European Journal of Climate Change - Vol. 03 Issue 01 Pp. 33-43 (2021)

European Academy of Applied and Social Sciences – www.euraass.com

European Journal of Climate Change

https://www.euraass.com/ejcc/ejcc.html

Research Article

Challenges in Chennai City to Cope with Changing Climate

Anushiya Jeganathan[a*], Ramachandran Andimuthu[a], Palanivelu Kandasamy[a]

[a] *Centre for Climate Change and Disaster Management, CEG Campus, Anna University, Sardar Patel Road, Chennai-600 025, Tamil Nadu, India.*

Received: 08 November 2020 / Revised: 15 December 2020 / Accepted: 27 December 2020

Abstract

Cities are dynamic systems resulting from the complex interaction of various socio-ecological and environmental developments. Climate change disproportionately affects cities mostly located in climate-sensitive areas; thus, these urban systems are the most critical in modern societies under changing climate scenarios, uncertain disruptions, and urban inhabitants' daily lives. It is essential to analyze the challenges in the metropolitan area through the lens of climate change. The present work analyses the challenges in Chennai, a coastal city in India and one of the chief industrial growth canters in Indian and South Asian region. The challenges are analyzed through the city's system analysis via land use, green cover, population, and coastal hazards. Land use and green cover changes are studied through satellite images using ArcGIS and assessing coastal risks due to sea-level rise through GIS-based inundation model. There are drastic changes in land-use patterns; the green cover had reduced much, including agricultural and forest cover due to rapid urbanization. The land use has changed to 59.6% of the reduction in agriculture land, nearly 40% reduction in forest land, and 47% of the wetland over time. The observed mean sea level trend for Chennai is + 0.55 mm/year from 1916 to 2015 and the area of 21.75 sq. km is under the threat of inundation to 0.5m sea-level rise. The population growth, drastic changes in land use pattern, green cover reduction, and inundation due to sea-level rise increase the city's risks to climate change. There is a need to ensure that future land-use developments do not worsen the current climate risk level, either through influencing the hazards themselves or affecting the urban system's future vulnerability and adaptive capacity. The study also urges the zone level adaptation strategies to ensure the resilience of the city.

Keywords: Urban system analysis, land use, green cover, sea-level rise, inundation.

1. Introduction

Climate Change is one of the defining challenges of our age, and one of the United Nation System's priorities. IPCC's continuous Assessment Reports lists the different aspects of climate change, the evidence for current impact, projected future impacts, and the most affected zones or groups and cited that coastal areas, settlements and activities; regions and populations with limited resources and capacities (urban) are more prone to climate change (IPCC, 2007; 2014). Urban regions, which cover only approximately 0.2% of

*Corresponding author: Email: anushiya.cc@gmail.com, (Anushiya Jeganathan).
Available online: 10 January 2021
DOI: https://doi.org/10.34154/2021-EJCC-0017/euraass
Journal reference*: Eur. J. Clim. Ch.* 2021, 03(01), 33 – 43.
ISSN-E: 2677-6472.

Cite as: *Jeganathan, A., Andimuthu, R. and Kandasamy, P. (2021). Challenges in Chennai city to cope with changing climate. Eur. J. Clim. Ch. 03(01), 33 – 43.*

the earth's land surface, contain about half of the human population (UNPD, 2001). Rapidly expanding urban settlements in the developing world face severe climatic risks in light of climate change. Cities consume a great majority 60-80% of energy production and account the equivalent share of global CO_2 emissions. The cities are more vulnerable to climate change because of their sensitivity and adaptive capacity. Climate change is of particular significance for cities because it accentuates the unusual behaviour, producing a more hazardous and less comfortable environment for citizens.

Urban areas always present some risk of flooding when rainfall occurs. Buildings, roads, infrastructure and other paved areas prevent precipitation from infiltrating into the soil and produce more runoff containing groundwater recharge. Heavy and prolonged rainfall has vast volumes of surface water in any city, easily overwhelm drainage systems. The most recent IPCC Working Group 2 report indicates that the most vulnerable urban encroachment are generally in coastal and river flood plains, due to rapid urbanization closely linked with climate-sensitive issues, and those in areas prone to extreme weather events. Cities in developing countries are at particular risk from climate hazards for several reasons: high-density populations; large sections of the urban population live in informal housing which is not regulated by land use controls and building standards; concentrations of solid and liquid wastes; considerable increase in impermeable surfaces and concentrations of buildings which disrupt natural drainage channels; urban expansion on hazardous sites (Bull-Kamanga et al. 2003).

