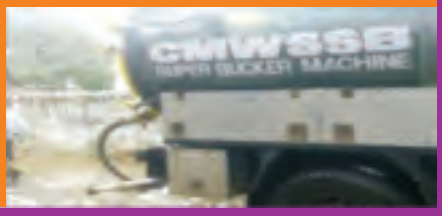
सत्यमेव जयते

CHENNAI FLOOD 2015



nidm
Resilient India - Disaster Free India

National Institute of Disaster Management
(Ministry of Home Affairs, Government of India)

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CHENNAI FLOODS 2015

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FOREWORD

Urban flooding has become a serious concern across the globe caused by rapid urbanisation and the changing climate. The occurrences of flooding have almost become an annual phenomenon in many cities over the last few decades. Urban flooding affects a huge number of people with deaths, injuries, displacement and loss of livelihoods. Flooding of urban areas even disrupts economic activities and incurs infrastructural damage resulting in huge economic loss.

Urban flooding is the interplay of various natural and human factors and has particularly become a concern globally due to increasing population and developmental challenges. The scenario of urban flooding in India is no different with more than one-third of the country's population already living in its urban areas. There has been an increasing trend of flooding in Indian towns and cities, of which the most recent ones are Hyderabad (India) Floods of 2020, 2019 Indian Flood which was a series of floods in Indian cities including Pune, Thane, Patna and Vadodara, Mumbai Floods in 2017, 2005 and Chennai Floods of 2015.

The Chennai Floods of 2015, which was triggered by the Northeast Monsoon coupled with development factors, was one of the deadliest floods that have occurred in the country. The 2015 floods of Chennai affected more than four million people in and around the city and caused a huge economic loss of around 3 billion USD. The severe impacts incurred due to the unregulated development indicate that there is a need for a holistic approach for the mitigation and management of urban flood risks.

This book has documented the event of Chennai Floods of 2015 in all its dimensions encompassing the causes, impact, response, relief and recovery activities. It also reflects upon the lessons learnt and decisions that have been taken in terms of land use planning norms and development regulations as an aftermath of this flood.The book intends to pave a way forward for strengthening flood-resilient urban development in the country.

(Manoj Kumar Bindal)

ACKNOWLEDGEMENT

The fatal consequences of the Chennai Floods of 2015 have revealed that the unregulated and erroneous development in the riverbanks and marshy lands to accommodate the rapidly growing urbanisation was at the root of it. The authors thus have attempted to document the catastrophe of 2015 covering the causes, impacts and relief and response activities to consolidate the lessons learnt during this disaster. The vision of this book is to build and strengthen flood resilience in Indian towns and cities by promoting a prevention-based approach instead of a relief-based approach and raising awareness at the community level.

The book would have been a distant reality without the contribution of many experts in this field. First of all, the authors would like to thank Major General Manoj Kumar Bindal, VSM, Executive Director of NIDM, for his immense support and guidance to conduct the study. We take this opportunity to acknowledge with gratitude the contribution of Shri Shekher Chaturvedi, Faculty, NIDM and team member in the field visit and survey. We also extend sincere thanks to Prof. Santosh Kumar, Head, GiDRR Division, for helping us execute the study through his inputs and colleagues and staff of NIDM for their co-operation and support.

The authors extend their heartfelt gratitude to the Office of the Commissionerate of Revenue Administration & Disaster Management, Govt of Tamil Nadu who facilitated our field visit after the floods and hosted the team. We thank all officials of the then Tamil Nadu State Disaster Management Agency, (since renamed TNDRRA) and Tambaram municipality for all the help rendered to the team to complete the study.

We are immensely grateful to our reviewers, Dr. GP Ganapathy, Professor, Centre for Disaster Mitigation and Management, Vellore Institute of Technology and Major General (Rtd.) Dr. V.K Naik for their insightful comments and suggestions which helped us in giving the final shape to the document.

All lacunae and shortcomings, however, rest with the authors.

Chandyopadhyay

(Dr. Chandrani Bandyopadhyay Neogi)

Mohana Manna

(Ms. Mohana Manna)

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ABBREVIATIONS

AAI	:	Airports Authority of India
ADB	:	Asian Development Bank
AEE	:	Assistant Executive Engineer
AMC	:	Antecedent Moisture Condition (AMC)
AMRUT	:	Atal Mission for Rejuvenation and Urban Transformation
ATIs	:	Administrative Training Institutes
BIS	:	Bureau of Indian Standards
BMTPC	:	Building Materials and Technology Promotion Council
CAPF		Central Armed Police Forces
CBRI	:	Central Building Research Institute
CDEF	:	Civil Defence
CII		Confederation of Indian Industries
CMA	:	Chennai Metropolitan Area
CMDA	:	Chennai Metropolitan Development Authority
CMWSSB	:	Chennai Metro Water Supply and Sewage Board
CPHEEO	:	Central Public Health and Environmental Engineering Organisation
CRRI	:	Central Road Research Institute
CSIR	:	Council of Scientific and Industrial Research
CWC	:	Central Water Commission
DCR	:	Development Control Regulations
DDMA	:	District Disaster Management Authority
DFIN	:	Finance Department
DMD	:	Disaster Management Department
DOS	:	Department of Space
DRD	:	Department of Rural Development
EFD	:	Forest and Environment Department
F&ES	:	Fire and Emergency Services
FIHD	:	Department of Fisheries
GLOFs	:	Glacial Lake Outburst Floods
GoI	:	Government of India

HTL	:	High Tide Level
IAS	:	Indian Administrative Services
IE (I)	:	Institution of Engineers (India)
IMD	:	India Meteorological Department
INR	:	Indian National Rupee
IPCC	:	Intergovernmental Panel on Climate Change
IRD	:	Irrigation Department
ISDR	:	International Strategy for Disaster Reduction
IT	:	Information Technology
JICA	:	Japan International Co-operating Agency
LLOFs	:	Landslide Lake Outburst Floods
lpcd	:	Litres per capita per day
MAFW	:	Ministry of Agriculture and Farmers' Welfare
MCA	:	Ministry of Corporate Affairs
MCF	:	Ministry of Chemicals and Fertilizers
MEITY	:	Ministry of Electronics and Information Technology
MFIN	:	Ministry of Finance
MHA	:	Ministry of Home Affairs
MHIPE	:	Ministry of Heavy Industries and Public Enterprises
MHUA	:	Ministry of Housing and Urban Affairs
MOCI	:	Ministry of Commerce and Industry
MOEFCC	:	Ministry of Environment, Forest and Climate Change
MOES	:	Ministry of Earth Sciences
MOJS	:	Ministry of Jal Shakti
MORD	:	Ministry of Rural Development
MOSPI	:	Ministry of Statistics and Programme Implementation
MOST	:	Ministry of Science and Technology
MPFI	:	Ministry of Food Processing Industries
MSJE	:	Ministry of Social Justice and Empowerment
MWCD	:	Ministry of Women and Child Development
NBCC	:	National Buildings Construction Corporation
NCC	:	National Cadet Corps
NDMA	:	National Disaster Management Authority

NDRF	:	National Disaster Response Force
NGOs	:	Non-Governmental Organisations
NIDM	:	National Institute of Disaster Management
NLC	:	Neyveli Lignite Corporation Ltd
NLRTI	:	National Level Research and Technical Institutions
NRSC	:	National Remote Sensing Centre
NSS	:	National Service Scheme
OMR	:	Old Mahabalipuram Road
PRIs	:	Panchayati Raj Institutions
PWD	:	Public Works Department
RD	:	Revenue Department
RWH	:	Rain Water Harvesting
SDMA	:	State Disaster Management Authority
SDRF	:	State Disaster Response Force
SERC	:	Structural Engineering Research Committee
SIDM	:	State Institute of Disaster Management
SLRTI	:	State Level Research and Technical Institutions
SoI	:	Survey of India
SRSAC	:	State Remote Sensing Application Centre
SWD	:	Storm Water Drains
TNCP	:	Town and Country Planning Department
TNHB	:	Tamil Nadu Housing Board
TNSCB	:	Tamil Nadu Slum Clearance Board
TNSDMA	:	Tamil Nadu State Disaster Management Authority
UDD	:	Urban Development Departments
ULBs	:	Urban Local Bodies
UNDP	:	United Nations Development Programme
URDPFI	:	Urban and Regional Development Plan Formulation and Implementation
USD	:	United States Dollar
WMO	:	World Meteorological Organisation
WRD	:	Water Resources department
WSD	:	Water and Sanitation Department

INTRODUCTION

1.1 BACKGROUND

The increasing occurrence of urban flooding events has become a serious concern across the globe. Around 5 percent of the cities worldwide, according to the World Bank (2012), have witnessed more than 50 large flooding events at least once between 2003 and 2008. Both developed and developing nations are victims of urban flooding. The most affected country is China followed by India, Indonesia, Bangladesh, Vietnam, Thailand and Pakistan. The major urban floods witnessed over the last two decades are Hyderabad (India) Floods of 2020, 2019 Indian Flood which was a series of floods in Indian cities including Pune, Thane, Patna and Vadodara, Mumbai Floods in 2017 and 2005, Chennai Floods of 2015,2011 Bangkok Floods, 2010-2011 Queensland Floods, 2010 Rio Floods and 2008 Hanoi Floods. Many of these towns and cities are susceptible to repeated instances of flooding. The World Bank has reported that the recurrence of flooding in urban areas has risen to 19 percent in 2008. In 2010 alone, 178 million people were affected by floods. The last century has witnessed around 7,486 hydro-meteorological events. The frequency of urban flooding is further expected to rise in the upcoming decades owing to the increasing urbanization and climate risks.

Urban Floods affect a large number of people with deaths, injuries, displacement and loss of livelihoods. Flooding in urban areas has killed more than 0.5 million people worldwide and displaced over 650 million people from 1985 to 2014. Figure 1.1 shows the number of people displaced due to urban floods from 1988 to 2014. During this period, the highest displacement was witnessed in 1999 (57.1 million) followed by that of 2004 (51 million) and 2000 (50.3 million). The issue of displacement due to floods has severe implications with a huge number of people living in the floodplains, especially in developing countries. According to the International Disaster Database, the total losses due to urban floods exceeded 40 billion USD in the year 2010 itself. The total economic losses and damages reported from 1985 to 2014 are reported to be around 800 billion USD. The Queensland Flood of 2010-11 is considered as one of the most expensive floods in recent time with a loss of more than 10,000 USD. The Indian towns also face huge economic loss due to urban floods. For instance, the economic losses due to the Hyderabad Floods of 2020 is estimated to be around 681 million USD while during the Vadodara Floods, the Indian Railways alone incurred a loss of approximately 1.36 million USD (10 crores INR). The outbreak of epidemics and water-borne infection also arises as secondary impacts adding to the casualties of urban floods. Urban flooding is also responsible for huge economic losses and damage that further gets multiplied due to disruptions of services and increased health risks.

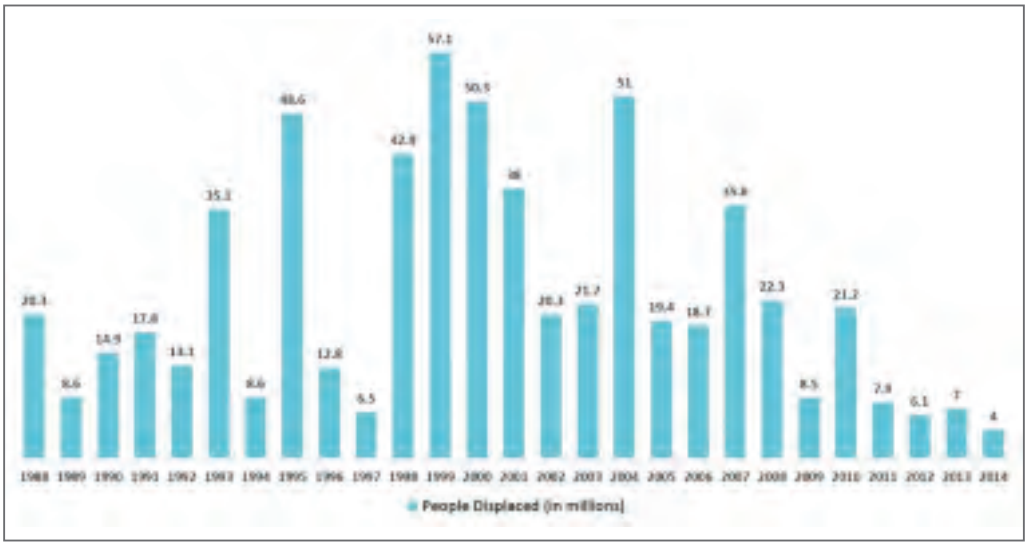


Figure 1.1: People displaced due to urban floods during the period of 1988-2014
Source: (Kocornik-Mina, McDermott, Michaels, & Rauch)

1.2 GENESIS OF URBAN FLOODS

Urban Floods typically result from the confluence of both meteorological and hydrological factors such as rainfall frequency and intensity, storms, temperature, etc. and exacerbated by human actions (WMO; Global Water Partnership, 2012). The replacement of earth's natural land cover and vegetation by impervious surfaces such as built-up structures and roads has raised the issues of inundation of urban over the last two decades. This is diminishing the natural storage capacity of the soil and alters the existing hydrological cycle often increasing the surface runoffs. According to the National Disaster Management Authority (NDMA), the volumes in case of urban floods can increase by upto 6 times while the peaks from

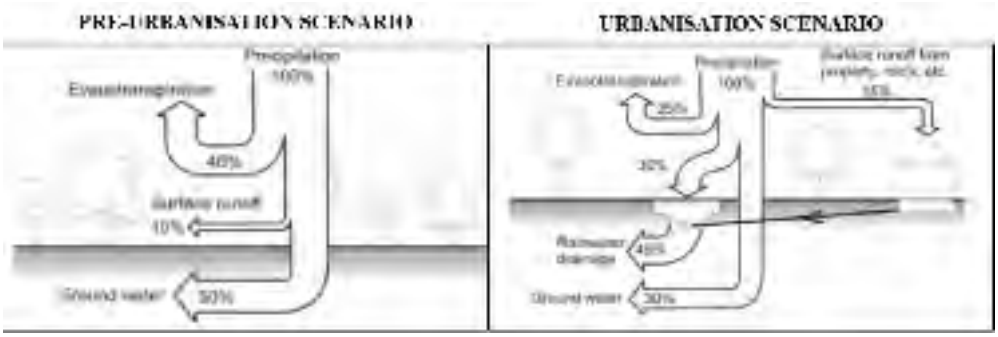


Figure 1.2: Water balance characteristics in an urban watershed
Source: (WMO; Global Water Partnership, 2012)

1.8 to 8 times in comparison to that of a rural flood. As a result, urban flooding can occur within a very short duration, sometime even within a couple of minutes due to high-speed flow. The artificial drainage channels that are constructed also fail to deal with the excess runoff creating inundation and flooding. Several issues like encroachment of river plains, land reclamation below flood level, disposal of wastes in water bodies, loss of natural drains and ponds, etc. also arise due to the increasing urban population. These urban challenges further get aggravated by impacts of climate change like increase in precipitation amount, the unpredictability of weather events, sea-level rise, etc. Figure 1.2 illustrates the impacts of urbanisation on water balance characteristics of any area.

The flooding in urban areas can be typically classified into local floods, riverine floods, flash floods, coastal floods (WMO; Global Water Partnership, 2008)(Tingsanchali, 2012).

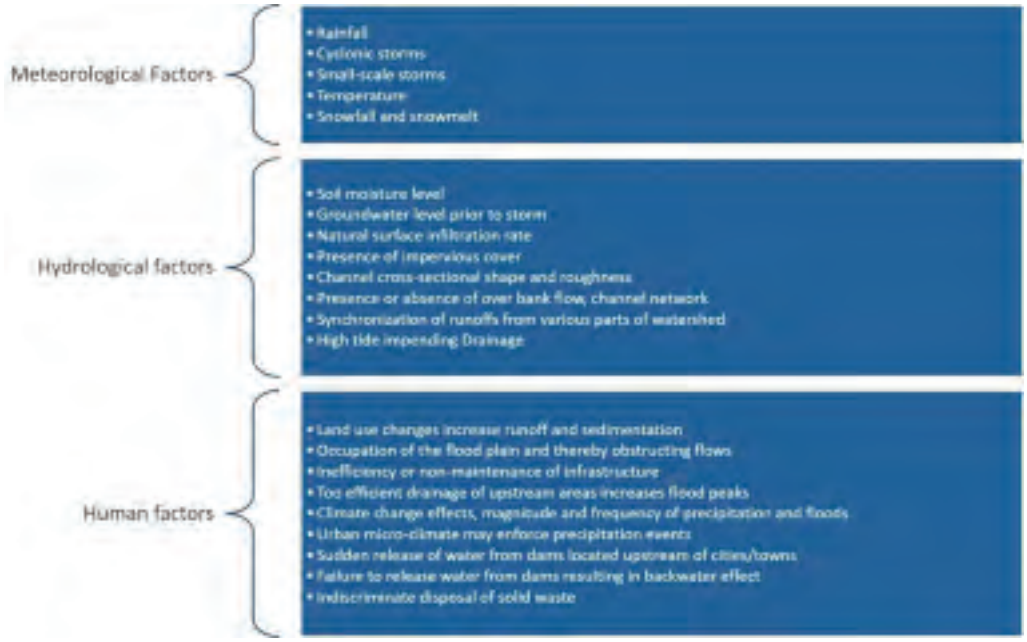
i. **Local Floods:** Very high rainfall intensity and duration during the rainy season sometimes caused by seasonal storms and depressions and exacerbated by saturated or impervious soil. Built environments like cities generate higher surface run-off that is more than local drainage capacity, thereby causing local floods.

ii. **Riverine Floods:** River floods occur when the river run-off volume exceeds local flow capacities. Urban areas situated on the low-lying areas in the middle or lower reaches of rivers are particularly exposed to extensive riverine floods. Often, urban growth expands over some of the floodplains, reducing the area into which floods can naturally overflow. Where parts of the city are below flood level and are protected by artificial levees, there is a risk that they may be breached and cause devastating urban flooding.

iii. **Flash Floods:** Changes in the urban area and storm intensity produce higher flows that exceed the capacity of small culverts under roads designed for unurbanised situation. Although adequate when designed, their carrying capacity may turn out to be inadequate and thereby overflow onto the roads creating new water paths and flood the built-up areas. Sometimes flash floods also result as an outcome of the outburst of Glacial Lakes and Landslide Lakes and are termed as Glacial Lake Outburst Floods (GLOFs) and Landslide Lake Outburst Floods (LLOFs) respectively.

iv. **Coastal Floods:** High tides and storm surges caused by tropical depressions and cyclones can cause coastal floods in urban areas located at estuaries, tidal flats and low-lying land near the sea in general.

