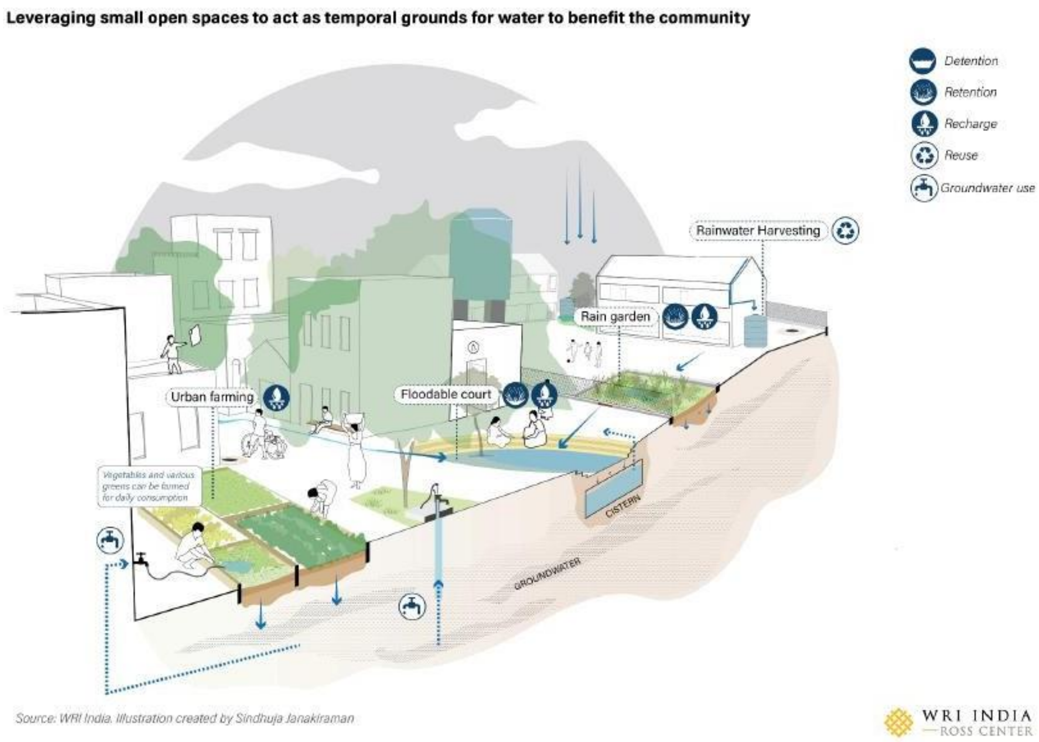


Fig : Leveraging small open spaces to act as a grounds for water to benefit thecommunity

There is no one solution that works for all urban cities when it comes to managing water resources; each one has unique complications. The main lesson is to gain a thorough contextual understanding of a city's natural infrastructure layer in order to support the Detention-Retention-Recharge stormwater management strategy for later use. The implementation of these intended ideas will require additional enablers, even though sound planning and design for water sensitive areas are essential. To mention a few, there are sophisticated data about a city's different socio-spatial and environmental layers available, creative finance and financing choices, cross-agency governance (such a joint benefits authority), active community engagement, and technological advancements. Without a place-based, systems thinking approach, all of these imagined conceptualizations for Sheher will fail and cities will overflow.

3.5.2: SUSTAINABLE URBAN DRAINAGE SYSTEMS (SUDS)

International Journal for Multidisciplinary Research (IJFMR)

E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

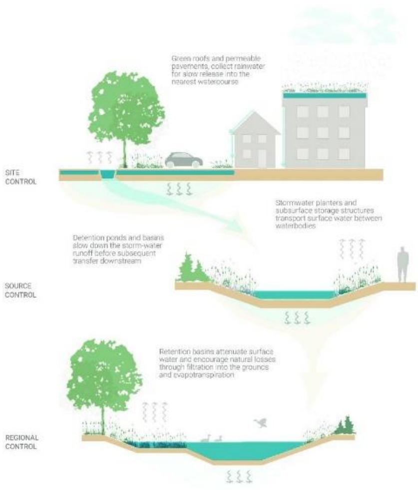


Fig: methods for sustainable urban drainage system

International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

3.5.2 : CITY OF 1000 LAKES :

Fig : Concept of connecting lakes

The goal is to clean up various contaminated water sources to the point that they can be recycled, groundwater recharged, and applied to land. A regional, metropolitan vision and strategy that outlines the fundamentals and guidelines for incorporating locally occurring natural processes and nature-based solutions (NBS) into the urban fabric to prevent pollution, floods, and droughts while also providing drinking water and reusable recycled water is part of the City of 1,000 Tanks program. The program anticipates growth in both the periurban area and the inner city within its bounds (from FSI 1.5 to FSI 2.3) during the course of the next ten years.