Most cities in Africa, Asia and Latin America and the Caribbean experience more heatwaves. Even small increases in average temperature can result in large shifts in extremes frequency (Kovats and Aktar, 2008). For larger, higher-density cities, the temperatures in central "heat islands" can be several degrees higher than in surrounding areas; in tropical cities, the temperature difference can reach 10 degrees by the end of the night. Many cities will face more problems with certain air pollutants as concentrations of air pollutants change in response to climate change because a portion of their formation depends, in part, on temperature and humidity. Urban populations will increasingly force to cope with increased flooding, air and water pollution, heat stress and vector-borne diseases (Parry et al., 2007). There are 3,351 cities in the low elevation coastal zones around the world. Of these cities, 64 per cent are in developing regions; Asia alone accounts for more than half of the most vulnerable coastal cities (U.N. Habitat, 2008).

Asia's densely populated megacities and other low-lying coastal urban areas are known as 'key societal hotspots of coastal vulnerability' with millions of people at risk (IPCC, 2007). The significant direct impacts of sea-level rise included inundation of low-lying areas, shoreline erosion, coastal wetland loss, saltwater intrusion, higher water tables and higher extreme water levels leading to coastal flooding (Leatherman and Nicholls, 1995). Worldwide coastal natural systems were highly susceptible to sea-level rise, and the loss of the coastal wetlands and beaches would likely produce significant ecological impacts (Titus, 1988; Nicholls, 2003). Human-induced pressures such as growing population, water abstraction, and the hydrological regime's alteration would exacerbate the effects of sea-level rise (Nicholls, 2007). Cities in coastal areas, especially in deltaic locations, tend to have a higher risk due to sea-level rise due to their tendency to be at lower elevations and experience significant subsidence.

Typically, the urban system shows the general characteristics of complex systems of environmental functions. It deals with the forces that arise within a network to cause changes through time (Forrester, 1970). This complex interaction creates rapid changes in metropolitan structure, patterns and forms (Besussi et al., 2010). Thus urban structure changes and behaviour including land-use changes, urban green cover, demographic changes, inundation due to sea level rise are necessary for urban system analysis to study the cities coping ability towards climate change. This urban system analysis outlines the extent to which climate will pressure the urban systems function and, hence, explore climate change challenges. This study analyses the challenges in Chennai city to cope with climate change through urban system analysis.

2. Study area

Chennai Metropolis is the 30th largest urban area in the world (Demographia, 2020). It is a flat coastal city located off the Bay of Bengal, lies between latitude 12°50'49" and 13°17'24"N, and longitude between 79°59'53" and 80°20'12" E (Fig. 1). It has a long coastal line, the coastal length being around 45 km from north to south. The city's terrain is more or less a flat plain with scattered hillocks, gentle sloping towards the Bay of Bengal in the east. Its average elevation is around 6.7 meters, and the highest point is 60 m. Chennai is a densely populated city in India and has a population density of 26,553 persons per square kilometers. The urban agglomeration of the metropolis goes nearly 8.7 million (Census, 2011). The city expands up to 1189 sq.km and there is almost 17- fold increases in spatial expansion. The population has overgrown in the last 20 years due to its significant industrialization and tremendous growth. Chennai's population may increase to reach 100.70 lakhs in 2025 (Sekar and Kanchanamala, 2011). Three major rivers, namely

Coovam, Adayar, and Kosathalayar pass through the city confluence with the Bay of Bengal. The city has a tropical climate, specifically a tropical wet and dry climate. The weather is hot and humid for most of the year. The metropolis gets most of its seasonal rainfall from the post monsoon/north east monsoon winds from October to December. Cyclones in the Bay of Bengal occasionally hit the city, and in recent years it has increased its frequency. Storm tide occurs invariably during northeast monsoon rain. Sometimes high tide with storm reaches 4m above mean sea level (MSL).