The factors responsible for urban floods have been listed below in Table 1.1 as categorised by WMO and NDMA.



Source: Adapted from (NDMA, 2010); (WMO; Global Water Partnership, 2012)

1.3 URBAN FLOODING: GLOBAL SCENARIO

The Los Angeles flood of 1938, which witnessed high runoff leading to floods and the Rapid City Flood of 1972 that resulted due to the clogging of water channels and drains, were some of the early instances of urban flooding. The major issues of urban floods, however, started arising in the 21st century and gradually amplified with urbanisation. The frequency of urban floods across the world started increasing resulting in heavy loss and damage. There have been 3,600 cases of urban flooding in the United States as reported by the National Weather Service between 1993 and 2017 (Poon, 2018). Illinois alone has suffered a loss of 2.3 billion USD between 2007 to 2014 (Grabar, 2019). The Hull Flood of 2007, Newcastle Flood of 2012, Ireland Flood of 2012-13 and Cumbria Floods of 2017 are a few of the catastrophic urban floodings in Europe. In Asia, almost every city of the continent is prone to urban floods because of their climatic conditions and topographical characteristics. Asian megacities like Bangkok, Manila, Guangzhou, Dhaka, Ho Chi MinhfF City, Jakarta and Mumbai are extremely vulnerable to frequent flooding. The Queensland Flooding of 2011 and Townsville Floods of 2019 are major events of urban flooding in Australia in the previous decade.

TOP 10 VULNERABLE CITIES TO FLOODING

1.	Guangzhou, China	6.	Miami, US
2.	Mumbai, India	7.	Tianjin, China
3.	Kolkata, India	8.	New York, US
4.	Guayaquil, Ecuador	9.	Ho Chi Minh City, Vietnam
5.	Shenzen, China	10.	New Orleans, US

1.4 URBAN FLOODING: INDIAN SCENARIO

Top 5 Asian Countries vulnerable to Urban Flooding

1. China
2. India
3. Indonesia
4. Philippines
5. Bangladesh

There has been an increasing trend of flooding in Indian towns and cities over the last few decades. Most of the major cities of India at present are vulnerable to urban flooding and have witnessed repeated instances of flooding. According to the UNDP, Mumbai is the second most vulnerable city to flooding after Guangzhou across the globe followed by Kolkata (3rd most vulnerable), Chennai (13th most vulnerable) and Surat (14th most vulnerable)(Kellet; Ghose, 2013).The average annual rainfall received in many parts of India has increased over the years leading to flooding of several cities like Mumbai, Surat and Kolkata repeatedly over the last two decades. The box below lists the significant flooding events in the country since 2000.

Significant urban flooding events in India since 2000

2000 – Mumbai. Chennai. Bangalore. Kolkata *(18th – 28th September)*. Hyderabad *(23rd – 24th August 2020)*.
2001 – Ahmedabad. Bhubaneshwar. Thane. Mumbai.
2002 – Delhi
2003 – Delhi. Ahmedabad. Vadodara.
2004 – Chennai
2005 – About 10 cities including Chennai; Mumbai was the worst affected *(26th-27th July)*.
2006 – Number of affected cities rose to 22. Surat was the worst affected *(4th – 10th August)*.
2007 – Number of affected cities rose to 35. Kolkata was the worst affected *(3rd- 5th July)*. Vishakhapatnam airport was inundated for more than 10 days.
2008 – Jamshedpur. Mumbai. Hyderabad *(8th- 10th August)* were worst affected.
2009 – Delhi *(27th July)*. Mumbai.
2010 – Delhi. Guwahati. Ahmedabad. Leh (6th August). Mumbai.
2011 – Guwahati
2013 – Surat *(23rd September)*. Kolkata (23rd – 25th August). Bangalore. Delhi (16th June).
2014 – Srinagar *(2nd-26th September)*
2015 – Mumbai got affected in the month of June while Chennai witnessed one of the deadliest floods in the month of December due to north-westerly monsoons *(8th Nov – 14th Dec)*.
2016 – Delhi *(31st July)*. Bangalore.
2017 – Mumbai (29th – 31st August). Gujarat (1st June – 31st July).
2018 – Kerala Floods affected eight towns and cities in the state (16th – 30th August).
2019 – A series of urban flooding occurred in the country affecting major cities including Pune. Thane. Patna and Vadodara.
2020 – Hyderabad (11th October).

Source: adapted from (NDMA. 2010)

India suffers huge infrastructural damages, destruction of properties, disruption of economic services and activities, human casualties and loss of lives with the increasing occurrences of urban flooding. It has been projected that by 2030 infrastructure of approximately 150 billion USD would be exposed to disaster risks because of urban flooding .

The heavy rainfall received in India during southwest monsoons makes its towns and cities extremely vulnerable to urban floods. The average annual rainfall received in the country varies from 2813 mm in Panaji on the higher side to 609 mm in Jaipur on the lower side. Many Indian cities like Cherrapunji (11,777); Port Blair (2872); Panaji (2813); Dibrugarh (2569); Dehradun (2220 mm); Shillong (2207); Mumbai (2186 mm); Agartala (2149); Kohima (1831) Kolkata (1800 mm), and Guwahati (1722 mm) receive high rainfall compared to that of flood-vulnerable cities of other countries like Guangzhou (1720 mm); Miami (1570 mm) and Jakarta (1755 mm). The coastal cities are also vulnerable to flooding because of storm surges and cyclones. The exponential growth of the population in urban areas further aggravates these conditions. India has witnessed an increase in urban population by 31.8 percent in the period of 2001 to 2011 and presently the Indian urban areas cater to 31.14 percent of its total population. The rapid urbanisation is leading to the reclamation of wetlands and floodplains, encroachment on drainage channels, clogging of channels due to improper waste disposal, poor maintenance of storm water drains, etc. It also leads to urban heat island effect increasing the rainfall received in urban areas. The issue of over-concretisation has been a serious problem for all the flood-prone towns and cities. The impacts of changing climate and seasonal unpredictability also addto the gravity of the situation.

1.5 URBAN FLOODING MANAGEMENT GUIDELINES

Urban Flooding has become a nightmare for urban planners, designers, engineers and Disaster Risk Reduction (DRR) professionals. The characteristics of urban floods being different from flash floods is a major challenge for the authorities. The July 2005 urban flood of Mumbai was an eye-opener for the entire nation and urban flooding was introduced as a separate disaster by NDMA, delinking it from riverine and coastal floods. The flooding in Surat in 2006 and the flooding of Kolkata in 2007 brought to the fore the need for comprehensive interventions for urban flood mitigation. The NDMA set up a committee in 2008 to formulate the **"National Guidelines on Management of Urban Floods"** which was published in the year of 2010. The National Guidelines have been prepared with an objective to guide the ministries and departments for the management of urban flooding risks and call for a proactive, participatory, well-structured, multi-disciplinary and multi-sectoral approach at various levels. The National Guidelines details out the roles and responsibilities of institutions at the national, state and municipal levels for management of urban flooding. The National Guidelines have also directed all the

Urban Local Bodies (ULBs) to implement catchment-based planning and designing for storm water drainage systems. A mandate for detailed contour mapping with 0.2-0.5 metres interval has been issued for planning drainage systems of urban areas as per the National Guidelines.

The **"Manual on Sewerage"** published in 1993 by the Central Public Health and Environmental Engineering Organisation (CPHEEO) has a specific section for the storm drainage basin. Guidelines on urban drainage which provide for drainage design for roads (SP-50-1999, IRC) was brought out by the Indian Roads Congress (IRC) in 1999. Both of these guidelines do not take into account the spatial distribution of rainfall over India or within cities. However, an exclusive and detailed **"Manual on Storm Water Drainage Systems"** has been published in May 2019 by CPHEEO under the MoHUA.

1.6 INSTITUTIONAL FRAMEWORK FOR URBAN FLOODING MANAGEMENT

The nodal ministry for providing coordination, technical inputs, and support for the management of urban flooding is the Ministry of Housing and Urban Affairs (MHUA). The ministry also acts as the nodal ministry for central assistance. The dissemination of warning and information is coordinated by the Ministry of Jal Shakti (MOJS) and Ministry of Earth Sciences (MOES) at the national level and State Disaster Management Authority (SDMA) and Revenue Department at the state level. The District Disaster Management Authority (DDMA) and ULBs coordinate preparedness and response at the district and local level. The following table details the responsibilities of the various agencies, authorities and departments in accordance with the National Disaster Management Plan of 2019.

Table 1.2: Responsibilities of Departments and Authorities for Urban Flood Management

Responsibilities		National Authorities	State Authorities
Understanding Urban Flood Risks	Mapping/ Zoning, Estimation of Possible Inundation levels, monitoring networks	MHUA, MO ES, MOJS, DOS	DMD, SDMA, RD, SRSAC, DDMA, PRIs (for peri -urban areas), ULBs
	Information Systems, Monitoring, Forecasting, Early Warning	MOES, MOJS	
	Hazard Risk Vulnerability and Capacity Assessment (HRVCA)	NDMA, NIDM, MSJE	
	Disaster Data Collection and Management	MHA (Nodal Body), MOSPI, all ministries/ departments.	DMD, SDM A, all departments.
	Overall disaster governance	MHUA	DMD, SDMA, RD, DDMA, ULBs, PRIs (for peri -urban areas)
	Response	MHUA	DMD, SDMA, RD, DDMA, ULBs, PRIs (for peri -urban areas)

Responsibilities		National Authorities	State Authorities
Inter-Agency Coordination	Warnings, Information, Data	MOES (IMD) - Nodal Body, MOJS, MOES, NDMA, MEITY	DMD, SDMA, RD, DDMA, ULBs, PRIs (for per i-urban areas)
	Non-structural Measures	MHUA, BIS, NDMA	DMD, SDMA, RD, DDMA, ULBs, PRIs (for peri -urban areas)
Structural DRR Measures	Civil Works	MHUA (Nodal Body), NBCC, BMTPC, CBRI, SERC, IE(I), CRRI	DMD, UDD, ULBs, PRIs (for peri-urban areas)
	Establishment/Strengthening of Emergency Operation Centres	Relevant Central Ministries, MHA	DMD, SDMA, ULBs, PRIs (for peri-urban areas)
	Hazard resistant construction, strengthening, and retrofitting of all lifeline structures and critical infrastructure	NDMA, NBCC, BMTPC, CBRI, SERC, IE(I)	SDMA, DDMA, ULBs, PRIs (for peri-urban areas)
Non-Structural DRR Measures	Preparation of comprehensive Urban Storm Drainage Design Manual (USDDM)	MHUA	DMD, SDMA, DDMA, UDD
	Preparation of Storm Water Drainage System Inventory	MHUA	DMD, SDMA, ULBs, PRIs (for peri-urban areas)
	Operation and Maintenance of Drainage Systems	MHUA	DMD, SDMA, ULBs, PRIs (for peri-urban areas)
	Environmental Impact Assessment	MOEFCC (Nodal Body) , MHUA	DMD, SDMA, ULBs, EFD, PRIs (for peri-urban area)
	• Techno-Legal Regime • Land use planning • City/Town Planning	MHUA, MFIN	DMD, SDMA, ULBs, EFD, PRIs (for peri-urban area)
	Constitution of Urban Flooding Cell for Integrated UFDM	MHUA	DMD, SDMA, UDD
	Public-Private Partnerships	NDMA, MHUA, MCA (Nodal Body), MCF, MOCI, MPFI, MHIPE, MFIN	UDD, SDMA, DDMA
Capacity Development	Risk Transfer	MFIN (Nodal Body), NDMA, MHA, MAFW	DFIN (Nodal Body), DMD, SDMA, State Department of Agriculture
	Education and Training	MHUA (Nodal Body), MHRD, MHFW, NDRF , NIDM, CBSE, MYAS	ULB, PRIs (for peri - urban areas), SDRF
	Awareness Generation	MHUA (Nodal Body), NDMA, NDRF, CAPF, NIDM	DMD, SDMA, RD, DDMA, SDRF, F&ES, CDEF, Police, ULB, PRIs (for peri-urban areas)
	Documentation	NIDM	DMD, SDMA, RD, DDMA, ULB, State ATI
	Empowering women, marginalised, and persons with disabilities	MWCD (Nodal Body), MSJE, NDMA, NIDM	DMD, SDMA, DDMA, RD, SIDM, ATI, and other state -level institutions
	Community-Based Disaster Management	MHUA (Nodal Body), MORD (Nodal Agency), NDMA, NIDM	DMD, SDMA, SDRF, RD, DDMA, ULB, SIDM

Responsibilities		National Authorities	State Authorities
	Mock Drills/ Exercises	MHUA, NDMA, All Govt. Ministries/ Agencies, NDRF, Armed Forces, CAPF	DMD, SDMA, RD, DDMA, ULB, SDRF, F&ES, CDEF, Police
Climate Change Risk Management	Research, Forecasting / Early Warning, Data Management, Zoning, Mapping	MOES, MOJS (Nodal Body), MAFW, MOEFCC, DOS, NLRTI	DMD, IRD, WSD (Nodal Body) , EFD, SDMA, Agricultural Department, FIHD, DDMA, ULBs, PRIs (for peri -urban areas)
	Hazard Risk Vulnerability and Capacity Assessment (HRVCA)	NIDM, MOJS (Nodal Body), MOST, MOST, CSIR, DOS, NLRTI	DMD, SDMA, RD, IRD, WRD, SLRTI
	Climate Change Adaptation (CCA)	MOES & MOEFCC (Nodal Body), MOST, DOS, MOJS.	DMD, SDMA, IRD, WSD (Nodal Body), EFD, DRD, DDMA, ULBs, PRIs (for peri-urban areas)

(NDMA, 2019)

CHENNAI – THE DETROIT OF INDIA

Chennai is the capital city of the state of Tamil Nadu. It is the sixth populous city of the country catering to 4.6 million over an area of 1,189 Square Kilometres. The estimated GDP of the city is around 58.6 billion USD which is further expected to reach up to 191 billion USD by the year 2025. The city is also considered the fourth city of India in terms of GDP per capita for the year 2014. The city of Chennai is also the biggest cultural, economic and educational centre of South India. The city is also popularly called "The Detroit of India" because of the presence of more than one-third of the country's automobile industry in the city.

Figure 2.1: Location of Chennai in the state of Tamil Nadu Map
Source: Maps of India

2.1 LOCATION AND LINKAGES

Chennai lies between 129'N to 1316'N and 805'E to 8019'E on the Coromandel coast. The city stretches linearly nearly 25.6 Kilometres from Thiruvanmiyur in the south to Thiruvottiyur in the north along the coast of the Bay of Bengal and runs inland in a rugged semi-circular fashion bound by the districts of Kanchipuram and Thiruvallur districts. Figure 2.1 shows the location of the city of Chennai in the state of Tamil Nadu map. The city has air linkages to and from all the major towns and cities of India and is well-connected through road and rail to the nearby towns and cities like Tirupati (113 Kms); Pondicherry (140 Kms); Nellore (155 Kms); Salem (279 Kms); Thanjavur (282 Kms) and Bangalore (293 Kms).

2.2 HISTORY AND EVOLUTION

The history of Chennai can be traced back to 400 years. "Madras", the former name of Chennai, is believed to have been derived from the name of a village called "Madraspatnam". The city was originally located in the province of Tondaimandalam, an area lying between the Penna River of Nellore and the Ponnaiyar river of Cuddalore. Madras is believed to be the conglomeration of three settlements at Mylapore, Triplicane and Santhome. The port of Mylapore, according to many geographers like Ptolemy,was known to have trade connections with Romans, Greeks, Arabian and Portuguese traders during the 2nd to 16th century The foundation of the present metropolis of Chennai was laid by the British East

India Company in the year of 1639 by acquiring the site where Fort St. George stands. The city started growing within a few years of British Settlement and the population expanded from 19,000 in 1646 to 40,000 in 1669. The city of Madras was then formed in the year 1798 comprising the Fort area and 16 hamlets. The city was later renamed in the year 1996 as Chennai in honour of the local chieftain Chennappa Nayak on whose land the city got developed.