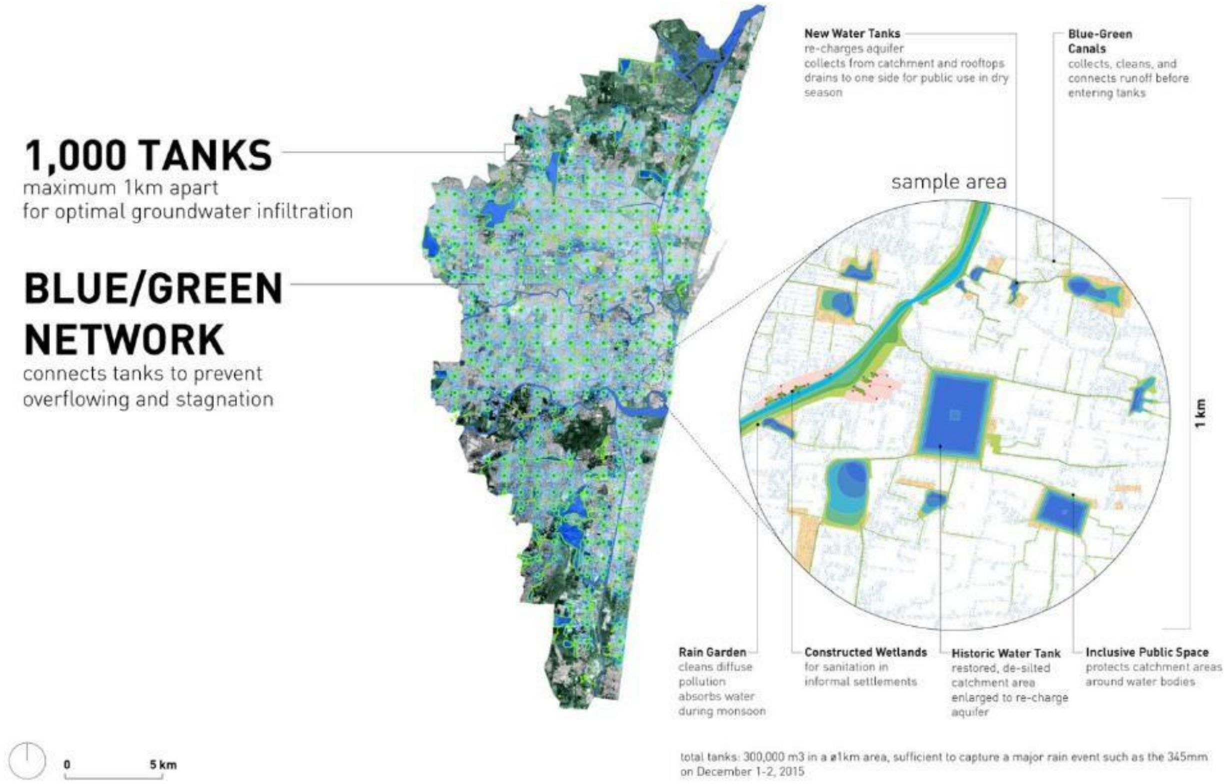


Fig : City of 1000 tanks master plan

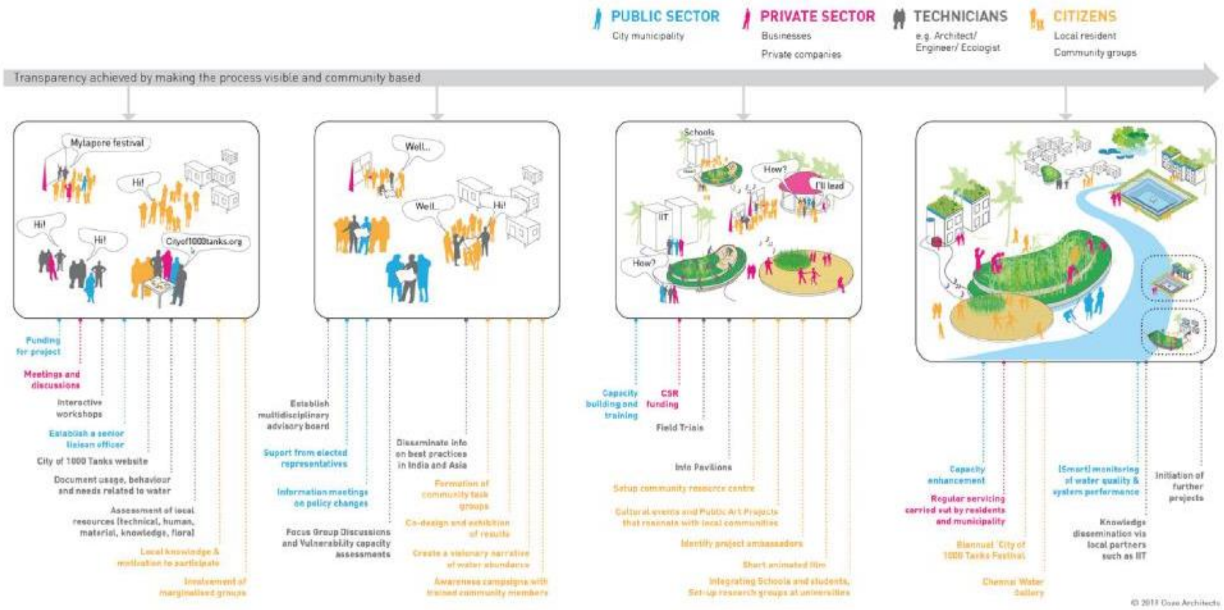


Fig: Community based design representation

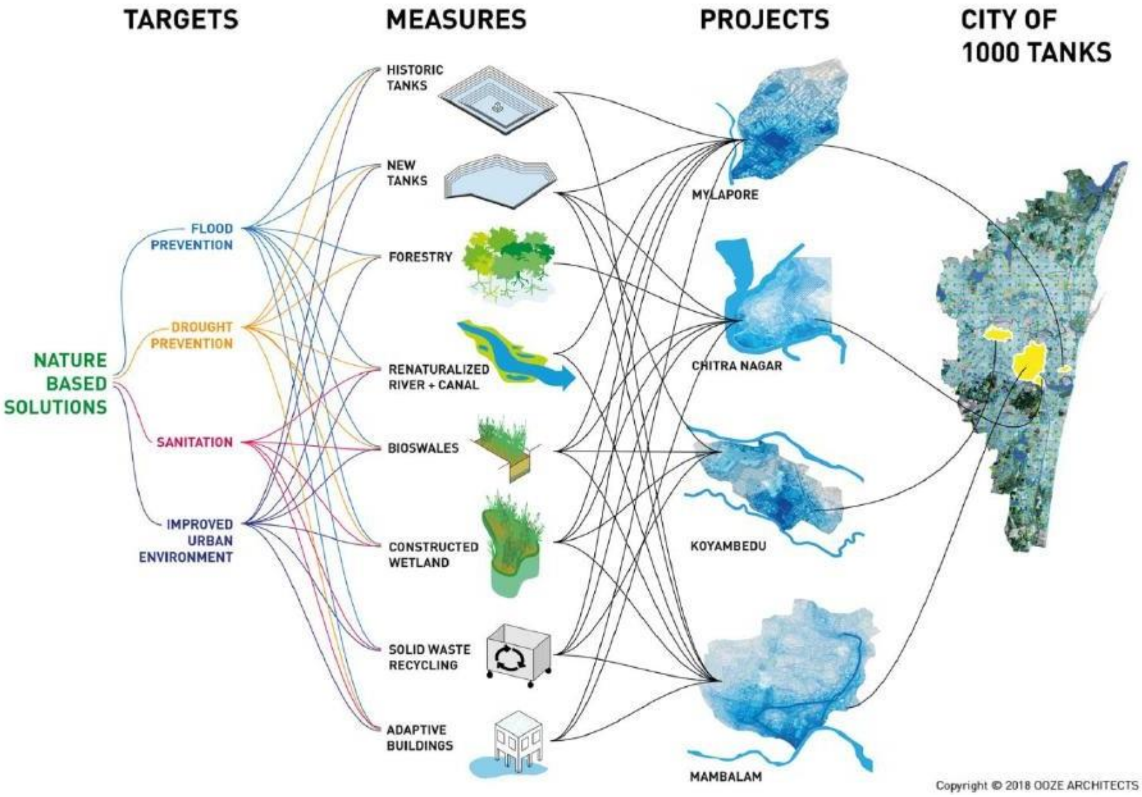


Fig : Holistic strategy applying an array of natural based solutions

3.5.3 DESIGN FOR FLOODING: ARCHITECTURE BY DONAL WATSONAND MICHELE ADAMS

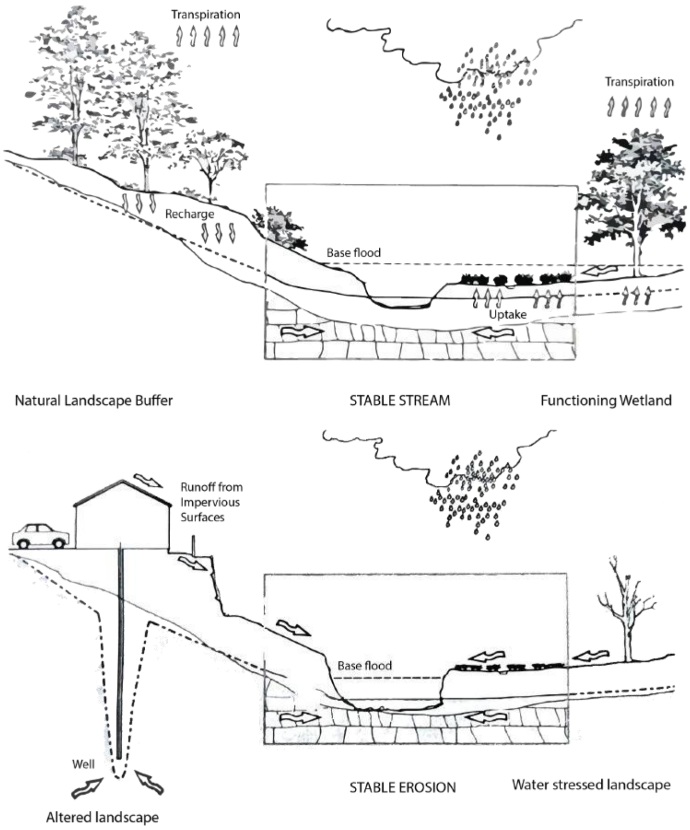


Fig: Natural and altered streamflow.

A. As the groundwater levels drops from natural conditions (above), the streamchannel may drop below connection to the flood plain (below)

1. **Tree trenches and structural soil cells:** A tree trench is a linear water management feature consisting of trees planted in amended planting soils designed to capture runoff from adjacent impervious areas. Trees trenches are suitable in linear areas with limited space to manage stormwater, such as along streets. In addition to managing stormwater, tree trenches enhance aesthetics by providing greening, improving air quality and reducing the urban heat island effect. Trees trenches are cost effective as a storm water and landscape improvements in highly developed areas and along roads. By providing soil and water availability to tree roots bulbs, tree trenches facilitate healthier and long lasting urban treescapes.