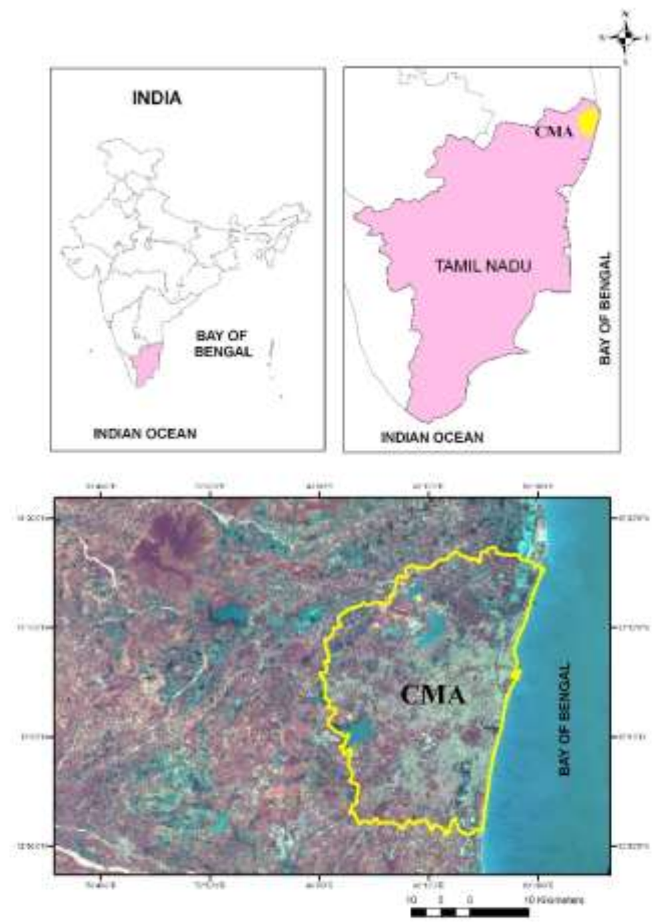

Figure 1: Study Area – Chennai Metropolitan Area.

2.1 Changes in Chennai's Climate

The city is witnessing a clear increasing trend of temperature during the past 60 years, and it has increased 1.2 °C during 1951-2010 (Jeganathan and Andimuthu, 2013). The long-term analysis (1813-2009) of rainfall trends show an increase of annual and monsoon rainfall and an insignificant increase of winter and post-monsoon rain (Ramachandran and Anushiya, 2015). Records have shown that there was several catastrophic flooding in Chennai. While in recent decades, flooding incidences reported very often. Incidences of the flood and its frequencies have been experiencing during 2006, 2007, 2008, 2010 and 2015. The heavy rainfall during November December 2015 resulted in catastrophic flood paralyzed the city, claimed more than 400 lives and caused enormous economic damages. On 2^{nd} December of 2015, rain occurred above 40 cm in 24 h. The regional climate change projection for the Tamil Nadu state of India, simulated by the Met Office Hadley Centre regional climate model PRECIS, shows an increase in maximum temperature would be 1.0, 2.2 and 3.1 °C for the periods the 2020s (2005–2035), 2050s (2035–2065) and 2080s (2065–2095), respectively, concerning baseline period (1970–2000). Similarly, the minimum temperature projections show an increase of 1.1, 2.4 and 3.5 °C, respectively. Simultaneously, the annual rainfall projections for the same periods indicate a general decrease in about 2–7%, 1–4% and 4–9%, respectively. However, significant exceptions have noticed over some pockets of western hilly areas and high rainfall areas where increases in rainfall are seen (Bal et al., 2016). While the climate simulations over the Chennai Metropolitan Area under IPCC SRES A1B scenario shows predicted rise of temperature 2.4°C to 2.5°C by midcentury (2041-2070) and 3.3 °C to 3.6 °C increase towards the end of the century (2071-2098). There would be a general decreasing trend of rainfall observed both in mid and end centuries (Anushiya & Ramachandran, 2015). Projection of climate change-induced sea-level rise using the SimCLIM model based on IPCC AR5-RCP 4.5 indicated that 07.37 cm in 2025 and 49.84 cm in 2100 for Chennai city (Ramachandran et al., 2017).