2.3 REGIONAL INFLUENCE

Chennai is one of the predominant cities and acts as the cultural, economic and educational centre of South India. The metropolitan area of Chennai serves about 8.6 million people as per Census 2011. Chennai is considered the primate city of South India because of the high dependency on surrounding settlements. The city of Chennai, because of its location, has also inter-state influence in some parts of Andhra Pradesh and few parts of Karnataka. Figure 2.2 illustrates the regional influence of the city of Chennai across various states. Some of the major cities that are extensively dependent on the city of Chennai are Kanchipuram, Ranipet, Vellore, Cuddalore, Neyveli in Tamil Nadu; Chittoor, Tirupati, Nellore, Madanappale, Kavali in Andhra Pradesh and Puducherry.The primacy of the city of Chennai though has witnessed a decline after 1981. The growth of Hyderabad and Bangalore as IT hubs post-2000 further reduced its regional influence.

Figure: 2.2 Regional Influence of Chennai

2.4 PHYSIOGRAPHIC FEATURES

The city of Chennai, located on the south-eastern coast of India, lies in a low-lying area and the topography of the city resembles that of a pancake. The average elevation of the city is around 6.7 m, the highest being 60 metres. The elevation of the city gradually rises as the distance from the seashore increases. Most of the localities of the city are at sea level making the drainage of those localities a serious concern. Some parts of the city are also undulating in nature creating issues of inundation and flooding during heavy rains.Figure 2.3 shows the contour while Figure 2.4 illustrates the slopes of the city.

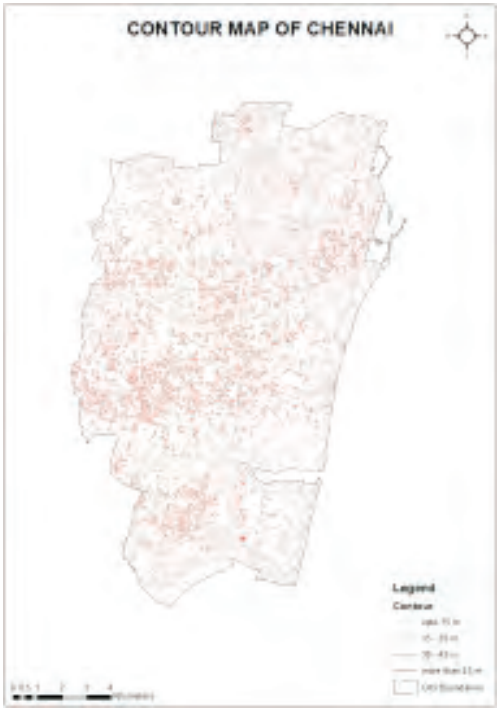


Figure 2.3: Map showing the Contours of Chennai

Figure 2.4: Map showing the slopes in Chennai

Two major rivers flow towards the east through the city: the Cooum River through the centre dividing the city into two halves; the Adyar River to the south dividing the southern half of the city into another two parts trisecting the city. Both the rivers are almost stagnant and do not carry enough water except during the rainy season. The Cooum River originates 48 Kilometres west of Chennai and receives a remarkable amount of sewage from its riverside neighbourhoods (ENVIS Centre). The Adyar River originates near Guduvancheri village which further receives the surplus water from the Chembarambakkam tank and serves as a medium of livelihood for the

fishermen residing along its banks. The Kortalaiyar River, the third major river, flows through the northern peripheries of the city draining into the Bay of Bengal at Ennore. Besides these rivers, the Buckingham Canal runs through the entire city parallel to the coast. The city of Chennai is also characterised by a large number of ponds, lakes and water reservoirs across the city. Some of the reservoirs like Poondi reservoir, Cholavaram lake, Red hills lake and Chembarambakkam tank also act as a major source of drinking water of the city. Figure 2.5 illustrates the rivers and major water bodies in the city.

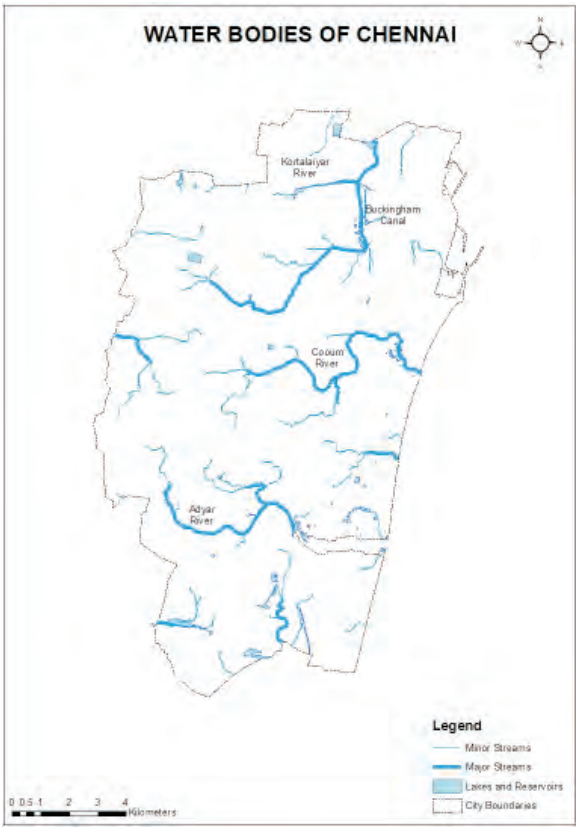


Figure 2.5: Rivers and major water bodies in the city of Chennai

The forest cover of Chennai constitutes only around 2 percent of the city. The major forest reserve in the city is the Guindy National Park spread over an area of 270.57 Hectares. It is a Reserved Forest with sparse vegetation cover. The urban parks of the city like Peoples park, the Napier park, the Horticulture-gardens, My Lady's Park, Children's Park Guindy, Snake Park, Nehru Park, Nageswara Rao Park, Independence Park, Anna Square Park, the Raj Bhavan, etc. also constitutes around 2 percent of the total land of the city.

The soil of Chennai majorly consists of clay, sedimentary rocks and sandstones. Most of the city, especially the inland areas, have clayey soil such as T. Nagar, West Mambalam, Anna Nagar, Villivakkam, Perambur and Virugambakkam. The riverbanks and coasts in the city such as Tiruvanmiyur, Adyar, Kottivakkam, St. Thomas Mount, George Town, Tondiarpet have sandy soil while few parts of the city like Guindy, Perungudi, Velachery, Adambakkam and a part of Saidapet have hard sedimentary rocks. The rainwater runoff usually percolates very quickly in the sandy soil areas while the runoff in clayey and hard rocks percolates very slowly and are held for a longer duration. The slow runoff percolation contributes to partial inundation in several parts of the city.

2.5 CLIMATE AND RAINFALL

Chennai has a tropical wet and dry climate. Being a coastal city and located on the thermal equator, the city does not experience any extreme variation in seasonal temperatures. The average highest temperature observed in the city is 35.13 Celsius while the average lowest temperature is around 22.29 Celsius. The weather remains hot and humid for most of the year. April-June are the hottest months of the year with temperature ranging from 31-37 Celsius. The coolest months in the city ranges from December to February with temperature varying from 21-25 Celsius. The annual maximum temperature and the annual minimum temperature observed in the city from 1981 to 2019 have been illustrated in Figure 2.6 and Figure 2.7 respectively.

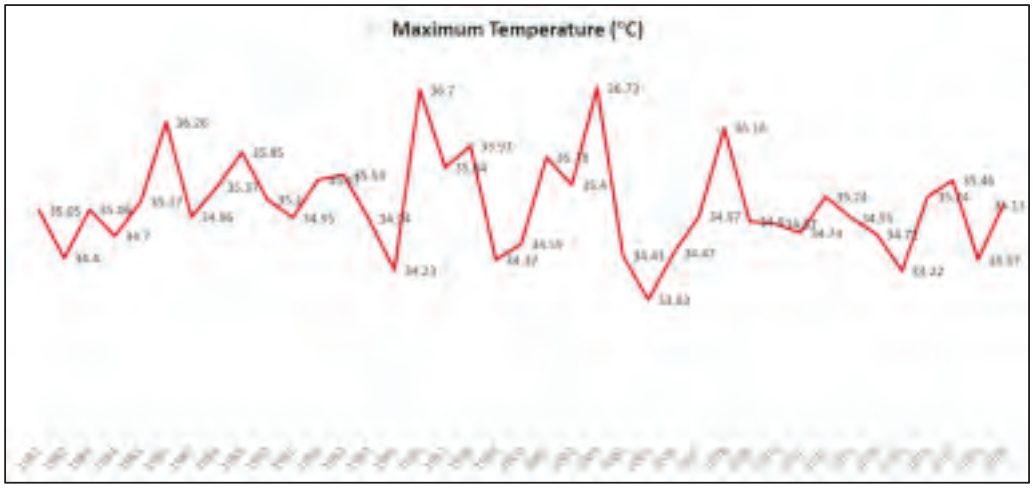


Figure 2.6: Annual Maximum Temperature (C) observed during the period of 1981-2019
Source: Indian Meteorological Department

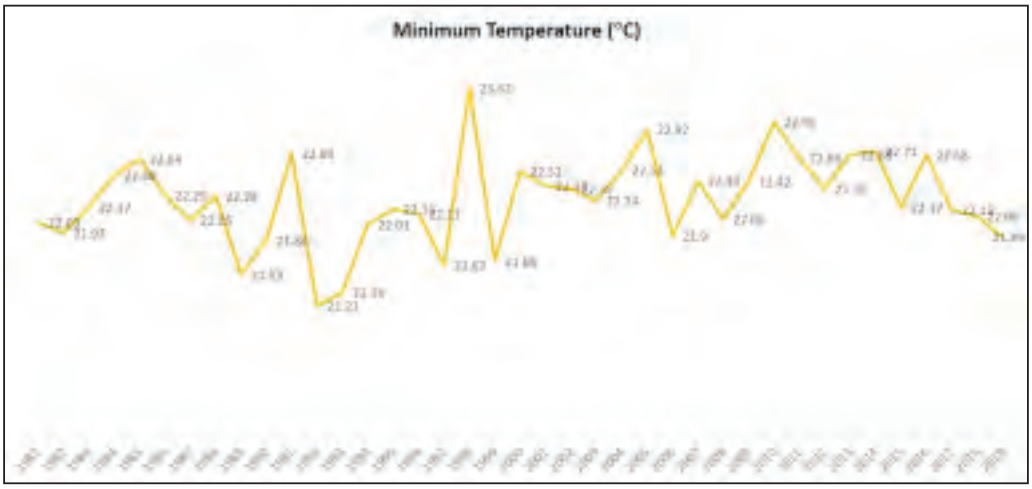


Figure 2.7: Annual Minimum Temperature (C) observed during the period of 1981-2019
Source: Indian Meteorological Department

The city receives most of its rainfall during the northeast monsoon period ranging from mid-October to mid-December (ENVIS Centre). The city also receives substantial rainfall from the advancing monsoon as well as the retreat of monsoons. It is sometimes hit by the cyclones in the Bay of Bengal causing storms and rains. The average rainfall received per year from 1981 to 2019 is 1145.46 mm. The highest rainfall was received in the year 2015 (1929.9 mm) and the lowest received in 2018 (26.87mm). Figure 2.8 shows the amount of annual rainfall received in the city from 1981 to 2019.

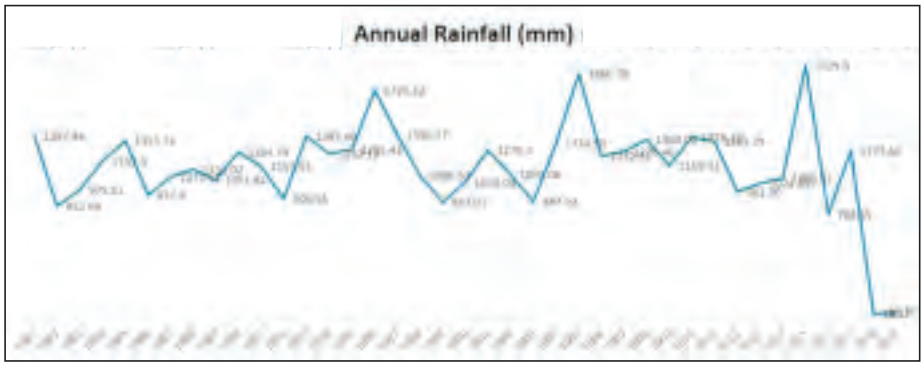


Figure 2.8: Annual rainfall received in Chennai from 1981 to 2019
Source: Indian Meteorological Department

2.6 DEMOGRAPHY AND POPULATION GROWTH

Chennai is one of the oldest cities in India. The population of the city was 3.68 lakhs in the year 1871 which grew exponentially to 46.81 lakhs by the year 2011. The Chennai Metropolitan Area (CMA) which was delineated in the 1970s initially had a population of 35.04 lakhs which further rose to 86.53 lakhs by the year 2011. Figure 2.9 illustrates the decadal growth of the city from 1871 to 2011 as well as the growth of the CMA for the period of 1971 to 2011.

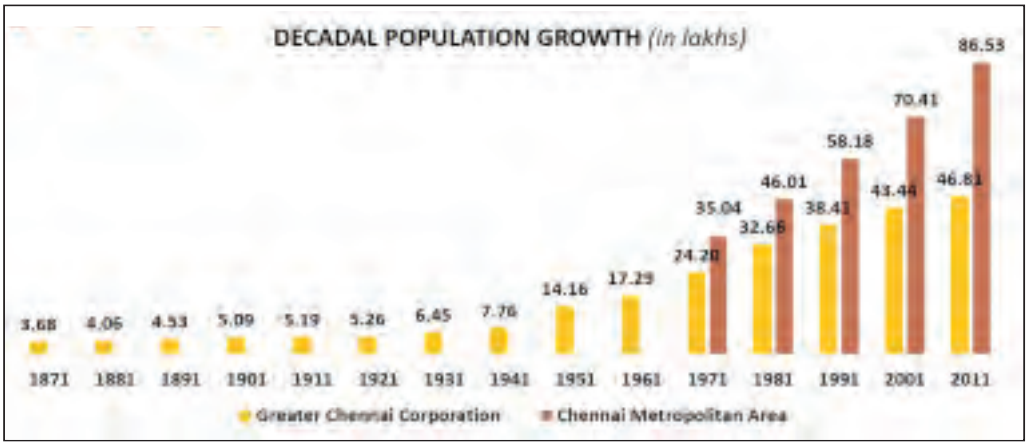


Figure 2.9: Decadal population of the city of Chennai during 1871-2011
Source: Census of India

The decade of 1941-51 has witnessed the maximum growth of population in the city. The population rose from 7.76 lakhs to 14.16 lakhs over this decade by a rate of 82.48 percent. After the year 1971, the growth of the city has started decreasing gradually. The city has seen only an increase of 7.77 percent of the population during the last decade of 2001-2011; however, the metropolitan area has witnessed a growth of 22.9 percent as shown in Figure 2.10

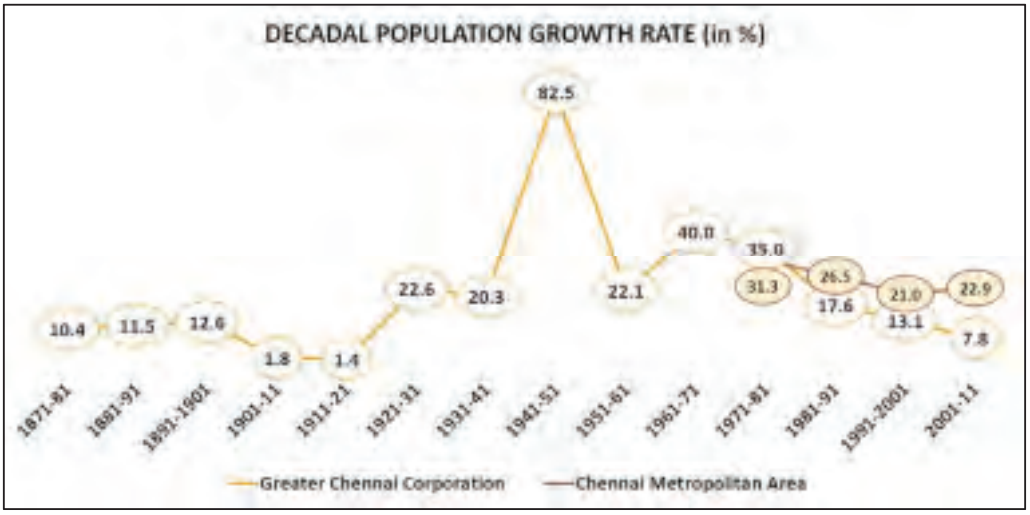


Figure 2.10: Decadal Growth rate of Chennai during 1871 to 2011
Source: Census of India

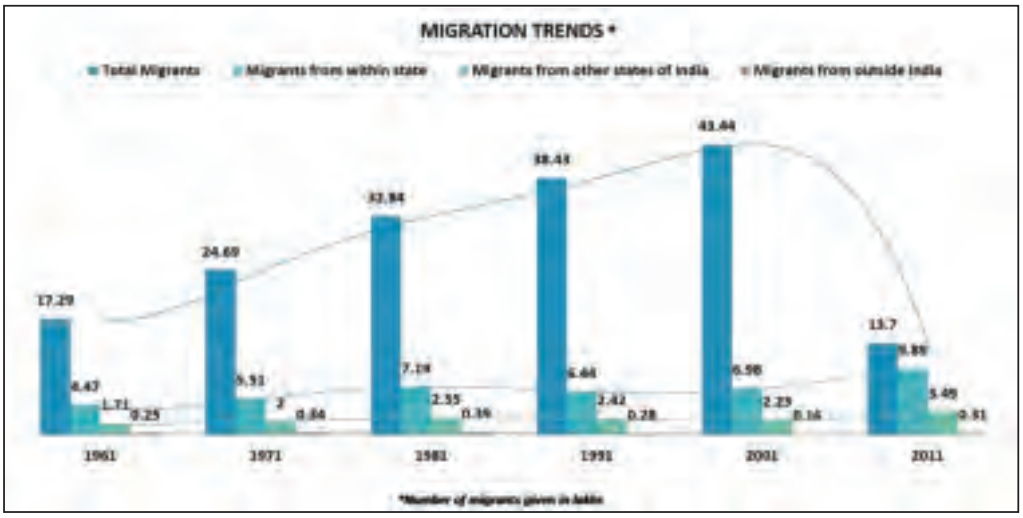


Figure 2.11: Migration Trends of Chennai from other places from 1961 to 2011
Source: Master Plan of Chennai and Census of India

The cosmopolitan nature and economic opportunities attract large numbers of migrants to the city. According to the Census 2011, the city drew 13.7 lakhs of migrants to itself. The migrants are predominantly from the state of Tamil Nadu who constitutes around 72.2 percent of the total. The migrants from other states of the country constitute around 25.5 percent while 2.26 percent of migrants are from outside the country. The trends of migration in the city over the period of 1961 to 2011 have been illustrated in Figure 2.11.