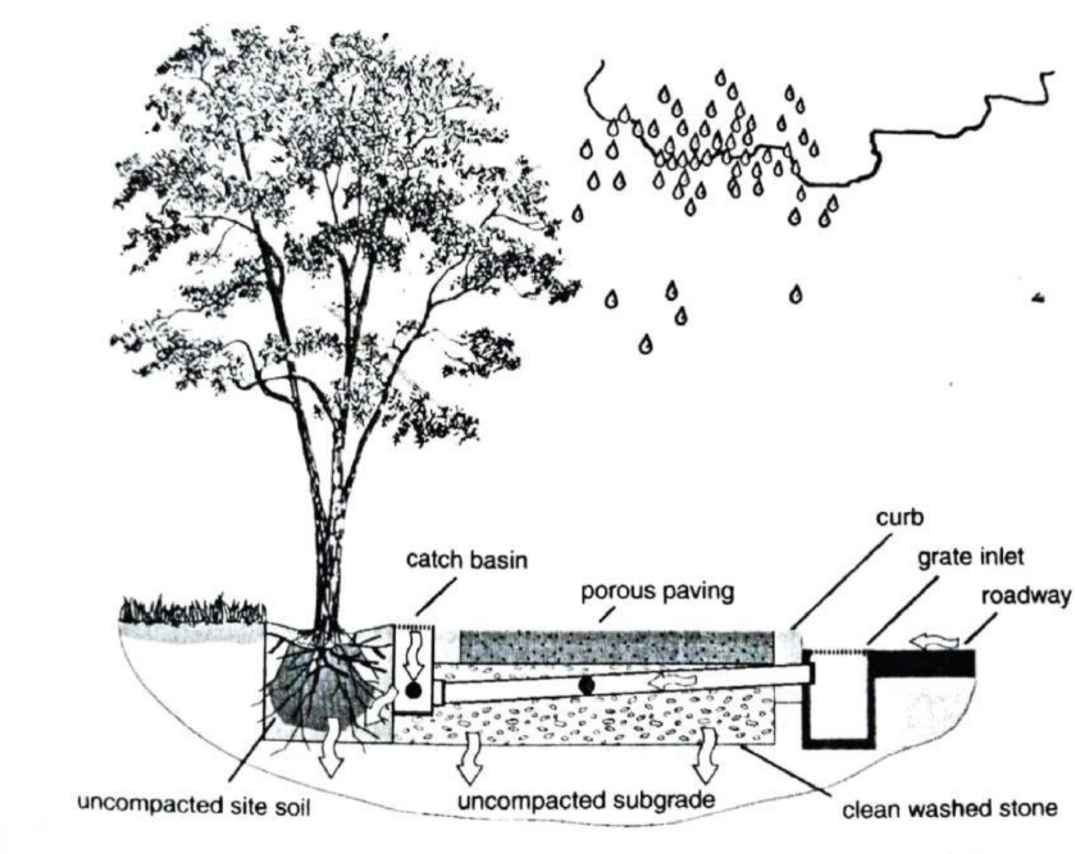


Fig : Tree trench system systematic

B. **RAIN GARDENS AND SMALL BIORETENTION AREAS:** A rain garden, also called a bioretention area, is a shallow depression intended to capture and soak up runoff from roofs or other impervious areas around buildings, driveways, walkways, and even compacted lawn areas. Rain gardens help to manage small storm events. They can be constructed with a subsurface sand or gravel bed for additional water storage capacity and an overflow to relieve larger rainfall events. A rain garden typically is filled with several feet of amended soils and planted with native vegetation.

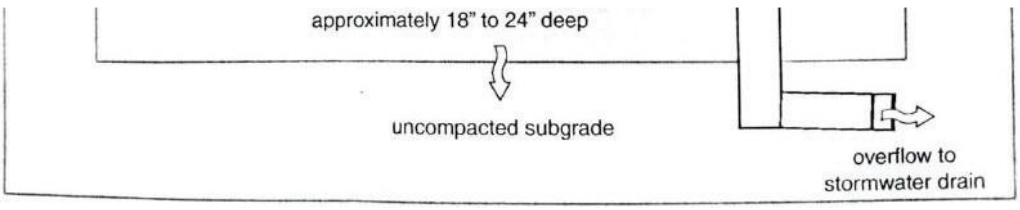


Fig: Bioretention swale schematic

CHAPTER 4 :FINDINGS AND DISCUSSION :