3. Methodology

3.1 Analysis of Land Use Changes

For the current study, the cloud-free satellite images of Chennai were acquired for periods 1991 and 2010. Landsat TM images were downloaded from the Global Land Cover Facility (GLCF) an earth science data interface (http://www.landcover.org/data/landsat/). IRS-1C LISS-III image for the year 2010 obtained from National Remote Sensing Centre (NRSC), Department of Space, Govt. of India, Hyderabad. The availability of cloud-free data in the chosen period impulses to select these images for land-use study. For spatial integration, 1:50,000 scale toposheets (Toposheet no. 66D1&5, 66C3, 66C4, 66C7, 66C8) were collected from Survey of India (SoI), Guindy. Then, the map for administrative boundaries of the study area prepared from the SoI toposheets. The satellite images were then imported into ERDAS IMAGINE 9.3 software, to have multi-band composite images of all layer stackings. Then, the geometric correction was performed on all the satellite images using the topographic maps of Chennai in 1:50000 scale. Georeferenced the all the satellite images by representing 17 ground control points in cartographic projection (UTM Zone 44N, WGS84) with the Root Mean Square Error 0.05. Merging carried out through a spatial enhancement module in ERDAS IMAGINE. To have the land-use based multi-temporal images for detecting urban land-use change, we delineated the administrative boundaries of Chennai city in the images and carried out the visual interpretation in this work, which consuming long period of ground truth verification.

The images were digitized manually using ARCGIS 9.3 software to analyze and compute the areas under each land-use class adopted in the land use scheme. In preparing the land use map, the most crucial step was choosing the land use classification scheme. Considering the standard categories defined by Anderson et al. (1976)'s level I classification as well as the local factors like topography, land use etc., along with appropriate ground knowledge seven separate land use classes were defined namely: agriculture land, barren land, forest cover, settlements, water bodies, wetland and others. The definition of agriculture land included all croplands and fallow lands. Principal crops cultivated in the study area are paddy, pulses, millets and oilseeds and paddy is the major crop. The definition of barren land used in this work indicates land without scrub, sandy areas, dry grasses, rocky areas and other human-induced barren lands. The settlements represented all built up structures include both residential and commercial areas. Water bodies denoted rivers, lakes, and reservoirs; wetland denoted marshlands where hydrophytic vegetation usually established. Others category includes an airport, air force, harbour and the lands utilized for other government activities.

3.2 Changes in NDVI

Urban green cover is the intrinsic component of the urban system. The vegetation index of Chennai was estimated to observe the green cover in the study area using the Normalized Difference Vegetation Index (NDVI). The NDVI is a commonly used vegetation index based on the reflectance properties of leaves in the red and near-IR wavelengths. It provides a measure of vegetation's amount and density on the land surface (Johnston, 2012). Well explained works of literature are available on the derivation of the NDVI with a standard procedure (Tucker et al., 1985; Thenkabail et al., 2004). This study adopted this standard mathematical form as below,

$$NDVI = R_{NIR}-R_{RED} / R_{NIR}+R_{RED}$$

where,

R_{NIR} = reflectance in near-infrared band (0.6-0.7 μm)

R_{RED} = reflectance in red band (0.75-1.5 μm)

NDVI transformation was calculated as a ratio between measured intensities in the red and near-infrared (NIR) portions of the electromagnetic spectrum and output values range from -1.0 to 1.0. Healthy vegetation reflects very well in the near-infrared part of the electromagnetic spectrum. Green leaves have a reflectance of 20% or less in the 0.5-to-0.7-micron range (green to red) and about 60% in the 0.7-to-1.3-micron range (near-infrared). These spectral reflectances are themselves ratios of the reflected over the incoming radiation in each spectral band individually; hence, they take on values between 0.0 and 1.0. Thus, the NDVI itself varies between -1.0

and +1.0. Negative values of NDVI correspond to deep water, and the values close to zero (-0.1 to 0.1) generally indicates the non-vegetated features such as barren surfaces areas of rock and sand. Low, positive values represent shrub and grassland (approximately 0.2 to 0.4), while high values indicate temperate and tropical rainforests (values approaching 1). Increasing positive NDVI values, shown in increasing green shades on the images, indicates increasing amounts of green vegetation. Values of NDVI for vegetated land generally range from about 0.1 to 0.6, with values greater than 0.5 indicating dense vegetation.

The urban green cover change has calculated with NDVI values of satellite images taken in 1991 and 2010. The georectified satellite images were processed through ERDAS IMAGINE 9.3 version and calculated NDVI based on the data's spectral properties under Indices mode. The obtained values were mapped and visualized through GIS with appropriate ground truth verifications.