2.7 SOCIO-ECONOMIC PROFILE

The Census 2011 reveals that out of the total population of the city, 23.35 lakhs (50.27 percent) are males and 23.1 lakhs (49.73 percent) are females. The sex ratio of the city of Chennai is 989 while that of CMA is 985, both of which are higher than that of the national urban average (929). The trends of the sex ratio as stated in the master plan have been shown below in Figure 2.12. The greater rise in the female population over that of males has resulted in a steady increase in the sex ratio of the city over the decades (CMDA, 2008).

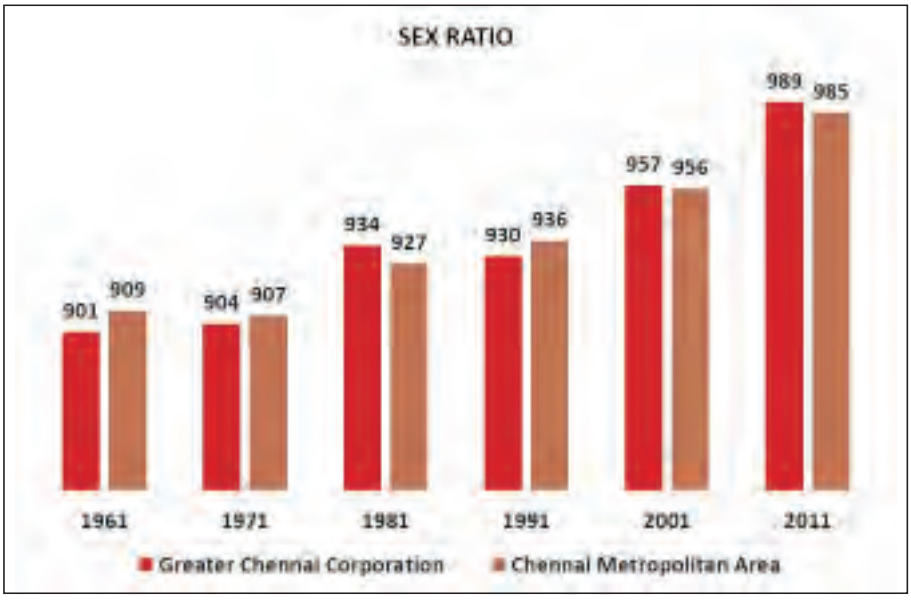


Figure 2.12: Sex Ratio of Chennai during 1961 to 2011
Source: Master Plan of Chennai and Census of India

The literacy rate of Chennai according to the Census 2011 is around 90.20 percent making it one of the most literate cities of India. The literacy rate in the city has increased gradually from 1961 to 1991 while the decade of 1991-2001 has seen the maximum increase in the number of literates in the city. The literacy rate in the Chennai Metropolitan Area has also witnessed a steady growth from 54.82 percent in 1961 to 90.23 percent in 2011. The increasing trend of the literacy rate in the city and the metropolitan area has been shown in Figure 2.13.

During the British Rule, Chennai was based on trade and commerce which eventually shifted to administration and services by the early 20th century. Post-independence of India, manufacturing became the major economic activity in the city making it the most important industrial centre in the State. The booming of IT/ITES industries in the 1990s shifted the economic base of the city to tertiary industries. The detailed workforce participation rate in manufacturing declined by 1.2 times while tertiary industries have increased two times from 1991 to 2011 as illustrated in Figure 2.14.

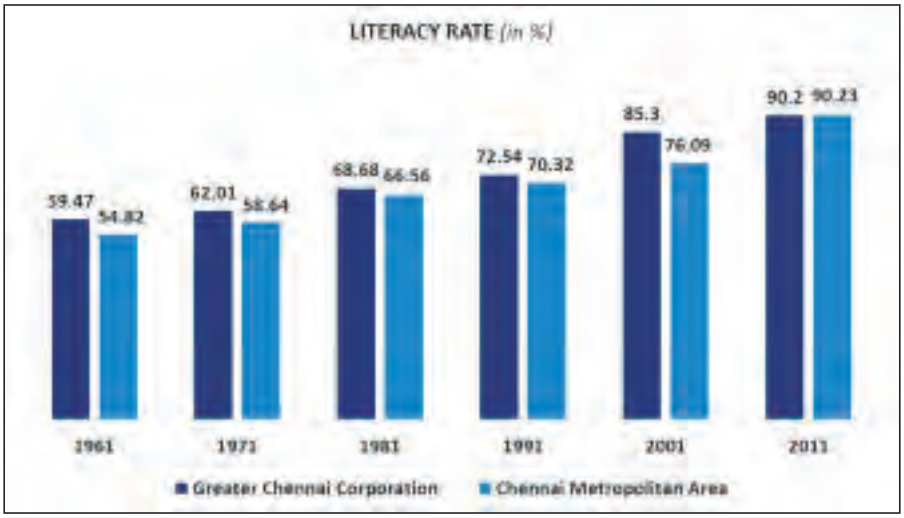


Figure 2.13: Literacy Rate of Chennai during 1961 to 2011
Source: Master Plan of Chennai and Census of India

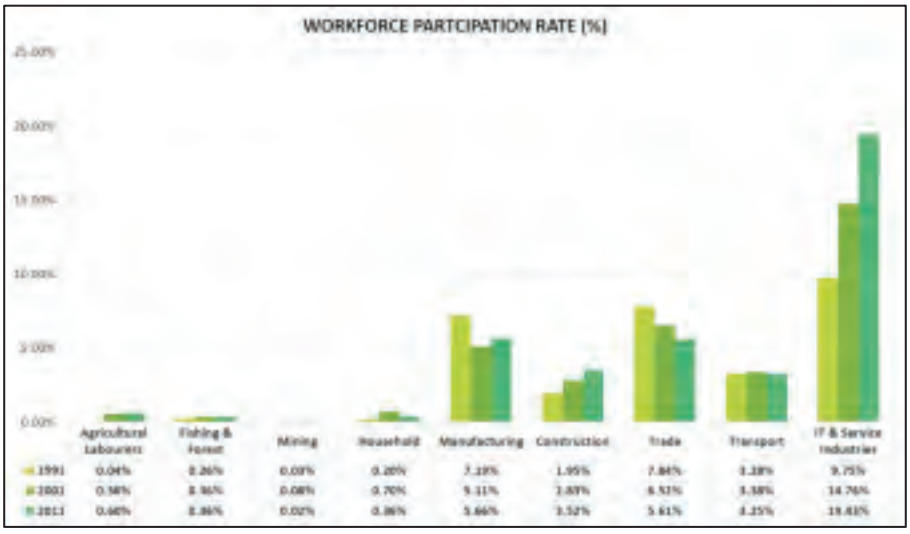


Figure 2.14: Workforce Participation Rate of Chennai
Source: (CMDA, 2008; Census of India, 2001-2011)

The dominant sectors of the economy in the city are fisheries, tourism, manufacturing and processing, banking, exports and imports and information technology. Among the tertiary sectors of the economy, the automotive industry is the most dominant. The presence of major automobile manufacturing units like Ashok Leyland, BMW, Ford, Mahindra & Mahindra, Fiat, Hindustan Motors, Hyundai, Mitsubishi, Nissan, Renault, etc. and allied industries in and around Chennai has given the city the title of "Detroit of India". The production of the automotive industry based in Chennai alone constitutes around 30 percent of the country's automobile industry and 35 percent of the automobile component industry (Narayanan, 2004; Machine Waypage, 2008). Besides the commercial production of automobiles, there is also Heavy Vehicles Factories (HVF) in the neighbourhood of Avadi to produce military vehicles.

The total workforce participation rate of the city is around 39.11 percent in 2011. Out of the total workers, around 75.35 percent are males and 25.65 percent are females. The workforce of the city consists of around 89.12 percent of main workers and 10.88 percent of marginal workers as illustrated in Figure 2.15.

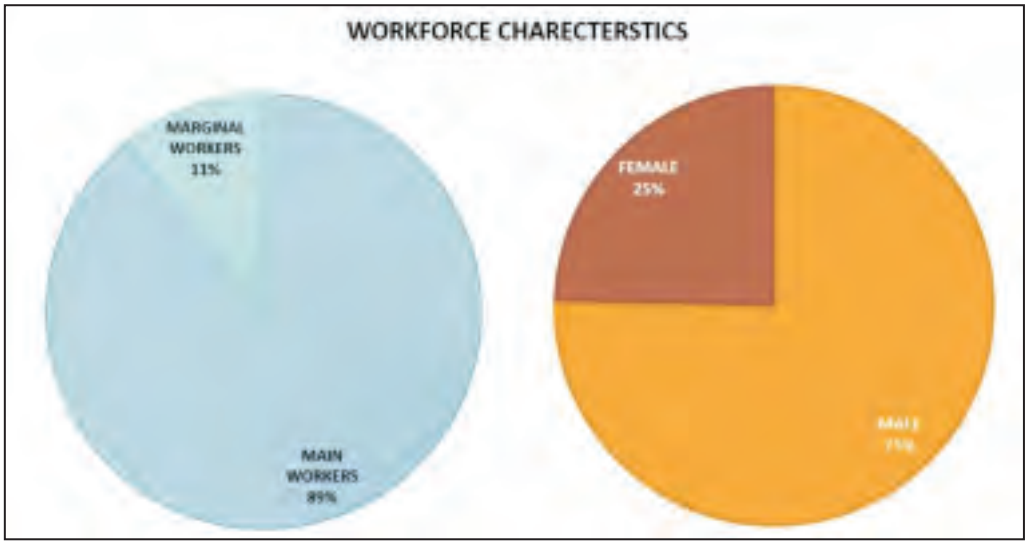


Figure 2.15: Workforce Characteristics of Chennai
Source: (Census of India, 2011)

2.8 URBAN MORPHOLOGY AND LANDUSE CHARACTERISTICS

The urban pattern of Chennai evolved out of scattered settlements in the 1600s. Each of these settlements grew around a nucleus of a temple and carries its history. During the 1700s, a lot of construction work was carried out across the central parts of the city. Few of the settlements also shifted towards the present Moore Market area in 1710 due to construction of a bridge connecting Eg. more. Congestion

around the fort started happening and the weaving community in 1733 started settling in the Chintadripet and Collepetta area due to the abundance of open space in these areas for weaving. The washer men who were in the Mint area also moved towards the west. The Potters from this area moved outside the Fort on the north side and formed a new colony (Kosapet). The Fort area and its surroundings which were covering nearly 69 kilometres were constituted as the City of Madras in 1798. After establishing the city corporation, conservancy and improvement of the city began. The Chennai Central Station was built in 1872 and the construction of the port was also started during the same period. Several parks such as Napier Park, Peoples Park, and Richardson Park were built during the 1850s for recreational purposes. The radial road pattern of the city also witnessed a change and ring roads were being developed during this period. The rail connectivity of the city also started expanding, thus boosting the trade and economy of the city. The harbour became operational in 1896.Many significant public buildings were constructed facing the beach near the fort over this century.

The city in the year 1901 evolved as a commercial, military and administrative centre for entire South India spreading over an area of 70 square kilometres with a population of around 5.4 lakhs. George Town was developed as the main business centre while the major residential areas are Chintadripet, Triplicane, Egmore,

Figure 2.16: Chronological Development of Chennai during the 16th to 19th century
Source: (Anil K. Gupta; Sreeja S. Nair , 2010)

Mylapore, Purasawalkam, Vepery and Royapuram among others. The population and the city limits further increased to 8.6 lakhs and 80 square kilometres respectively by the year 1941 and the city developed into a provincial metropolis. The period between 1941 to 1971 saw tremendous growth of population and economic activities in Chennai. The city developed in a semi-circular pattern with extensions in five main directions. The tremendous growth that happened during these years led to unregulated development in many areas that originated many of the current challenges faced in the city. The condition of water supply and drainage services started deteriorating and slums were forming up across the city. With the industrialisation and increasing number of vehicles, many environmental issues emerged during this period. The chronological development of the city from 1600 to 1971 has been illustrated in Figure 2.16.

Industrial establishments started developing after 1971 in the north, west and northwest fringes of the city. Several residential areas like Alandur, Tambaram and Pallavaram also started coming up in the fringes following the electrified suburban line. In the year 1980, the built-up area in the city increased to 47.82 Square Kilometres. After 1980, a large number of private engineering colleges and medical institutions came up in the city. During this period, the city of Chennai also evolved as one of the booming centres for IT / ITES companies. The built-up area in the city increased from 87 Square kilometres in 1991 to 131 square kilometres in 2011. The

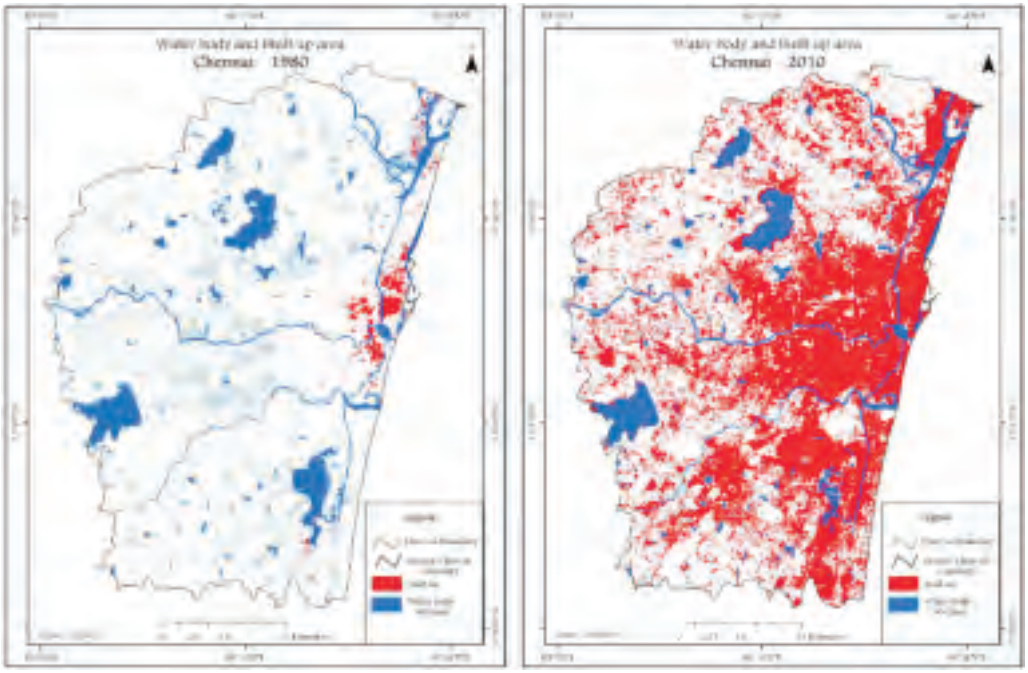


Figure 2.17: Change in built-up area from the period of 1980 to 2010
Source: (TNM, 2016)

rapid development during this period has replaced 99 percent of the green cover by the non-vegetative developments in most of the wards reducing the water-holding capacity of the city drastically (Anil K. Gupta; Sreeja S. Nair, 2010). The reduced water-holding capacity of the city's surface and the increased impermeable surfaces in the city has resulted in high peak flow during heavy rains. The increased runoff and reduced water-retention capacity of the city have also lowered the ground-water recharging process. The change in the land use and land cover from 1980 to 2010 has been illustrated in Figure 2.17. The proposed land use of 2026 for the Chennai Metropolitan Area has also been detailed out in Table 2.1.