4.1 PORTFOLIO OF CHENNAI MAPS :

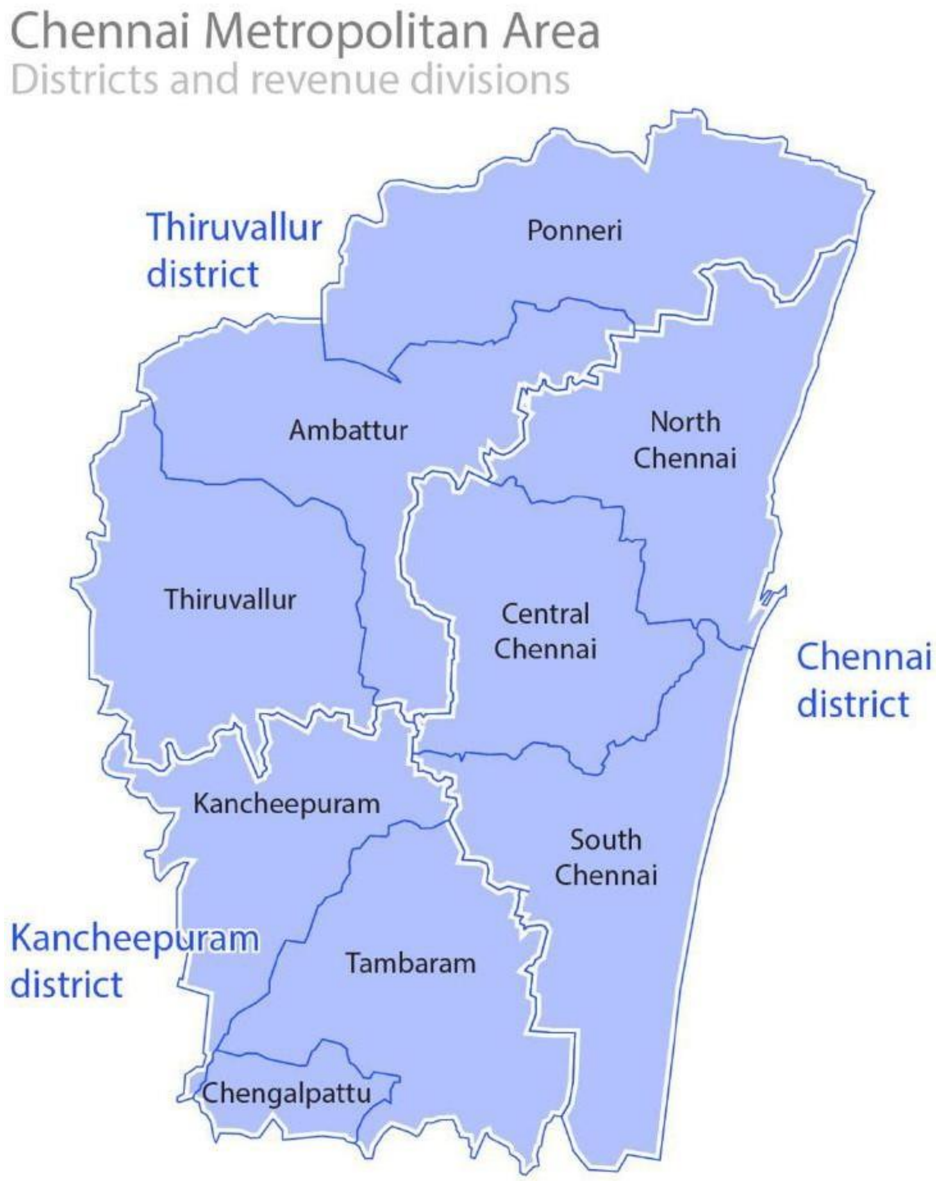
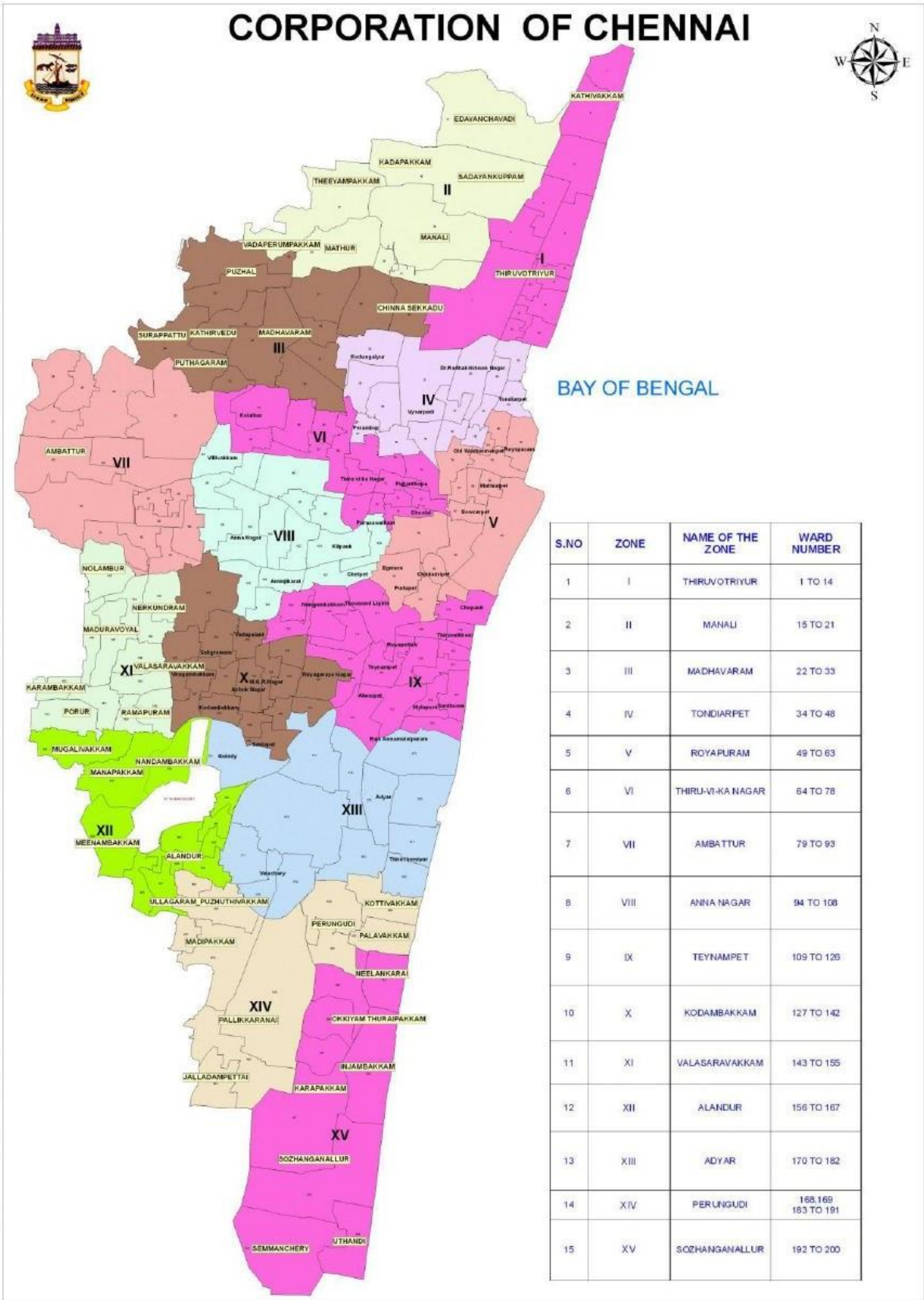


Fig : Chennai city limit map

International Journal for Multidisciplinary Research (IJFMR)

E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Fig : Chennai Map



S.NO	ZONE	NAME OF THE ZONE	WARD NUMBER
1	I	THIRUVOTRIYUR	1 TO 14
2	II	MANALI	15 TO 21
3	III	MADHAVARAM	22 TO 33
4	IV	TONDIARPET	34 TO 48
5	V	ROYAPURAM	49 TO 63
6	VI	THIRU-VI-KA NAGAR	64 TO 78
7	VII	AMBATTUR	79 TO 93
8	VIII	ANNA NAGAR	94 TO 108
9	IX	TEYNAMPET	109 TO 126
10	X	KODAMBAKKAM	127 TO 142
11	XI	VALASARAVAKKAM	143 TO 155
12	XII	ALANDUR	156 TO 167
13	XIII	ADYAR	170 TO 182
14	XIV	PERUNGUDI	168,169 183 TO 191
15	XV	SOZHANGANALLUR	192 TO 200