3.3. Sea level rise and Coastal inundation

Sea level rise data from 1916 to 2015 were downloaded from Tides and Currents products of Center for Operational Oceanographic Products and Services (CO-OPS) of National Oceanic and Atmospheric Administration (NOAA) (https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=500-091). The sea-level rise and inundation were studied using GIS-based inundation model. Inundation modelling is a simple process in which the water level along the shoreline on the coastal DEM is raised by selecting a land elevation above the current water level elevation and then delineating all areas at or below that elevation, thus placing them in inundation zone (Gesch, 2012). Many studies use GIS-based inundation model to delineate potentially inundated areas resulting from projected SLR (Cooper et al., 2001; Dasgupta et al., 2007). It offers real case scenarios of land use and potentially vulnerable areas based on ground elevation (Boateng, 2012). In this study, potential land area losses to SLR arrived at by integrating digital elevation data with projected SLR of 0.5m. SRTM 90 m data downloaded from http://srtm.csi.cgiar.org/ data had used as the base data. Using ERDAS IMAGINE, the digital elevation model (DEM) generated from the source data and contours was developed at the interval of 0.5m. The inundated areas were identified from DEM using Raster Calculator in ArcGIS 9.3. The resulted image was then superimposed with the land use map to place the inundated zones and land use patterns for the projected sea-level rise of 0.5m and analyzed.

4. Results and Discussion

4.1. Changes in land use patterns

Analysis of land use for the year 1991 revealed that the Chennai Metropolitan Area (CMA) had an equal spacing of major land use categories. The settlement, agriculture, and barren land shared approximately equal areas during 1991. Bare land with developmental activities occupied 27.9% (332 sq. km). The settlement occupied an area of 330 sq. km of built up with 27.7% and the area under agriculture was 26% (311 sq. km) of the total area. Around 7% of water bodies seen in the study area included three major rivers, the city's major three reservoirs that meet out city's water need and tiny ponds. Noticeable forest areas exist in the city such as Guindy National Park, Nanmangalam, and Sembakkam reserve forest, Vandalur and Avadi reserve forest. In 1991, the area under forest cover was 4.1% of the total area. It is a gift for CMA with natural wetlands, a considerable number of wetland bodies is present in the study area and one among is a 2700-year-old wetland, namely Pallikaranai wetland (Krishnan 2013). These wetlands are valuable ecosystems and play a significant role in the city's groundwater recharge, flood control, and biodiversity. In 1991, around 28 sq. km area of the wetland was seen and occupied 2.4% of the total area of CMA.

The classification under ‘others’ category occupied 4.7% of the total area, including institutional lands, airport, port, and military control lands. Analysis of land use for the year 2010 disclosed that a drastic reduction in agriculture land due to urban proliferation occupied only 10.6% of the metropolis' total area. The area under the barren land also reduced slightly compared with 2002 land use and occupied 25.1% of the area. The area under newly occupied settlements has tremendously increased, and it occupied nearly 47.7% of the total area. It is interesting to note that the urban expansion has taken place in the west, southwest and southern parts of the city. The growth might be due to the Government's developmental activities and the boom of I.T corridors in this part. In 2010, the forest area was reduced and covered only 2.5% of the total metropolitan area. While wetlands in the city lost almost half of its size and occupied only 1.2% of the metropolis' total area.

The land-use changes during 1991-2010 revealed 59% of the reduction in agriculture land during 2010 compared with 1991 land use. In the last three decades, the agricultural activity within this metropolis had become abysmally minimal for various reasons, including non-availability of water for irrigation purposes, labour cost, and cost of agricultural input (SoER, 2013). The overall settlement area had increased by 71% during the whole study period, and the maximum transformation has noticed in the agricultural lands and barren lands. Approximately 47% of the wetland has lost over time of study period, mainly due to human interventions resulting in heavy loss of wetland ecosystems and biodiversity. Nearly 40% decrease of forest land and a 5% reduction in water bodies were observed by 2010 for the whole study period. Simultaneously, the land use under the 'others' category had a 33 % increase (Figure 2). The systematic assessment of land use analysis exposed that the study area had undergone tremendous growth and dimension in urban land use, which will affect storm water drains. The fast degradation of wetlands natural flood carriers was also a perturbing issue in CMA. The profound changes in urban land use may impact energy use, infrastructure, water, and environmental degradation and have to be studied integrated. A significant concern should be there to preserve the remaining limited agricultural lands and wetlands.