Table 2.1: Proposed Landuse of Chennai as detailed out in Chennai Development Plan of 2026

Landuse	Greater Chennai Corporation(GCC)		Rest of Chennai Metropolitan Area	
	Area *(in Hectares)*	Percent Share to the total area	Area *(in Hectares)*	Percent Share to the total area
Residential	8,343.25	47.36	45,593.78	45.02
Commercial	714.24	4.05	880.35	0.86
Institutional	2,868.97	16.28	3,888.85	3.83
Industrial	822.5	4.67	10,690.41	10.56
Open Space & Recreational	1,000.65	5.68	392.86	0.38
Agricultural	-	-	7,295.81	7.2
Non-urban	113.31	0.64	2,332.92	2.3
Urbanisable	-	-	2,075.89	2.05
Others	3,754.79	21.31	28,147.55	27.79
TOTAL	**17,617.70**	**100**	**1,01,298.42**	**100**

Source: (CMDA, 2008)

2.9 CITY INFRASTRUCTURE

2.9.1 Transport and Connectivity

The city of Chennai has a total road network of 2780 Kilometres in a predominantly radial and ring pattern. The prime radial network of the city comprises Anna Salai (NH45); Periyar EVR Salai (NH4); Chennai - Kolkotta Salai (NH5) and Chennai-Thiruvallur Salai (NH205) (CMDA, 2008). The Southern Railways with three major lines, i.e., Chennai Beach - Tambaram; Chennai Central - Thiruvallur and Chennai Central - Gummidipoondi (CMDA, 2008). The Chennai International Airport facilitates air connectivity in the city while the Port of Chennai, the third oldest port, is a major cargo port and has been operational since 1881.

2.9.2 Housing and Shelter

The city consists of nearly 12.6 lakhs of household units according to the 2011 Census. Nearly 96.8 percent of these dwelling units in the city have pakka walls with 87.8 percent of them having a pakka roof, 8.7 percent having a semi-pakka roof and 3.5 percent having a kutcha roof (Census of India, 2011). Out of these dwelling units, nearly 41 percent are either one-room units or units without an exclusive room. It also has a slum population of 13,42,337 which constitutes about 28.7 percent of the city population (Census of India, 2011). The city also houses 84 fishermen villages along the coast and during the present times, the fishermen housing is looked after by Tamil Nadu Slum Clearance Board (TNSCB) and Fisheries Department (CMDA, 2008). The principal stakeholders in providing housing in the Chennai area are Tamil Nadu Housing Board (TNHB) and TNSCB in the public sector along with other corporate builders and individuals (CMDA, 2008).

2.9.3 Water Supply and Sanitation

The city of Chennai is equipped with water supply and sanitation facilities serving the city and its surrounding municipal towns. The average water supply in the city is 90 lpcd while during the best times it is 107 lpcd which is lower than that of the URDPFI standard of 150 lpcd for metropolitan and mega cities (CMDA, 2008). The availability of services for the slums and the poorer sections are still scanty and only 25 lpcd of water are supplied to these areas (CMDA, 2008). The extent of the area covered by the sewerage system in the corporation area is around 99 percent while 486 million litres per day are being treated (CMDA, 2008).

2.9.4 Solid Waste management

Chennai is also the largest generator of solid waste; producing around 5400 MTof solid waste per day in the year 2008 which is further estimated to reach upto 6590 MT per day by the year 2026 (CMDA, 2008; Greater Chennai Corporation, 2008). The city is well-equipped with a network of 7 transfer stations and two landfill sites at Kodungaiyur and Perungudi for transferring and disposal of solid waste(Greater Chennai Corporation, 2008)The landfill site at Kodungaiyur spread over an area of 269 acres handles waste of around 2600-2800 MT daily while the remaining waste is disposed at Perungudi that is spread over an area of around 200 acres. The city has adopted the mechanism of source-separated waste collection from households. The biodegradable wastes are sent to decentralised waste processing facilities while the dry waste gets recycled. According to the Master Plan of Chennai Metropolitan Area for 2026, around 400 MT of dry waste gets recycled per day in the city. The remaining waste is sent to transfer stations and landfill sites. The bio-medical waste of the city is treated and disposed of at Thenmelpakkam village and Chennakuppam in Kancheepuram District along with the bio-medical wastes produced in the districts of Thiruvallur, Kancheepuram, Villupuram and Cuddalore

(CMDA, 2008). The e-waste generated are separated by scrap workers and are treated at seven recycling industries (CMDA, 2008). Around 700 MT of construction waste are generated in the city, which is disposed in specifically identified areas within the city by the Greater Chennai Corporation (CMDA, 2008).

2.9.5 Educational Facilities

The city of Chennai, as of 2016, housed 1493 Primary Schools, 1034 Upper Primary Schools, 923 High Schools and 492 Higher Secondary Schools(GCC, 2017). Out of these, the city corporation runs around 119 primary schools, 92 middle schools, 38 High Schools and 32 Higher Secondary Schools employing around 3,116 teachers and educating 88,524 students. Besides, 200 Kindergarten schools are also operational in the existing school premises (GCC, 2017).

2.9.6 Health Infrastructure

Chennai is considered the health capital of the country because of its excellent facility, competent specialists and good nursing care. There are around 138 Urban Primary Health Centres, 14 Urban Community Health Centres, 3 Emergency Obstetric Centres, 1 Communicable Disease Hospital with 238 medical officers and 1,043 paramedical staff run by the GCC. Averages of 17,800 patients are treated in these health facilities (GCC, 2017). Apart from government health facilities, there are around 130 private hospitals in the city.

2.10 HAZARD PROFILE

Chennai is multi-hazard vulnerable because of its location. The city is vulnerable to various natural disasters like cyclones and storm surges, monsoon floods, tsunami and even earthquake. The rapid urbanisation has also made the city extremely vulnerable to urban floods. Being a manufacturing hub in south India, the city is also vulnerable to various industrial disasters and fire outbreaks. The city of Chennai has been victim to various natural calamities in the last three decades. The recent outbreak of the COVID-19 pandemic has also had a huge impact in the city with total confirmed cases of 2,94,073 as of 22nd April 2021. The following section details the hazard profile of the city in detail.

2.10.1 Earthquake

The city of Chennai is not seismically active as compared to the northern and westerns parts of India, however, the whole of the Chennai Metropolitan Area falls under the seismic zone III and witnesses small to moderate earthquakes. The biggest earthquake witnessed in the city was of 5.2 magnitudes on 25th September 2001 at 2:56 pm whose epicentre was offshore of Pondicherry. The city also witnessed a similar earthquake of 4.6 magnitudes in the year 1987 on 3rd December.

2.10.2 Tsunami

The areas vulnerable to tsunami are 500 metres from High Tide Level (HTL) along the coast. One of the most notable tsunamis that have been witnessed in the city was the Indian Ocean Tsunami 2004. The tsunami had a moment magnitude of 9.1-9.3 and maximum Mercalli intensity. The coastal communities got struck by waves upto 30 metres high resulting in heavy inundation. 4 coastal villages got affected impacting 73,000 people. Around 30,000 people were evacuated while human losses included 206 deaths and 9 injuries. More than 17,000 houses were damaged along with other properties. The city had witnessed another tsunami in the year 1883 as an impact of Krakatau Volcanic Expression in Indonesia. The tsunami witnessed a water surge of around 1.5 metres in height (GCC, 2017).

2.10.3 Floods

The city with lots of drainage rivers and water bodies is extremely prone to flooding. The city also has several low-lying areas creating inundation. The city witnessed several floods over the last three decades. Some of the notable floods are that of 1976, 1996, 1998, 2005 and 2015 that have been further detailed out in Table 2.2. The major reasons for flooding in the city as analysed by the Greater Chennai Corporation are as follows:

- Plain terrain of Chennai with an average altitude of 6.7 metres.
- Formation of sand bar at the mouth of the rivers obstructing the discharge route.
- Clogging of drains due to disposal of solid waste and construction debris.
- Inadequately designed capacity of stormwater drains.
- Lack of continuous connectivity of stormwater drainages.
- Encroachments of river basins and marshy lands.
- Influences of high tides and low tides.
- Inadequate cross culverts/vents of proper size wherever the road is passing across the water flow.

Table 2.2: List of major floods witnessed in Chennai

Events	Impacts
1976 Floods	Submergence of TNHB Quarters in Kotturpuram bank of Adyar River coupled with storm & high tides in the sea.
1996 Floods	The city was flooded by Aadyar, Cooum and Kosasthalaiyar Rivers. The surplus water from the Poondi reservoir caused collapse of the Karanodai Bridge at

Events	Impacts
	Redhills. The surplus water from the Chembarambakkam tank also flooded Adayar.
1998 Floods	Thanikachalam Nagar in Madhavaram was flooded by the Kodungaiyur canal.
2005 Floods	The major water bodies like Cooum, Adyar, Otteri Nallah, Buckingham Canal, Virugambakam and Arumbakkam Canal of the city got flooded due to unprecedented rainfall received in a day. The event was also coupled with a stampede during relief distribution at a school in MGR Nagar. The stampede leads to 42 deaths and injury to 37 victims.
Chennai Floods of 2015	The city witnessed a severe flood during December 2015 immediately after a prolonged depression over the month of November. Power supplies got suspended while all the major hospitals stopped functioning. The Airport and train services got closed. The flood observed around 422 deaths in the state and property damage and loss of 14,602 crores INR.

2.10.4 Cyclones

Chennai, situated on the Eastern Coast of India witnesses cyclones regularly. It has witnessed seven major cyclones from 2005 to 2012. The impacts of these cyclones have been detailed out in Table 2.3. The most vulnerable areas to cyclone extend to a distance of 20 Kilometres from the coast. The following are the major risks associated with a cyclone in the city:

- cyclonic wind velocities combined with the heavy storm;
- coastal flooding due to high waves.
- flooding due to heavy storms.

Table 2.3: List of major cyclones witnessed in Chennai

Events	Impacts
Nada Cyclonic Storm -2005	The Nada Cyclonic Storm with winds exceeding 75 Km/hr encountered the coast of Tamil Nadu near Karaikal affecting Chennai and other nearby areas.
Cyclone Fanoos-2005	The city also experienced Cyclone Fanoos in 2005 that struck the east of Chennai coast with a wind speed of 85Km/hr on 9th December.
Nisha Cyclone-2008	The Nisha Cyclone hit with a speed of 83-102 Km/hr on 26th November.
Cyclone Jal-2010	Cyclone Jal hit Chennai with a wind speed of 100-100 kmph. Over 16 flights were diverted to Bangalore due to poor visibility. 1 death was witnessed in the city

Events	Impacts
Cyclone Thane-2011	Fishing activities got halted in the wake of the cyclone thane with a wind speed of 140-165 kmph. People lying in low-lying areas were evacuated. Huge infrastructural damage was observed.
Cyclone Nilam-2012	Cyclone Nilam hit Chennai with a wind speed of 85-100 kmph on 28th October. 3 crew members at Chennai port died while a few of them were trapped during the storm.
Vardha Cyclone-2016	The cyclone made landfall in Chennai on 12th December 2016 with a wind speed of more than 140 Km/hr resulting in huge devastation. Average rainfall of 119.1 mm was recorded in the city during the storm. It was the most severe cyclone witnessed in the city over the last two decades.

Source: (GCC, 2017)

2.10.5 Fire Outbreaks

The city of Chennai is also extremely vulnerable to fire outbreaks like other metros of India. There have been two major instances of fire outbreaks in the chemical godowns in the Madhavaram Area on 29th February 2020 and at Erukkenchery on 13th December 2019. Some of the other fire incidents in the city are fire in Chennai Parking Lot on February 24, 2019, engulfing around 187 cars in the fire and the fire in Chennai Silk showrooms at T Nagar in 2017. The fire at the Chennai Silk showrooms took two days to be extinguished gutting all the textiles present in the building.

2.10.6 Biological Disasters

The raging outbreak of the COVID-19 pandemic has severely impacted Chennai with total confirmed cases of 2,94,073 out of which 29,259 were active cases as of 22nd April 2021. Chennai is one of the worst affected city in the country by the COVID-19 outbreak among the metropolitan cities. The city also witnessed several positive cases during the swine flu outbreak in 2009. Further, the dengue outbreak in 2001 was also a major epidemic that occurred in the city.

URBAN FLOODING VULNERABILITY IN CHENNAI

The city of Chennai has witnessed several major flooding events in 1943, 1976, 1985, 1996, 2000, 2004, 2005 and 2015 (NDMA, 2010) thereby revealing that the city is extremely vulnerable to flooding. The low-lying topography of the city and the huge amount of rainfall received in a short span are two major factors. The rainfall pattern in the city is also unique in comparison to other parts of India as it receives rainfall from both the southwest and northeast monsoons from June to December. The large numbers of water bodies present across the city often overflow during heavy rainfall creating local inundation in several parts of the city, especially in low lying areas. These factors get further aggravated by the rapid and unregulated development across the city along with environmental challenges and climate change impacts. The following section tries to detail out the major factors that are exacerbating vulnerabilities to urban flooding in the city.

3.1 METEOROLOGICAL AND HYDROLOGICAL FACTORS

The geography of South India acts as a major factor increasing the vulnerability to flooding as the rivulets, ponds, streams and rivers originating from the Western Ghats flow towards the East to the Tamil Nadu coast. This factor gets coupled with the high vulnerability of the eastern coast of our country to storms, depression, tsunami and floods. Chennai having a flat topography and absences of the natural slope in the city also cease unrestricted runoff during heavy rainfall.

The drainage system of Chennai possesses an immense threat to flooding. Several past instances of catastrophic flooding events have occurred in Chennai such as in the year 1943, 1976 and 1985 due to the flooding of rivers and failure of drainage systems during heavy rain associated with depressions and cyclonic storms. Over the last decade, the city was severely flooded from October 30 to November 2 in the year 2002 due to heavy rains of around 16-20 cms attributed to a trough of low pressure from the Gulf of Mannar to the South-west bay off the Tamil Nadu coast (Anil K. Gupta; Sreeja S. Nair , 2010). The residential areas of the city were cutoff affecting the life and services in those areas. Similar events of flooding have been observed in the city during heavy rains in the subsequent years of 2004, 2005, 2006, 2007 and 2008 (NDMA, 2010).

3.2 DEVELOPMENT RELATED FACTORS

The city of Chennai used to act as a sponge to absorb the excess water flow from its surrounding sub-region supporting paddy fields and fish farming. With the rapid growth of the city as a manufacturing hub during the post-independence period, the natural hydrological system got distressed as the new industries, educational

institutions and housing estates got developed replacing the permeable surfaces which earlier used to act as an absorbent for the excess water from its surrounding area. Thousands of smaller ponds and streams have been filled up in the process multiplying the increase in surface water flow. The major tanks are also silted and the amount of water flowing into them has increased often inundating the cities.

The development of a business district catering to IT Park and many multinational corporate headquarters in the flood plain of the Adyar River is another concern, which has risen as an outcome of regulated development. Most of these areas were originally marshy and low-lying which have been filled up and used for developmental projects making these areas extremely prone to urban flooding. The business in these areas would also be affected in case of any flooding event causing huge economic losses. In the past three decades, massive planned and unplanned housing has encroached the Adyar riverbed putting millions of residents in danger in case of any flooding event. Most of the storm water drains are not properly maintained. The poor garbage disposal system in the city also adds to the problem of blockage and silting in both the natural as well as urban stormwater drains.

3.3 INCREASING TREND OF FLOODING

Several empirical studies like (Sikarwar & Chattopadhyay, 2020) have suggested that the average annual rainfall in the city has decreased over the last decades but the impacts of climate change have resulted in high rainfall in shorter durations leading to the failure of the existing drainage system. The repeated flooding of the city since 2002 over the last decade is major evidence of that. This repeated flooding results in direct and indirect threats to the lives of the 86.53 lakhs people residing in the metropolitan area. Further, the floods also disrupt the economic activities leading to economic loss for the state as well as the entire country. The surrounding settlements that are dependent on Chennai for different purposes also face indirect impacts of flooding in the city. Chennai, being the capital city of the state of Tamil Nadu, houses all the administrative authorities and functionaries of the state which also gets disrupted during the occurrence of floods affecting the entire state.

DISASTER RISK MANAGEMENT SCENARIO IN CHENNAI

The prevention, mitigation and management of disasters in the city of Chennai are governed under the State Disaster Management Policy of Tamil Nadu and the Disaster Management Act of 2005. The Disaster Management Act was passed in 2005 for provisions of effective management of disasters and matters connected there with or incidental thereto. The state of Tamil Nadu has a Disaster Management Policy since 2004-2005 for prevention, mitigation and management of disasters in the state which also covers post-disaster measures of relief, rehabilitation and reconstruction (CMDA, 2008). There are several other norms and regulations which regulate the development and construction practices in the city to mitigate the risks and to build resilience. The disaster management mechanism in the city is coordinated by the Greater Chennai Corporation with the coordination of various other authorities and institutions under the supervision of the Tamil Nadu State Disaster Management Authority (TNSDMA).