Fig : Ward map of Chennai

Fig : Water bodies in and around the cities

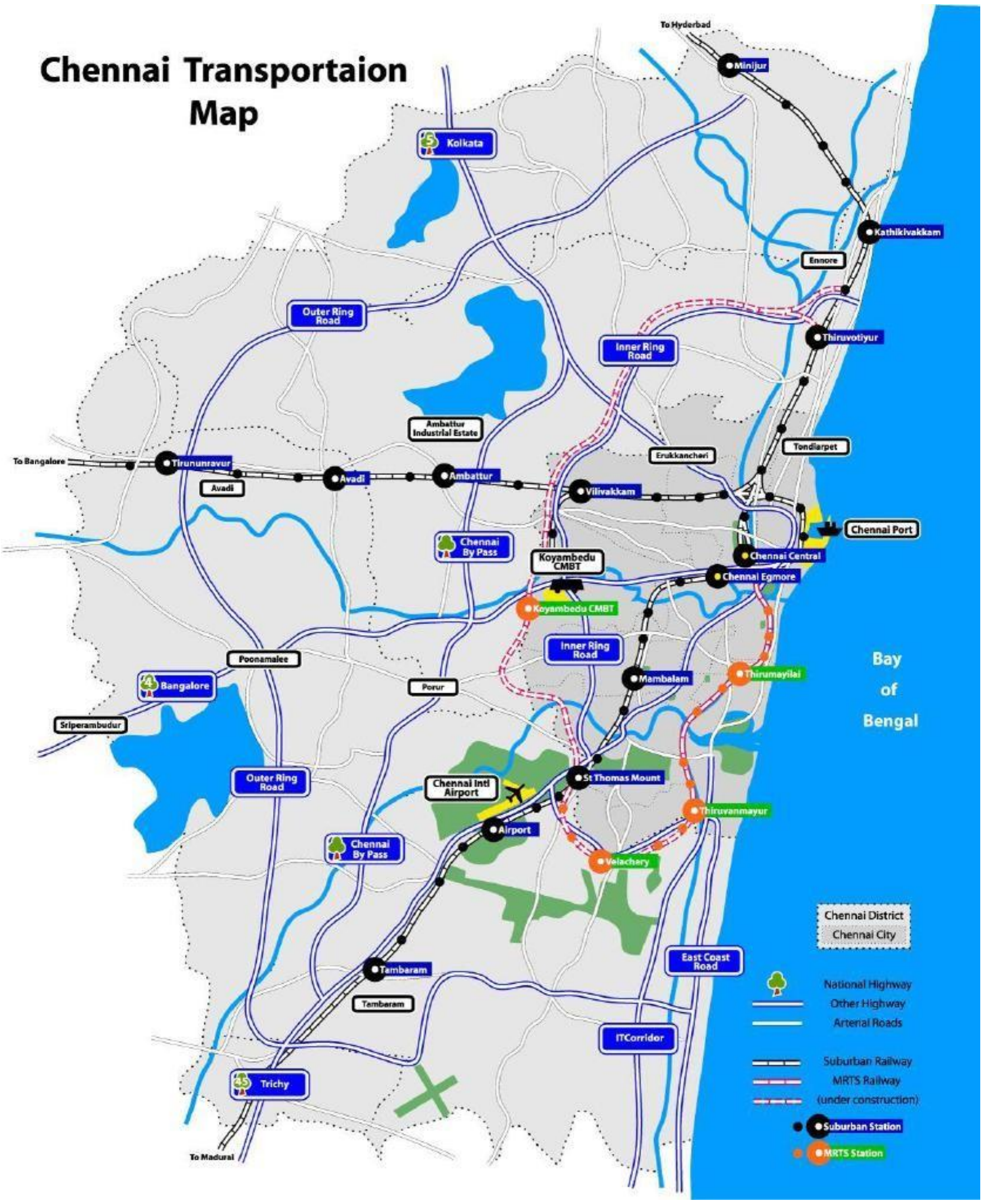


Fig: lake maps of Chennai

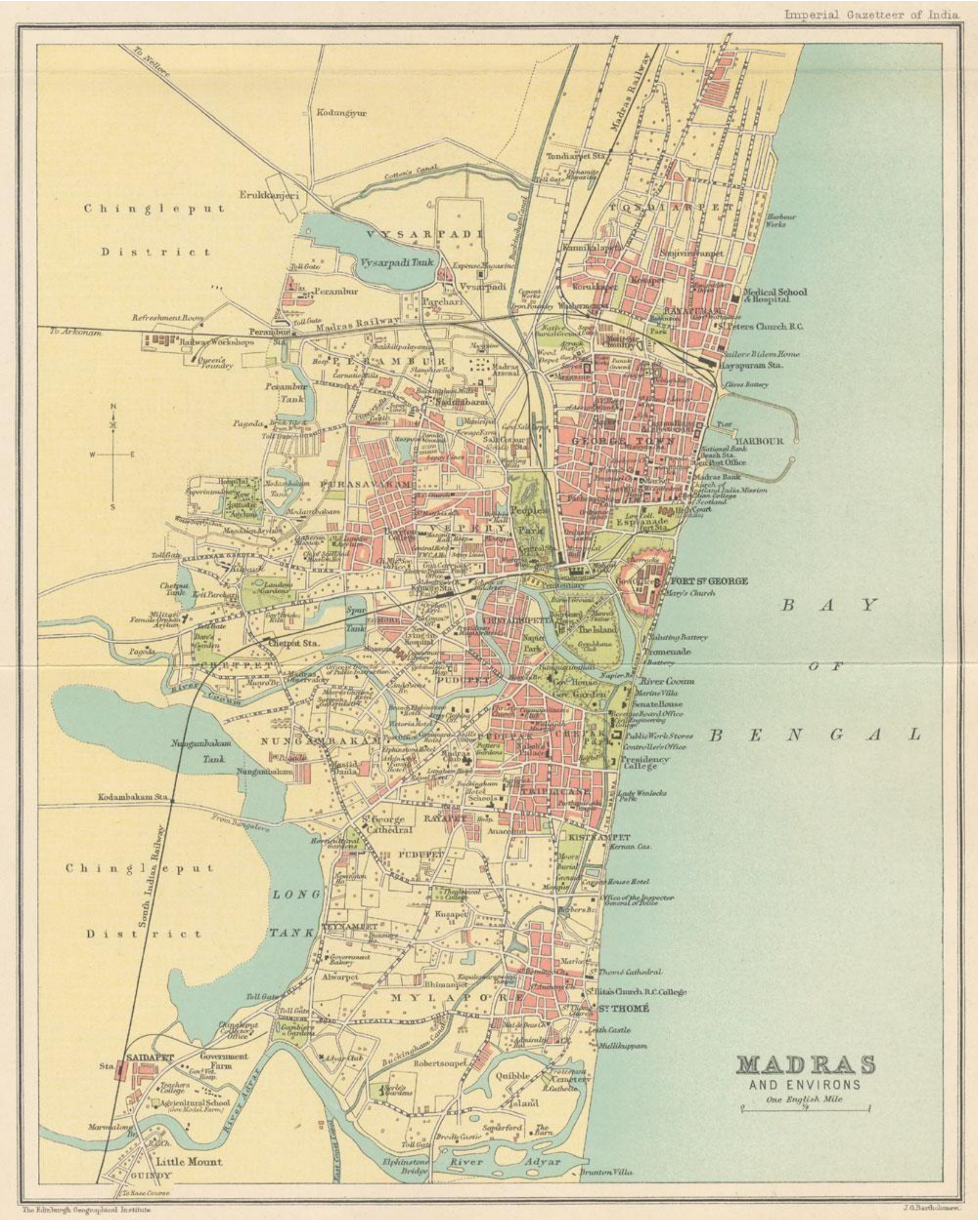


Fig : Old map of Chennai

4.2 IDENTIFIED MACRO LEVEL CAUSES AND LOCATION OF FLOODWITH APPICABILITY FOR CHENNAI :

4.2.1 SEA

A. **Type Of Flood :** Coastal

B. **Causes and intensity of flood**: Cyclones, Storm Surges, Tidal flooding, Tidal backflows that run through the rivers and affect the main city.

C. **Other problems:** Sea level rise, Coastal erosion in North towards Ennore, Formation of sandbars at

Ennore creek, Coastal accretion along Adyar and Cooum river mouths.

D. **Solutions/key features identified :** Although it is impossible to completely stop sea level rise, the government must have strategies for it in addition to evacuation procedures. Ecological measures can mitigate coastal erosion. Expansion along the coast will add more area.River mouths must be cleaned on a regular basis, nevertheless, to ensure that water outflow is unaffected.

E. **Applicability , Scale of Intervention – Community /govt/ combined :** Governments, NGOs, coastal settlers, and other stakeholders would need to hold open, inclusive meetings in order to develop a long-term sustainable solution. Regulation of real estate is also necessary.

4.2.2 CANAL

A. **Type Of Flood :** Storm surge.

B. **Causes and intensity of flood**: Acts as a barrier between Sea and Land as an inland waterway Storm Surge/Tsunami, excess rainfall

C. **Other problems:** It is difficult to link to other water bodies because untreated sewage effluents and other debris, such as plastics, prevent water from being safely discharged.

D. **Solutions/key features identified :** 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.

E. **Applicability , Scale of Intervention – Community /govt/ combined :** Combined intervention will be the only sustainable solution as it gives ownership and distribution of workload to citizens and Government alike. Public Private partnerships PPP can also be promoted, though there should be a policy that prevents any vested interests.

4.1.3 LAKES

Type Of Flood : pluvial