4.1 TAMIL NADU DISASTER MANAGEMENT POLICY

Tamil Nadu Disaster Management Policy aims to reduce the negative impact of all kinds of disasters through a vibrant disaster management machinery so that loss of lives, property & critical infrastructure is minimised and economic and development gains made by the State are not lost due to such calamities/disasters.

(Govt. of Tamil Nadu)

The key components of this policy are the following:

(i) Convergence of disaster management and development planning

(ii) Formulation of disaster management plans at all levels taking into account the local conditions

(iii) Focusing on the reduction of vulnerability of communities instead of mere disaster relief

(iv) Fostering a culture of prevention among the community and various organisations/departments of Government through training and awareness campaigns

(v) Involving the community at all stages in disaster management activities and

(vi) Creating a trained and committed volunteer force on the line of home guards for disaster management.

(CMDA, 2008)

4.2 DEVELOPMENT CONTROL RULES AND BUILDING REGULATIONS

The constructions in the CMA are regulated by Development Control Rules (DCR) concerning zone, location, height, number of floors, size of buildings, set-backspaces to be left around and the use of the building and land. Building Rules under the Local Bodies Acts provide for the regulation of location of buildings, foundations, plinths, superstructures-walls, floors and rooms, licensing of surveyors and inspection of municipal engineers at various stages of constructions, regulations on dead and super imposed loads, wind load/pressure, reinforced cement concrete and framed structures, construction materials, etc. Structural safety and soundness are also regulated under the Building Rules under the Local Body Acts. A pro-active approach of integrating Special Rules for Hazard Prone Areas in the existing Building by-laws of the Local Bodies should be initiated to build more resilient infrastructure in the city.

4.3 CITY DISASTER MANAGEMENT MECHANISM

The Commissioner of Greater Chennai Corporation is responsible for the overall management of disasters in Chennai Corporation areas. The structure of disaster management mechanism in Chennai includes District Disaster Management Committee, Disaster Management Teams and Crisis Management Groups, Emergency Operation Centre, Site Operation Centres, Modalities of involvement of the army and other defence forces, NGOs and other institutions (CMDA, 2008). The administrative structure of the GCC has been illustrated in Annexure I.

The overarching role of the Greater Chennai Corporation Commissioner in handling the situation during a disaster is highlighted below: -

(a) Take stock of the vulnerability of the district to different types of disasters

(b) To review the preparedness of the district for tackling disasters

(c) To examine the Disaster Management Plan for the district and

(d) To ensure that a robust Decision Support System (online and offline communication system) is in place in the DEOC and connected with the Sub-Division, Taluk / Block and Zone (in Corporation) level.

(TNSDMA, 2017)

The response activities in the city are executed according to District Response Plan. The response plan is focused on operational direction and coordination, emergency warning and dissemination, rapid damage assessment and reporting, search and rescue, medical response, logistic arrangements, communication, temporary shelter management, law and order, missing persons search/media management, animal care, involvement of NGOs and voluntary organisations (CMDA, 2008).

The Development Plan of Chennai 2026 provides for the preparation of a Relief Management Plan on the occurrence of any disaster for identifications of the relief

needs, mobilization points, transportation and coordination with relief teams. Preparation of recovery and reconstruction plan post any disaster is also mandated under Development Plan of Chennai 2026 to restore normalcy to lives and livelihoods of the affected population, both for short term and long term, taking into account restoration of basic infrastructure, reconstruction/repair of life-line buildings/social infrastructure/damaged buildings, medical rehabilitation and restoration of livelihoods through assistance /aid/grants.

Mock drills are also conducted regularly by the Police, Fire Department, National Cadet Corps (NCC), and Home guards for creating awareness about search and rescue in c of any emergency(CMDA, 2008).

4.4 PREPAREDNESS AND MITIGATION MEASURES FOR FLOODING

A pre-monsoon preparedness review meeting is conducted annually under the Chairmanship of Chief Secretary to Government of Tamil Nadu to assess the probabilities of monsoon floods and cyclones well in advance and further planning for those events in advance. A Disaster Management Plan and a handbook detailing the warnings of IMD, high risk areas and emergency contact numbers have also been prepared. The copies of this handbook are distributed to all the line departments, educational institutions, and offices of the elected representatives. Besides, the District Co-ordination Committee conducts meetings with concerned organisations and local bodies to review the preparedness and to take effective action.

(CMDA, 2008)

A Control Room functions in the Greater Chennai Corporation to monitor the flood situation in the field and other related issues including water stagnation, tree fall, the status of subways, relief centres, food packets issued, pumps utilised for the removal of inundated water, evacuation operation, collection and distribution of relief materials, etc. A two-way VHF/HFcommunication system and a toll-free public utility service telephone has been installed at the district headquarter. The Office of the State Relief Commissioner at Ezhiligam also host a permanent control room functioning round the clock. During the outbreak of any flood situation or other emergency, reports are collected from Zonal offices on an hourly basis and further submitted to Commissioner. The flood mitigation issues pertaining to other departments/agencies are also coordinated by the control room.

As an aftermath of the flooding of 2004 and 2005 in the city, the following steps are taken before monsoons to avoid flooding because of torrential rains:

a. The PWD is directed to keep a constant watch over all the dams and major anicuts and take necessary measure to plug the breaches and to ensure advance intimation to the public before the release of excess water. Cyclone shelters and buildings identified for accommodating displaced persons are inspected for keeping them in readiness.

b. The Highways Department is directed to keep all machinery like bulldozers, power-saws etc. in adequate quantity and good condition to clear obstructions/roadblocks caused by uprooted trees, electric posts etc. during the time of cyclone flood etc.

c. The GCC Commissioner is directed to check the stock position of essential commodities like rice, kerosene, etc. in the godowns and make available an adequate number of lorries in good running condition to move the commodities to the affected people.

d. The Public Health Department ensures the availability of disinfectants, basic medicines and other essential medical supplies.

e. In times of emergencies, the assistance of navy and coast guard authorities, Army and Air force is taken to tackle the problem of evacuation, and dropping off food to the affected people etc.

f. All oil corporations are required to keep adequate stock of fuel at the vulnerable points in the State and to provide refuelling centres for helicopters that are pressed into service.

g. The medium of TV and Radio are utilised to caution the public to take precautionary measures and to move to safer places and

h. All the line departments including Electricity Board are instructed to have effective coordination at the GCC level under the leadership of the Commissioner.

(CMDA, 2008)

A disaster management cell functions in the GCC to tackle the challenges of flooding. Before the monsoon in October-December every year, desiltation and cleaning of drains are done as a precautionary measure. In addition, the nodal officer and zonal officers are identified and vested with adequate powers to tackle any flooding emergency. During this time, the public are also notified about the identified relief centres are identified and specific planning for evacuation is carried out. Equipment for draining out flood waters are kept ready. Relief arrangements for food are made and emergency contacts are notified through newspapers, radio and television. All the concerned agencies such as Police, Fire and Rescue services, Metropolitan Transport Corporation, District administration, Health Department, Army and Navy are alerted in advance. The Government review the readiness to tackle the flooding situation is reviewed before the monsoon every year.

(CMDA, 2008)

The disaster management mechanism in the city has been further upgraded after the 2015 flooding in the following ways:

- Wireless networks have been installed by GCC for continuity of communication in case of breakdown of telephone and other communication networks.
- Introduction of WhatsApp group for communication among all the officials engaged in flood work to exchange the information that is coordinated by the control room duty staff.
- A dedicated Public Relation Officer has been posted in the control room for media management. He is responsible for collecting data and details of relief operations for press releases.
- Two more control rooms apart from the GCC and the State Revenue Department have been established, one each at the Secretariat and State Emergency Operation Centre. A proper communication system has also been set up among all the control rooms.

(GCC, 2017)

FLOODS OF 2015

The 2015 flood in Chennai was one of the deadliest floods witnessed in the city affecting more than 4 million people in and around the city. The flood occurred in December 2015, claimed around 422 lives and displaced around 18 lakhs people. The flood also caused 87 deaths in Andhra Pradesh and 3 deaths in the Union Territory of Puducherry. The disaster caused a huge economic loss of around 3 billion USD making it the costliest disaster of 2015 in the country and the eighth costliest across the globe (Narasimhan T. , 2015).

5.1 GENESIS OF THE 2015 FLOODS

The 2015 flood in Chennai was triggered by the Northeast monsoon that sets on the Eastern Coast of India. During the second week of November, heavy rain occurred on the coast of Tamil Nadu and Puducherry owing to a depression formed in the region. Chennai received around 1113.80 mm of rainfall in November 2015 making it the wettest month of the year in the last 100 years. This heavy rainfall coupled with high-speed wind resulted in fall of more than 911 trees across the city (GCC, 2017). During 28th-29th November, another depression arrived over Tamil Nadu bringing additional rain to the city. These repeated depressions formed over the Bay of Bengal near the Tamil Nadu coast are believed to be triggered by El Nino of 2015 which started developing in 2014 (Narasimhan, Bhallamudi, Mondal, Ghosh, & Mujumdar, 2016). El Nino is the warm phase of the El Nino Southern Oscillation (ENSO) and is associated with a band of warm ocean water that develops in the central and east-central equatorial Pacific, including off the Pacific coast of South America. El Nino typically causes less than normal rainfall in the case of the southwest monsoon. However, it brings about above-normal rainfall during the northeast monsoon. This happens due to the difference in seasonal wind patterns between the two monsoons. Many empirical studies suggest that the constant warming of the Bay of Bengal off the coast of Tamil Nadu and Andhra Pradesh resulted in heavy rainfall during the period.

The city received the highest daily rainfall of 319.6 mm on 2nd December 2015. The pattern of rainfall received during this period has been depicted below in Figure 5.1. The prolonged period of heavy rainfall in the city resulted in the overflowing of the water bodies present in and around the city. The antecedent moisture condition (AMC) of the soil was also extremely low resulting in huge runoff across the rivers and the canals of the city.

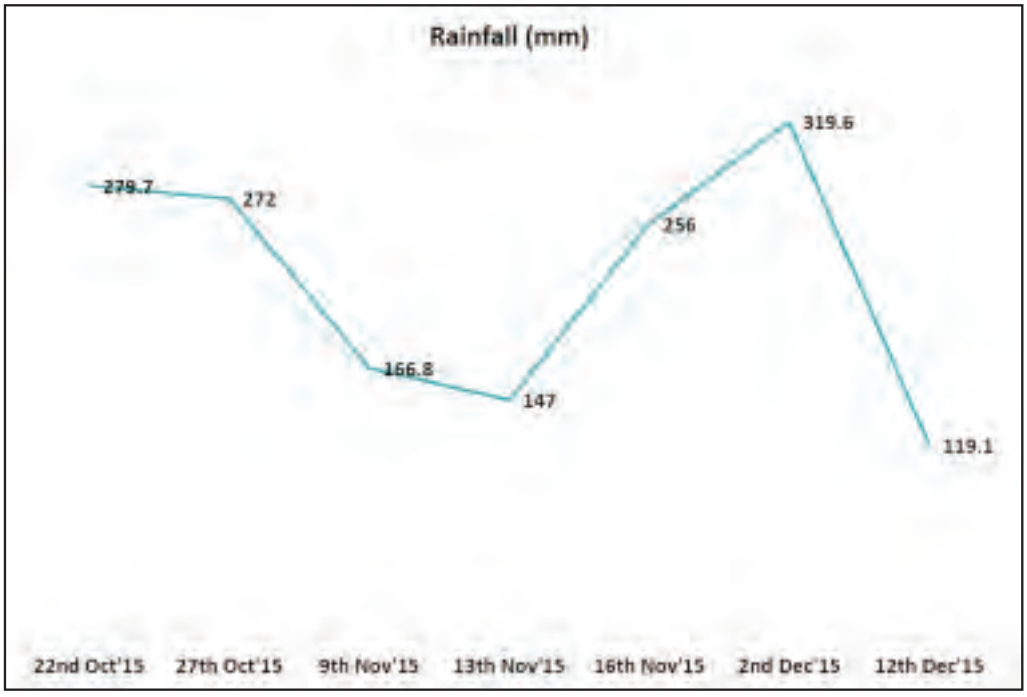


Figure 5.1: Rainfall received from 22nd October to 12th December 2015
Source: (GCC, 2017)

In Kanchipuram District, 908 out of 912 tanks were over flowing draining the excess water through 170 drains into Chembarambakkam Lake. On 2nd December, the state authorities opened the sluices of the Chembarambakkam Lake releasing 821 cubic metres per second into the city for 12 hours, which lead to flooding of Adyar and Cooum Rivers and their link canals (Bremner, 2015). Similarly, in the Kovalambasin,65 tanks were over flowing causing in undation in Sholinganallur and Perungudiareas. In Tiruvallur Districts surplus water released from Puzhal-Redhills and Poondi reservoir caused flooding in the Kosasthalaiar basin (GCC, 2017).The carrying capacity in the Coumand the Buckingham Canal exceeded beyond their designed capacity. Canals including 31 minor canals in Chennai city flooded the nearby areas.

Out of the 200 wards of Chennai around 165 wards were underwater. Some of the most affected are as were Mudichur, West Tambaram, Manapakkam, Saidapet, Jafferkhanpet, Kotturpuram, etc. Many in undated are as were with more than 2 metres of water level. The Chennai International Airport was closed and trains cancelled. Schools too were closed and examinations postponed. The Government of India (GoI) declared Chennai as a disaster Zone (Bremner, 2015).

By December 4th, the flood waters gradually began to recede and some of the major roads could be reopened, though 40 percent of the city remained submerged. The

Greater Chennai Corporation jointly with other Departments cleared stagnated water and 911 fallen trees. The lifelines of the city were restored within days and the rail and air services were resumed. The banking services were also partially restored. The inundation levels of the city during 3rd December and 7th December 2015 are illustrated below in Figure 5.2 and Figure 5 3. By the end of the month, the city came back to its normalcy. Schools and hospitals also resumed their operations (Narasimhan, Bhallamudi, Mondal, Ghosh, & Mujumdar, 2016).

5.2 IMPACTS AND DAMAGES DUE TO FLOODS

The death toll caused by the floods in the state of Tamil Nadu was 422 while there were 87 deaths in the flood-affected districts of Andhra Pradesh and 3 deaths in the Union Territory of Puducherry (The News Minute, 2015). 18 patients were reported to be dead on 5th December 2015 in MIOT International Hospital, as the flood waters damaged the power units supplying power to the ventilators. This was one of the most infelicitous incidents of the 2015 floods. Further, around 1.8 million people were displaced due to the flooding. About 3.042 million families suffered total or partial damage to their dwellings. It was reported that

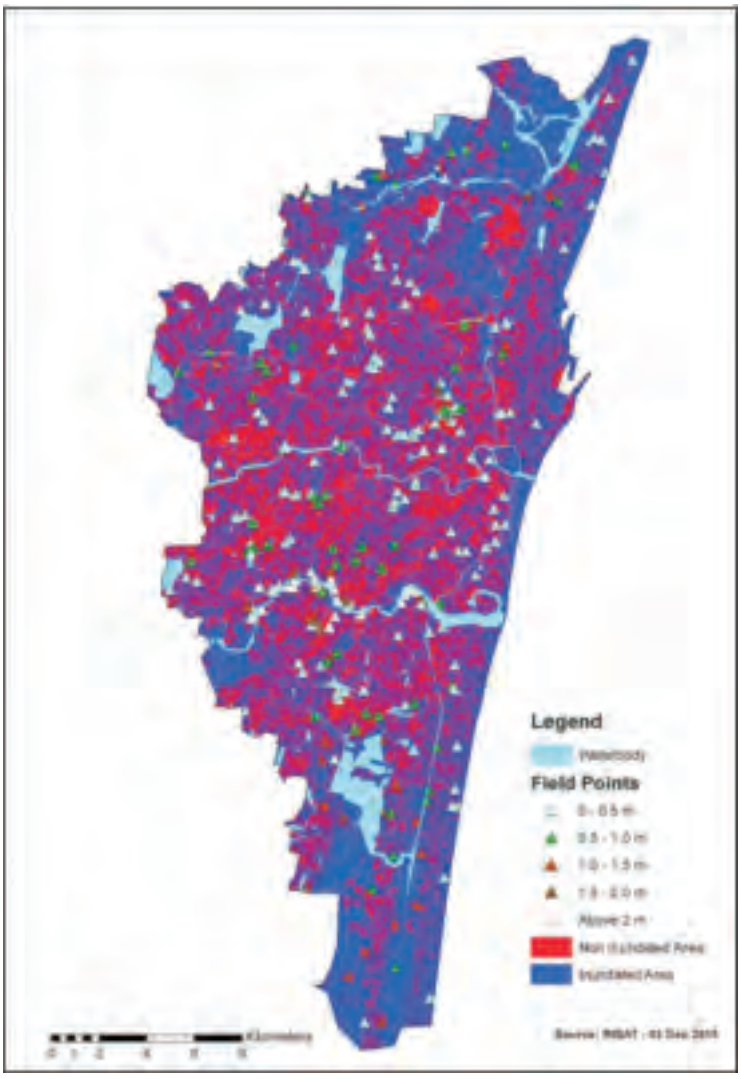


Figure 5.2: Inundation in the city of Chennai as on 3rd December 2015 Source: (GCC, 2017)

more than 100,000 structures were damaged because of the floods (Narasimhan T. , 2015). Almost 30% of Chennai households faced losses between Rs. 2 lakhs to Rs. 20 lakhs (DNA Web Team, 2015)(Express News Service, 2015).