A. **ACauses and intensity of flood**: retains more water However, it also has encroachments and trash that have caused lakes to disappear entirely or partially.

B. **Other problems:** lakes being filled in to make way for new construction, with no upkeep. the disposal of industrial waste.

C. **Solutions/key features identified :**With ecological interventions, these water bodies can be cleaned and given new life.

D. **Applicability , Scale of Intervention – Community /govt/ combined :** Lakes, tanks, and other bodies of water ought to be transferred from private ownership to specific neighborhood associations. - Governo: Citizen groups made up of locals, government officials, and other interested parties.

4.1.4 RIVER

A. **Type Of Flood :** Riverine

B. **Causes and intensity of flood**: Flooding downstream occurs when an excessively abrupt outflow from reservoirs upstream flows into the sea.To exacerbate the situation, tidal backflows that force water backward from draining into the sea flood the surrounding area along the river and as far as the water may travel.Additionally, backflows from the rivers meet and flow through the metro rail traffic corridors.

C. **Other problems:** Contaminated rivers even though they carry water from the very source that supplies the city's entire water supply.
D. **Solutions/key features identified :** These water bodies can be cleaned with ecological interventions and a new life can be given to it.
E. **Applicability , Scale of Intervention – Community /govt/ combined :** Lakes, tanks, and other bodies of water ought to be transferred from private ownership to specific neighborhood associations. - Governo: Citizen groups made up of locals, government officials, and other interested parties.

4.2 URBAN FLOOD INUNDATION MITIGATION SOLUTIONS :

A. Causes and intensity of flood: The city as a whole and the three districts of Chennai, Thiruvallur, and Kancheepuram at the regional level should take into consideration a water master plan. Storm water drain networks need to be strengthened and even supplemented at the neighborhood and zone levels. In places where natural water flow has been blocked, neighborhoods have flooded. Subterranean train routes are extremely dangerous and may require closure when floods occur.

B. Solutions/key features identified :

1. The loss of lakes, tanks, rivers, wetlands, and marshes is a stark example of the city's disregard for natural drainage.
2. Stakeholders must be brought together immediately, and policy changes, eviction orders from the courts, and attempts to bring all water bodies together under one non-politically driven entity must all be prioritized.
3. It is necessary to add to and strengthen storm water drains with parks, retention basins, marshes, and other ecological interventions like vertical gardens, pavement greening, permeable pavement, and roadways.
4. Neighborhoods and houses need to be encouraged and forced to save rain water in overhead tanks and have permeable grounds, waffle gardens etc.
5. Waffle gardens can also be promoted in areas adjoining the marsh to help restore the balance and retention capacity.
6. 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.

C. Applicability , Scale of Intervention – Community /govt/ combined :

1. PPP for the city's stormwater infrastructure, which includes the MRTSand adjacent areas' vertical gardens and permeable materials.
2. Government needs to provide infrastructure to neighborhoods.
3. In order to establish community water supply grids that will mandate a park and a water storage facility for each area, there should also be Governo - Citizen groups that are backed by the government.

SUMMARY : During monthly progress meetings, all stakeholders.micro and macro should be held accountable.The public and final users must be involved in the open planning process. Enforcement of pollution control is necessary. Every member of the public society, regardless of background.All stakeholders and the team of professionals working on the systems must use an efficient, non-egoistic approach in order to plan them. instead of having split factions that are unwilling tocome together out of a need for acceptance.

CHAPTER 5 : CONCLUSION:

Fig: intervention map for Chennai

In Conclusion , the research gives holistic recommendations of urban resilience to floods in the Chennai region. The suitable strategies are suggested to various ecological factors and regions that are vulnerable to flood in the chennai region.

REFERENCE/ BIBLIOGRAPHY:

1. Associated Programme on Flood Management - Factors related to causes offlood. (Pg no- 6)
2. Urbanization and climate change impacts on future urban flooding in CanTho city, Vietnam By H. T. L. Huong and A. Pathirana.
3. Flood types - Flood types (floodsite.net)
4. University of georgia - institute for resilient infrastructure system- Developing Flood Solutions Along the Mississippi and Missouri River Basins
5. The 20 cities most vulnerable to flooding. (n.d.). Retrieved from http://www.livescience.com/38956-most-vulnerable-cities-to-flooding.html
6. Hallegatte, S., Green, C., Nicholls, R. J., & Corfee-Morlot, J. (2013). Future flood losses in major coastal cities. Nature Climate Change, 3(9), 802-806. doi:10.1038/nclimate1979
7. Flood risk and context of land-uses: Chennai city case - Anil K. Gupta* and Sreeja S. Nair 2010.
8. Swamy, G.S.N.V.K.S.N., and Nagendra, S.M.S., (2016) "Study of Urban Heat Island (UHI)
9. Chennai Floods (2015) and Possible Solutions from Developed Countries Saravanan J, Naveen Chander K.
10. Near real time flood inundation mapping using social media data as an information source: a case study of 2015 Chennai flood. Retrieved from
11. https://geoenvironmental-disasters.springeropen.com/articles/10.1186/s40677-021-00195-x
12. ssOn the ecological roles of salamanders by Davic RD, Welsh HH Jr (2004) - https://www.jstor.org/stable/30034122
13. Resilience and stability of ecological systems by Holling C (1973)- https://www.jstor.org/stable/2096802
14. Land and climate conditions of Japan Retrieved from - I.Land and Climateof Japan (mlit.go.jp)
15. Effects of the underground discharge channel/reservoir for small urban rivers in the Tokyo area retrieved from https://iopscience.iop.org/article/10.1088/1755-1315/703/1/012029/pdf
16. "Underground Temple" Safeguards Greater Tokyo from Floods Retrieved from https://www.nippon.com/en/views/b06302/?pnum=2
17. Differences in Environmental Information Acquisition from Urban Green—A Case Study of Qunli National Wetland Park in Harbin, China retrieved from https://www.researchgate.net/publication/346018508_Differences_in_Environmental_Information_Acquisition_from_Urban_Green-A_Case_Study_of_Qunli_National_Wetland_Park_in_Harbin_China/download?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6Il9kaXJlY3QiLCJwYWdlIjoiX2RpcmVjdCJ9fQ
18. The Qunli storm water park in china to retain and filtrate storm water by Kim Assael retrieved from shttps://architypereview.com/project/qunli-stormwater-wetland-park/ 19.Urban planning - With incomplete details of water bodies, Chennai's master plan is a recipe for yet another disaster Retrieved from https://scroll.in/article/813912/with-incomplete-details-of-water-bodies-chen nais-master-plan-is-a-recipe-for-yet-another-disaster
20. https://www.theguardian.com/cities/2016/mar/30/story-cities-11-reclamation -mumbai-bombay-megacity-population-density-flood-risk

21. Creating a flood resilient Indian 'Sheher' through Water Sensitive Urban Design retrieved from https://wri-india.org/blog/creating-flood-resilient-indian-%E2%80%98shehe r%E2%80%99-through-water-sensitive-urban-design
22. https://www.researchgate.net/figure/Tools-for-Sustainable-Urban-Drainage- Systems-SuDS-HCC-2015_fig5_356442825
23. City of thousand lake retrieved from https://www.cityof1000tanks.org/
24. http://www.ooze.eu.com/en/urban_strategy/city_of_1000_tanks_chennai/#:~:text=City%20of%201%2C000%20Tanks%20intends,both%20to%20the%20underground%20aquifer.