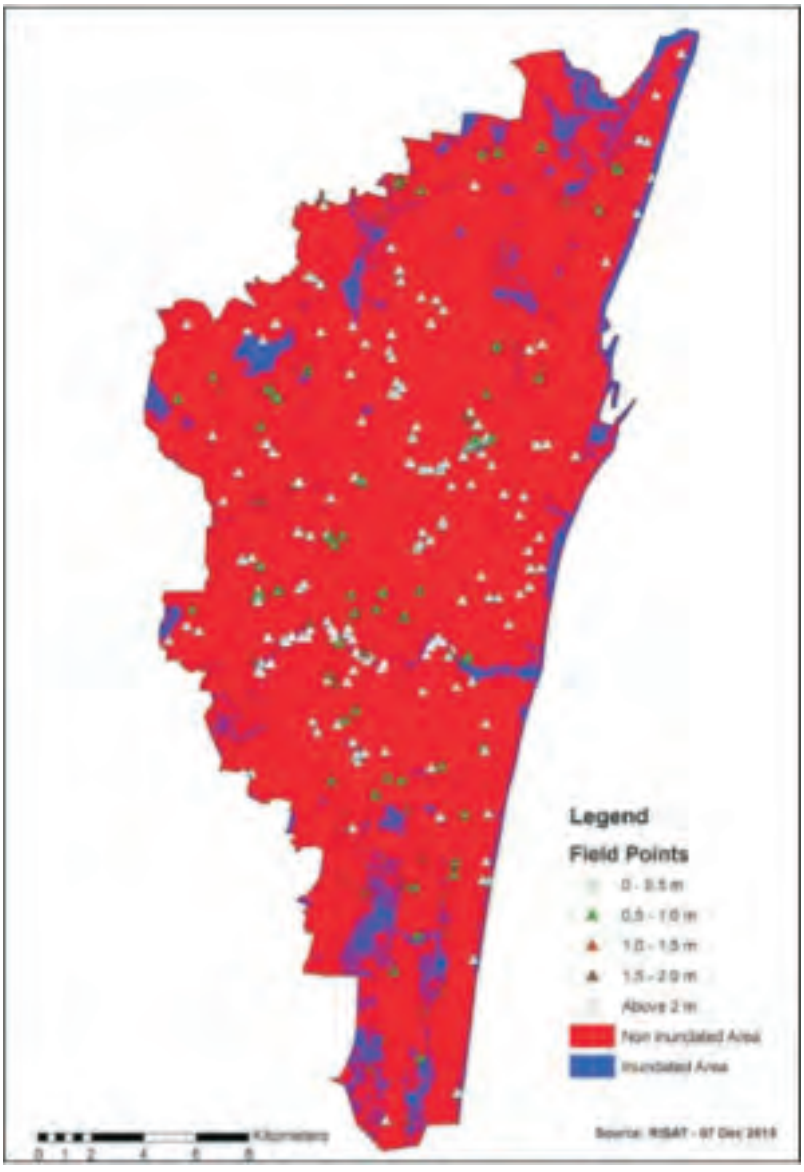


Figure 5.3: Inundation in the City of Chennai as on 5th December 2015
Source: (GCC, 2017)

Figure 5.4: Damage and destruction caused in Residential areas post 2015 floods, A shop keeper in T. Nagar indicating the flood water level reached in his store; Damaged contents behind the Hotel Lemon Tree in Porur(clockwise)
Source: AIR; DNA India

According to the report of The Hindu, 1.5 lakhs of street vendors sustained cumulative losses of around INR 3 billion. The Chennai real estate market sustained an estimated loss of nearly INR 300 billion while over 20,000 small and medium industrial units across Tamil Nadu reported total losses of over INR 140 billion (DNA Web Team, 2015). Most of the premium hotels of Chennai were closed for more than 10-15 days after the floods. Famous commercial pockets like T. Nagar experienced floodwater levels of 4-6 feet. Shops in these areas reported extensive contents damage due to loss of electricity for prolonged duration and water-logging. More than 3,82,768 lakhs hectares of crops had been lost in the surrounding districts of Chennai due to flooding, and roughly 98,000 livestock animals and poultry were dead (The Hindu, 2016).

Figure 5.5: Damaged MEP systems and cattle stuck in floods(left to right)
Source: AIR; WordPress

5.3 RESPONSE AND RELIEF

Most of the residential areas including gencroached are as along with water bodies were marooned for more than 10 days. Around 280 boats and choppers were used for rescuing people and supplied relief materials to the low-lying areas such as Kargil Nagar, Madhavaram, Villivakkam, Kolathur, Tondiarpet, Mambalam, K.K. Nagar, Jaffer khanpet, Ekkatuthangal, Guindy Industrial Estate, Defence Colony, Ramapuram, SriNagar Colony, Saidapet, Valasaravakkam, Manapakkam, Kotturpuram, Madhya Kailash, Velachery, Pallikaranai, Thiruvanmiyur, Neelangarai, Perungudi, Madipakkam, Ram Nagar, Karapakkam, Sholinganallur, etc.

The mobile communication network was down in many parts of the city. Major intercity and interstate roads were cut off during the flood and severely affected the public movement. The city was cutoff from the surrounding towns and cities owing to the disconnection of roads. Chennai was severely affected and the supply of basic commodities like vegetables, milk and bread among others were stopped. Due to the failure of the power supply in the city, it was difficult to rescue the people during the night. The Government of Tamil Nadu appointed 15 senior officials as Monitoring Officers for heading Relief and Rescue operations for each zone in a planned and systematic manner (GCC, 2017).

Figure 5.6: Rescue and Relief Operations carried out post the flood
Source: (GCC, 2017)

Floodwater was cleared by using 470 Pump sets, 82 JCBs and Poclain trucks, 49 Fire service machines and 75 super suckers of CMWSSB (GCC, 2017).ln addition, 6 heavy-duty pumps having a capacity of 250 HP each supplied by Confederation of Indian Industry (CII), New Delhi and 4 from Neyveli Lignite Corporation Ltd.(NLC) were used in heavy waterlogged areas (GCC, 2017). The relief materials were supplied by boats and choppers in the low-lying areas of the city.

Figure 5.7: Clearance of Flood Water and debris by the Government Authorities
Source: (GCC, 2017)

Figure 5.8: Clearance of tree fall by the Emergency teams and civic authorities
Source: (GCC, 2017)

About 176 relief centres were opened in the city by GCC and more than 1.2 lakhs individuals were sheltered in these relief centres for more than 20 days. Necessary relief materials like mats, bed sheets and food materials were supplied promptly. In addition to this, donors and NGOs distributed food and relief materials to the affected people in pockets. Apart from in-house kitchens in some relief centres, food was also prepared and distributed from Amma Canteen and all four common kitchens of Greater Chennai Corporation.

Figure 5.9: Shelter Camps and Food Distribution Drives
Source: (GCC, 2017)

Figure 5.10: Centralised Relief Material Centre
Source: (GCC, 2017)

A centralised Relief Material Distribution Center for Chennai, Thiruvallur, Kancheepuram and Cuddalore was opened at Jawaharlal Nehru Indoor Stadium for prompt and speedy distribution of relief materials to flood-affected people. The relief materials were received from the Districts Collectors, Co-operative Societies, Aavin, MTC and Southern Railways, Indian Navy, various Public Sector Undertakings, Indian Military, NDRF, NSS and NGOs. It included 1,99,244 General food packets, 32,992 mats, 2,07,433 bed sheets, 12,500 litres of Milk, 54,448 Water Bottles, 2,122 Rice Bags, 10,390 Dress Material Packs, 3,004 Medicine Boxes and 2,38,568 litres of water totalling 1577.65 tonnes received over15 days.

(GCC, 2017)

The flood-affected areas were sanitised by more than 250 MT of bleaching powder supplied by the Government and NGOs. The volunteers of NGOs and Residential Welfare Associations contributed to the door-to-door distribution of relief materials and applying bleaching powder in the flood-affected areas. There was no delay in the distribution of perishable items to the victims resulting in little wastage.

Figure 5.11: Distribution of Relief materials by Volunteers of NGOs and Residential Welfare Associations
Source: (GCC, 2017)

5.4 SHORT-TERM RECOVERY

5.4.1 Clearance of Garbage

The immediate concern after the relief and rescue was the restoration of the services. One of the major challenges was the clearance of the garbage from the city that got accumulated during the floods. The GCC mobilised 16,111 sanitary workers and labourers with 675 lorries and 100 JCBs were mobilized from other local bodies along with its equipment and human resources for clearance of garbage. The residents throwing a huge quantity of damaged household articles/debris on roads/streets daily was adding to the already accumulated garbage heap which created a serious challenge for the Corporation. Despite the challenges, the GCC managed to clear 2.2 Lakhs MT of garbage/debris at the rate of 8,148MT perday (GCC, 2017).

Figure 5.12: Clearance of Garbage by Greater Chennai Corporation
Source: (GCC, 2017)

5.4.2 Financial Aid and Ex-gratia

The Hon'ble Prime Minister of India announced an ex-gratia of INR 2 lakhs for the next of kin of those who lost their lives in the floods dues to heavy rains in Tamil Nadu. An ex-gratia relief of INR 50,000 was also sanctioned for those who were seriously injured in the floods. The then Tamil Nadu Chief Minister announced an initial allocation of 5 billion for relief and rehousing, with 400,000 for each family which had lost relatives in the floods. The then Opposition party Dravida Munnetra Kazhagam (DMK) donated 10 million to the state government on behalf of the party. Several notable actors and sports persons also donated for relief and recovery of the victims of the Chennai Floods.

5.4.3 Post-flood sanitisation

The State authorities took an initiative to sanitise all the civic facilities post the 2015 floods. By the end of December, most of the parts of the cities were sanitised and no flood-related disease outbreaks were witnessed in the city.

5.5 LONG-TERM RECOVERY

5.5.1 Slum Clearance and rehabilitation Programme

The Government of Tamil Nadu began Slum Clearance Programme as a long-term recovery approach on 29th December 2015. Several illegally constructed dwellings in the Saidapet area of the city were demolished. The residents of the slums were rehoused in the government housings built in Okkiyam Thoraipakkam and Perumbakkam. The State Government further announced an allowance of 30,000 INR to the rehoused residents for resettlement (The Hindu, 2016). The healthcare and medical services for these residents were also arranged. Children were provided with schooling facilities while job seekers were provided with vocational training (The Hindu, 2016). By the end of 2016 March, about 4,100 families which were living in the area had been resettled, and the illegal constructions were

Figure 5.13: Slum Clearance Programme by Government of Tamil Nadu
Source: The Hindu

demolished widening the Adyar River in Saidapet to 220 metres from its previous 50-metre width by the city corporations (Lopez, Encroachments cleared, 2016).

5.5.2 Repair and Reconstruction Works

The Greater Corporation of Chennai quickly began the repairing and re-paving of the damaged roads. The previously planned storm drain project got fast-tracked as an after-effect of the floods (Lopez, Work on civic projects on an overdrive, 2016). The Airports Authority of India (AAI) repaired the walls of the Chennai International Airport which got damaged during the floods of 2015 by February 2016. Chennai's Water Resource Department begun the revitalising and repairing works in Poondi, Cholavaram, Red Hills and Chembarambakkam reservoirs in March 2016. The project included works for strengthening bunds, installation of flood-warning systems and repairing sluice gates.

Restoration works were proposed under the provisions of the Smart Cities Programme and AMRUT scheme. Several projects were initiated with the funding of the World Bank and ADB for climate-change reduction initiatives and restoration of water bodies and tanks (The Hindu, 2016).

Figure 5.14: Repairing works of Roads by the Civic Authorities
Source: The Hindu

5.5.3 Preparation of Comprehensive Disaster Response Plan

The Government of Tamil Nadu prepared a comprehensive Disaster Management Plan in response to harsh criticism of a severe lack of transparency and coordination during the crisis.

5.5.4 Desilting of Water Bodies

In April 2016, the Chennai city corporation began the process of mechanically desilting the city's canals and drains using imported recyclers and robotic excavators(Lopez, Corporation goes high-tech to clean up city's canals, 2017).

5.6 CHALLENGES FACED

The State Government and the National Government, notwithstanding some initial challenges, rescued the trapped victims very efficiently with the help of the army, NDRF, NSS and several other agencies. Local representatives like volunteers of NGOs, welfare associations and several other agencies joined hands in the relief and rescue operations. The help received by the authorities from the residents and citizens is praise-worthy. This situation also emphasises the role of communities in

efficient disaster management. Despite it being one of the most successful relief and rescue operations, the lack of preparedness to tackle the flood of such intensity has revealed the following challenges faced during and post the flooding:

- The offices and institutions like schools, colleges, etc. faced numerous challenges during the flooding including the need to shift and secure important records and maintenance of computers, printers and other water-sensitive physical infrastructures. The educational institutions further faced the challenge of equipping themselves as shelter homes.
- The lack of accessibility to several parts of the city due to severe flooding made identification and delineation of delivery points and transport routes more difficult, which in result deprived some local communities of necessities like food supplies and medicines.
- During the first 24 hours of flooding, the major issue faced by local supermarkets was to safeguard perishable items from getting wet as well as to keep them from spoiling due to power cuts.
- First responders and information providers faced difficulties in providing accurate real-time information to local communities on flooded areas, accessibility of roads, road condition, traffic flow and current weather scenario.
- Flooding of roads, tracks and supporting infrastructure, delayed and suspended provision of necessary services such as hospitals.
- No backup power supply for emergency facilities, which in turn resulted in the death of 18 patients in MIOT hospital.

These challenges could have been easily avoided with proper coordination and planning among the GCC, TNSDMA and the other civic authorities dealing with essential services such as PWD, Fire Department, Public Health Department, Electricity Boards, Water Supply Boards, etc. A proper response and relief plan could have been developed in advance. Precautionary measures that need to be executed at an individual level should have been disseminated in the public interest. Besides, more accurate and reliable weather predictions are also important for better preparedness. The construction norms for roads needs to be revised as the most physical damage affect the roads. The damage to roads also disconnected several settlements making the rescue and relief operations more challenging.

A NATURAL CATASTROPHE OR A DEVELOPMENT BASED DISASTER?

The heavy rainfall triggered by the El-Nino is believed to have played an important role in causing the Chennai floods of 2015. However, the impacts would have been less severe, but for the unregulated development and filling up of lakes and water bodies, which created havoc in the city. Several IT firms and manufacturing industries were closed due to inundation. The Auto Component Manufacturers Association reported that more than 50 percent of the employees of the manufacturing industry lost their homes and objects in the floods. The water level reached the ground floor of the shops and offices destroying their inventories and machinery. The IT parks and the multinational corporate headquarters located on the banks of the Aadyar River also faced issues of submerging during the floods. Several post-flood studies have revealed that the river floodplains have been developed as residential complexes and business districts such as those in Velachery and Tiruvanmiyur risking thousands of lives. The big corporations, middle-class housing and slums built on the swamps, marshlands and low-lying areas got inundated as they were at the receiving end of large overflowing regional tanks. This section details some of the major developmental factors that worsened the impact of the 2015 floods in Chennai.

6.1 ENCROACHMENT OF WATERSHEDS

The hydrological aspects have been mostly disregarded in the planning of the city. The marshlands of the city and the riverbanks were replaced by impermeable surface to facilitate rapid development in the city. The marshland of the city post-independence was reduced to almost 600 ha around 2010-11 from 5,000 ha (Sengupta, 2015). This reduces the absorbing capacity of the discharge that flows from West to East. Several fishing and agricultural villages and hamlets were also engulfed by the development in the city, leading to several ecological and environmental challenges.

6.2 FILLING UP OF LAKES AND WATER RESERVOIRS

The recharge structures like lakes, tanks, ponds and streams in the city were gradually filled up over a period of time, increasing the surface water flow manifold. The natural course of water has also been tampered. The major tanks are silted due to indiscriminate dumping of solid wastes resulting in overflowing during heavy rains.

6.3 RECLAMATION OF ENVIRONMENTALLY SENSITIVE AREAS

The reclamation of the environmentally sensitive areas for the development purpose was a dominant practice in Chennai. Some of the developments across

several parts of the city that have been analysed in a study (Jayaraman, 2015) are given in the following subsections:

6.3.1 Development of Indian Maritime University, Uthandi

Indian Maritime University is an engineering university that was developed in a flat sandy area, which was part of a flood plain on the western side of the Buckingham Canal and Kovalam Creek at Uthandi. The area had been entirely paved for the construction of this institute replacing the sand exacerbating flooding through increased run-off.

Figure 6.1: Site of Indian Maritime University in 2002
Source: (Jayaraman, 2015)

Figure 6.2: Site of Indian Maritime University in 2015
Source: (Jayaraman, 2015)

6.3.2 Manufacturing plants and units near Chembarambakkam Lake

Overflowing of the Chembarambakkam Lake was one of the major hydrological factors impacting the 2015 floods. The blame for such a scenario lies with the civic authorities and the manufacturers and suppliers who have populated hydrologically sensitive catchment areas with their factories.

Figure 6.3: Catchment of Chembarambakkam Lake in 2002
Source: (Jayaraman, 2015)

Figure 6.4: Catchment of Chembarambakkam Lake in 2015
Source: (Jayaraman, 2015)

6.3.3 Replacing Agricultural lands by manufacturing units at Orgadum

Several multinational automobile manufacturers like Renault Nissan, Daimler Benz and Ford operated auto factories on lands that were once water bodies, paddy lands and forests.

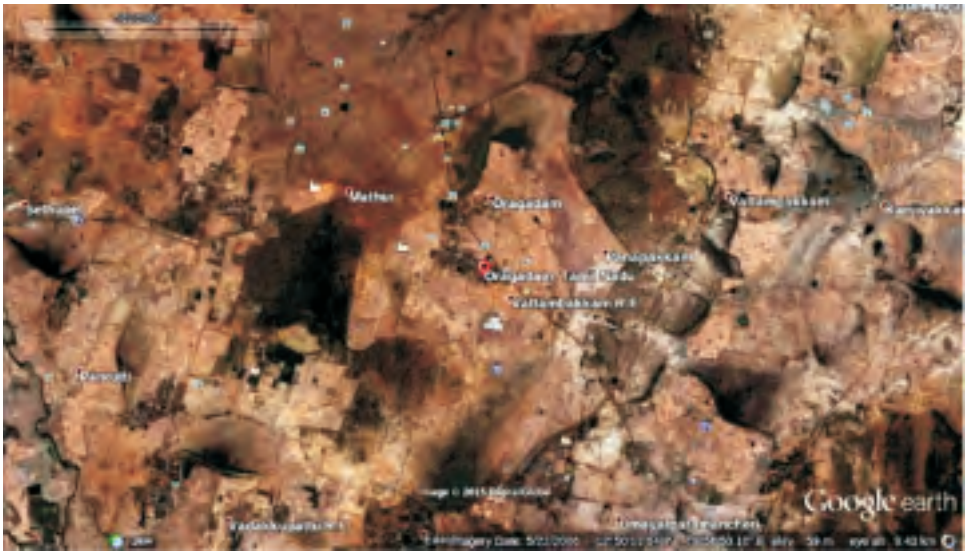


Figure 6.5: Orgadum in 2006
Source: (Jayaraman, 2015)

Figure 6.6: Orgadum in 2014
Source: (Jayaraman, 2015)

6.3.4 Kovalam Creek

The banks of the creek have been encroached by resort tourism and high-end farm houses compromising the ability of the creek to mitigate flooding.

Figure 6.7: Kovalam Creek in 2002
Source: (Jayaraman, 2015)

Figure 6.8: Kovalam Creek in 2015
Source: (Jayaraman, 2015)

6.3.5 Okkiyam Thuraipakkam

Figure 6.9: Okkiyam Thuraipakkam in 2002
Source: (Jayaraman, 2015)

Okkiyam Maduvu is a narrow chicken's neck water-course that facilitates tidal exchange in the marshland of Pallikaranai. The Chennai authorities instead of leaving a health buffer around the Maduvu permitted IT companies, apartment complexes for IT employees, and the Kannagi Nagar colony to come up close to where flood waters converge to pour into the Maduvu. These areas were badly affected during the floods.

Figure 6.10: Okkiyam Thuraipakkam in 2015
Source: (Jayaraman, 2015)

6.3.6 Siruseri

Figure 6.11: Siruseri in 2002
Source: (Jayaraman, 2015)

The area where IT industries have been developed in SIPCOT, Siruseri, is the converging point for flood waters from two drainage systems entering the Kovalam creek. This region of SIPCOT was underwater and inaccessible during the 2015 floods.

Figure 6.12: Siruseri in 2015
Source: (Jayaraman, 2015)

6.3.7 Velachery

Figure 6.13: Velachery in 2000
Source: (Jayaraman, 2015)

The MRTS corridor developed in the Velachery area attracts huge construction of offices and complexes in the area reclaiming all the wetlands in the area.

Figure 6.14: Velachery in 2015
Source: (Jayaraman, 2015)

6.3.8 Sholinganallur

Figure 6.15: Sholinganallur in 2002
Source: (Jayaraman, 2015)

Sholinganallur has witnessed local land-use change drastically in the areas between the Old Mahabalipuram Road (OMR) and the Buckingham Canal. The OMR, a multi-lane raised road, has been constructed in an order that cuts across the drainage path of waters headed to the Buckingham canal.

Figure 6.16: Sholinganallur in 2015
Source: (Jayaraman, 2015)

6.4 DEVELOPMENT OF INFORMAL SETTLEMENTS IN RIVER PLAINS

The development of informal settlements and slums along the river banks and canals not only risk human lives but also narrow down the channels due to siltation, sewerage disposal and dumping of solid wastes. Several families lived in the slums along the river beds. Around 30,922 slums families were found to be living in the river plains in the year 2009 which further increases with the population growth (Sundarmoorthy, Ramadurai, & Anuthaman, 2009).

6.5 RECOMMENDATIONS

The policymakers, city administrators and academicians should focus on mitigation strategies to control the impacts of unregulated development and directing the upcoming development to be resilient and risk-free. A well-planned development, especially in the peri-urban area of the city, could have reduced the impacts of the floods. The hydrological aspects should be integrated into the developmental plans to avoid encroachment of marshy lands and flood plains. With the increasing impacts of climate change across the world, it would be beneficial to mainstream climate change adaptation into urban planning and development. Some of the major aspects of mitigation that need to be considered in urban developmental activities are as follows:

- **Industrial Development:** Industrial developments should be planned considering the flood risks in the urban area to provide sustainability to business operation and to control flood damages potential.
- **Transport and Communication Development:** The planning and designing of transport and communication infrastructure should be planned in accordance with the flood-hazard zoning and the potential risk of damage and loss.
- **Urban Water Resources Management:** The urban planning process should focus on efficient planning and management of water resources to safeguard the functioning of the water system during floods. The effective use of floodwater should also be considered as a major component.
- **Local Flood Management Plan:** A local flood management plan should also be prepared as a preparedness measures by the development authorities in consultation with all involved stakeholders.

MITIGATION AND MANAGEMENT STRATEGIES FOR FLOODS OF CHENNAI

After witnessing the catastrophic floods of 2015 the civic and planning authorities of Chennai have taken a pro-active approach in the mitigation and management of urban flooding risks in the city. Several projects and programmes were initiated in the city of Chennai for reducing the risks of flooding. Many initiatives have also been taken to mitigate the climate change impacts in urban areas. The civic authorities start their preparedness in September every year to tackle the monsoon challenges in the city. The preparedness activities include clearing of water bodies and storm water drains, removal of floating materials, strengthening the bunds, preparing relief centres, stopping the road cut works and pruning of trees to minimize tree falling. The Greater Chennai Corporation has taken up the following projects in coordination with other civic authorities to reduce flooding during Northeast Monsoon.

7.1 PROJECTS TAKEN IN THE EXTENDED AREAS OF GCC

An Integrated Storm Water Drain Project has been implemented by the GCC in the extended areas of the corporation. The project has been funded by several multi-lateral organisations like the World Bank, German Development Bank and Japan International Cooperating Agency (JICA). The project has been estimated to benefit 30 lakh people on completion.

7.2 PROJECTS TAKEN IN THE CORE AREAS

92 missing links in the sewerage system were identified and rectified by demolition and reconstruction of existing drains at 11 places and construction of new drains in 81 places. The areas that benefited from the project are as follows:

- RK Nagar, Tondairpet, Kodungaiyur
- Kolathur, Sidco Nagar, Villivakkam
- Korattur, Anna Nagar
- Rajbhavan and Srinagar Colony, Saidapet
- Purasawakkam, TNagar
- Velachery, Shozhinganallur, Adyar

7.3 WATERWAYS CLEANING

- GCC procured anamphibian vehicle from Finland for Rs. 4.10 crore for desilting of macrowater ways. Approximately 2,42,046 Cum of Silt and Hyacinth was removed from North Buckginham Canal, Kodungaiyur Canal and Captain Cotton Canal following the floods.

- GCC has procured three Multipurpose Robotic Excavators for Rs. 19.65 crores for the de-siltation of micro-drains from Liechtenstein.
- The carrying capacity of all these major water-carrying channels has been increased by the deployment of such modern machinery.

(GCC, 2017)

7.4 PREPAREDNESS MEASURES

Table 7.1: Preparedness Measures by GCC

Measures before Monsoon	Actions to be taken during rain
Chute Pipe Cleaning.	Examine manhole covers to be in good condition.
Inlet chamber cleaning of sands / debris near the chute pipe.	Continuous cleaning of garbage in chute pipe/inlet chamber/ vertical gratings.
The missing link of the storm water drains to be constructed and covered with a pre-cast slab.	Ensure the flow of water from the road to SWD, monitor periodically by inspection.
Ensuring the network	Pump & Motor can be used to maintain
Every year SWDs to be cleaned	Blockage in SWDs to be cleared by motor/sucker lorry if necessary
Tools and materials like crowbars, manhole lifting hooks, ropes, FRC door cover slabs, etc. be kept ready for use.	Keep open the manhole cover of SWDs to drain water with a safety precaution sign around the manhole cover.
Repair in SWD structure to be attended.	Make a temporary kutcha drain to drainout water from a higher level to a lower level in case of an emergency.
Street joints of SWD to been sured.	If needed enlarge the chute pipe.
Garbage removal around bins to be done.	Providing barricades, signboards for diverting traffic.
Manhole cover to be in good condition, damage done to be replaced.	The flow of water inside the SWDs is periodically monitored to ensure that the water is running in full capacity inside the SWD.
Removal of debrisIsilt inside the SWDs	The SWDs are frequently checked for removal of any blocks at the draining point with rivers and canals.
	Diesel/Submersible pumps are provided in the needed location to drainout water in SWDs.
	Roadcut may be done to drain more water with safety signboards.

Source: (GCC, 2017)

7.5 MEASURES TO BE TAKEN IN INUNDATION-PRONE AREAS

The inundation-prone locations in the city have been identified in all zones (Zone 1 to 15) according to the severity of inundation. The following measures are taken by the GCC:

- RWH structures to be cleaned and refilled.
- Chute pipe should be cleaned
- De-silting of disposal points and storm water drains/canals.
- Keeping JCB, Bulldozers, cranes, pumps and Super-sucker Lorries ready.
- Providing inlet chambers and pipe connections to the nearest existing drain.
- De-silting storm water drains.
- Breaking the top slabs and desilt the SWD where the chronic obstruction is noted and cover with a precast slab.
- The missing link of storm water drains to be constructed and covered with precast slabs.
- Available machinery/pumps to be checked and kept in ready condition. A logbook to be maintained by Assistant Executive Engineer (AEE) regarding the same.

(GCC, 2017)

7.6 PREPAREDNESS OF RELIEF CENTRES

The GCC has identified and notified around 197 relief centres across the city keeping in mind the vulnerability of areas prone to inundation and the need fore viction. The community halls, schools and public buildings are identified to act as relief centres. The details of these relief centres including locations, contact persons are given in their respective municipal zonal offices. The relief centres are to be provided with safe drinking water, toilet facilities, lighting arrangements, food packets, bread, milk, etc.

(GCC, 2017)

7.7 PREPAREDNESS STRATEGIES FOR SUBWAYS

There are 22 subways in Chennai city of which GCC maintains 16 subways and 6 subways are maintained by the Highways Department. The details of the locations of subways are provided in the respective municipal zonal offices. These subways are equipped with pump sets to bailout water from the subways. Depending upon the necessity, pumpsets from Agriculture Engineering Department, Fire Service Department and Private Sources would be deployed.

7.8 PREPAREDNESS MEASURE FOR TREEFALL

The preparedness for treefalls include spruning of trees in anticipation of the up rooting of trees during cyclone, storms and rainfall. Vehicle-mounted saws and power saws are kept ready in zones 1 to 15 to cut and remove the trees fallen on the roads.

WAY FORWARD

Chennai, being a city that has witnessed several major flooding events in the last 40 years, needs to implement preventive and mitigation measures in tune with the experiences gained and the lessons learnt. The unrelenting development pattern has compromised the city's natural drainage pattern, without conforming to development regulations. The development of IT corridors and business district by filling up the water reservoirs and tanks, ignoring the basics of sustainable development, is another instance of poor implementation of the national and state policies. The Disaster Management Act 2005 and the Tamil Nadu Disaster Management Policy focus on the culture of prevention and mitigation. There is a need for the integration of disaster risk reduction measures with development regulations and spatial planning. With the shortage of land and increasing population, the solution is to use the land in such a manner that mitigation measures are integrated into construction practices with proper planning and design. The following are some of the action strategies that should be adopted for flood-resilient urban development:

- **Mainstreaming DRR in developmental activities:** The best approach to mainstream risk mitigation measures in development and planning is to include them in Development Control Regulations and building by-laws, as these norms regulate the development in the cities. The DCR and building rules are still not integrated with DRR activities. This should be of immediate concern to the Urban Development Authority and the State TNCP Department.
- **Strengthening of existing land regulations w.r.t. DRR:** The conversion rules in the state need to be stricter to avoid the conversion of marshy lands and water bodies into developmental lands. The exiting conversion rules are extremely lenient and can be misused by real-estate developers and contractors.
- **Monitoring and Enforcement of Norms and Regulations:** Proper evaluation and scrutiny should be done before sanctioning any development or building permits. Regular monitoring should be carried out to supervise the concerns like encroachment of marshy lands, water bodies, development in eco-sensitive areas, etc.
- **Flood Mitigation and Preparedness:** The preparedness projects and measures implemented by GCC under the supervision of TNSDMA to tackle the flooding issues during monsoons are commendable efforts. In addition to such measures, the large-scale flood hazard maps and hydrology maps of the City of Chennai should be revised after a certain duration and thereafter the

future flood risk scenarios should be projected with sensitivity to Climate Change and highlighting the problem areas faced during the previous floods.

- **Climate Change Considerations for Design and Maintenance of Urban Drainage Infrastructure:** Urban drainage infrastructures should be designed keeping into account the predicted aspects of climate change (Arnbjerg-Nielsen, et al., 2013)(Mailhot & Duchesne, 2010). Design and maintenance guidelines should be revised and redrafted taking into the impacts of climate change (Djordjevic´, Butler, Gourbesville, Mark, & Pasche, 2011).
- **Water Sensitive Urban Design (WSUD) Measures:** WSUD measures have become popular in the recent decade. Some of the popular WSUD measures are reducing or limiting inflow (Djordjevic´, Butler, Gourbesville, Mark, & Pasche, 2011), increasing surface storage or storage at sources (Mailhot & Duchesne, 2010), better design and deployment of surface flow features (Djordjevic´, Butler, Gourbesville, Mark, & Pasche, 2011) and disconnecting the extremely impervious area from the water flow pathways (Mailhot & Duchesne, 2010).
- **Flood Resilience Measures for buildings:** Sustainable measures incorporated to reduce the impacts of flooding into the building fabric, fixtures and fittings can be considered as resilience measures (Djordjevic´, Butler, Gourbesville, Mark, & Pasche, 2011). Careful detailing of the property and its surroundings such as flooring height, entrance details, steps, driveway slopes, etc. can be used to achieve flood resilience (Djordjevic´, Butler, Gourbesville, Mark, & Pasche, 2011).
- **Real-Time Urban Flood Information Systems:** The real-time warning system might benefit municipal bodies and other agencies for processing rainfall data and finally passing it to the public (Djordjevic´, Butler, Gourbesville, Mark, & Pasche, 2011).
- **Creating awareness among communities and different stakeholders:** The residents of the city are equally responsible for such a catastrophic event. The communities should be aware of the environmental risks and challenges and should not compromise with the regulations for self-interests.The real-estate builders and developers must also put a conscious effort to implement mitigation and prevention measures in the construction of their projects.

The current scenario of increasing urban floods in the country calls for the on-ground implementation of a prevention-based approach of disaster management instead of a relief-based approach. The above measures should be adopted in every urban area for building and strengthening flood resilience in the country. While risk-sensitive development is imperative, the role of individual citizens in apparently unrelated efforts like rainwater harvesting, waste segregation, recycling of waste etc. would also contribute significantly towards mitigation measures for urban floods.

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ANNEXURE I:

ADMINISTRATIVE STRUCTURE OF GCC

Source: (GCC, 2017)

ANNEXURE II:

LIST OF INUNDATION-PRONE AREAS IN CHENNAI

CHRONIC INUNDATION LOCATIONS DURING 2015 FLOODS					
Zone	Very High Vulnerability (Above 5 Feet)	High Vulnerability (3-5 Feet)	Medium Vulnerability (2-3 Feet)	Low Vulnerability (less than 2 feet)	Total
I	1	7	0	6	14
II	0	0	0	3	3
III	2	6	1	1	10
IV	0	7	0	7	14
V	0	1	0	12	13
VI	0	0	0	36	36
VII	0	0	0	6	6
VIII	1	1	0	7	9
IX	5	20	0	40	65
X	0	9	0	0	9
XI	4	13	0	9	26
XII	0	0	0	8	8
XIII	24	17	0	26	67
XIV	0	0	0	16	16
XV	0	3	0	7	10

Source: (GCC, 2017)

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