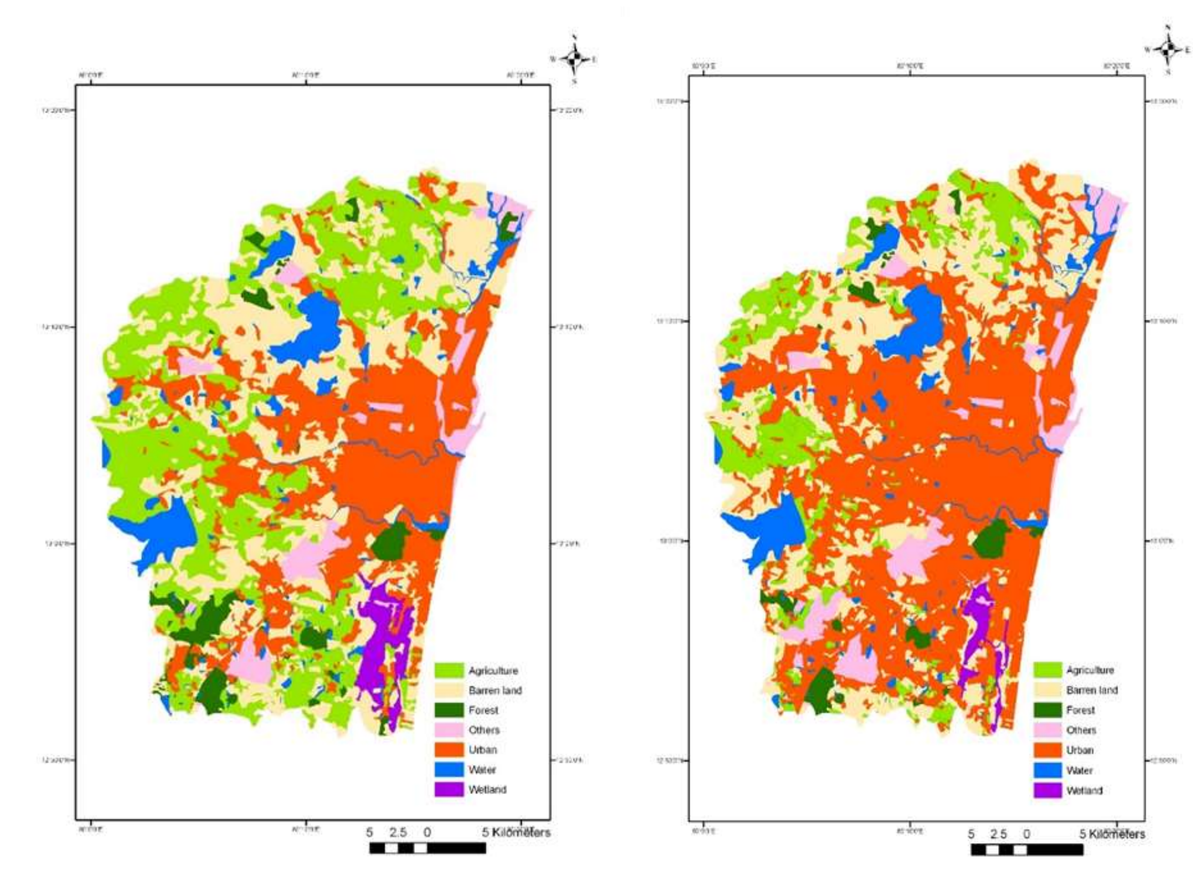

Figure 2: Land use map of CMA in 1990 and 2010.

4.2 Changes in green cover

The NDVI measures vegetation's amount and vigour on the land surface. NDVI transformation is calculated as a ratio between measured intensities in the red and near-infrared (NIR) portions of the electromagnetic spectrum and output values range from -1.0 to 1.0. Increasing positive NDVI values, shown in increasing green shades on the images, indicates increasing amounts of green vegetation. NDVI values near zero and decreasing negative values indicate non-vegetated features such as barren surfaces (rock and soil) and water, snow, ice, and clouds. Values of NDVI for vegetated land generally range from about 0.1 to 0.7, with values greater than 0.5 indicating dense vegetation. Figure 3 shows the NDVI in 1991 and 2010. The urban green cover has undergone drastic changes from 1991 to 2010. The reduction in green cover affects microclimate and thermal discomfort.

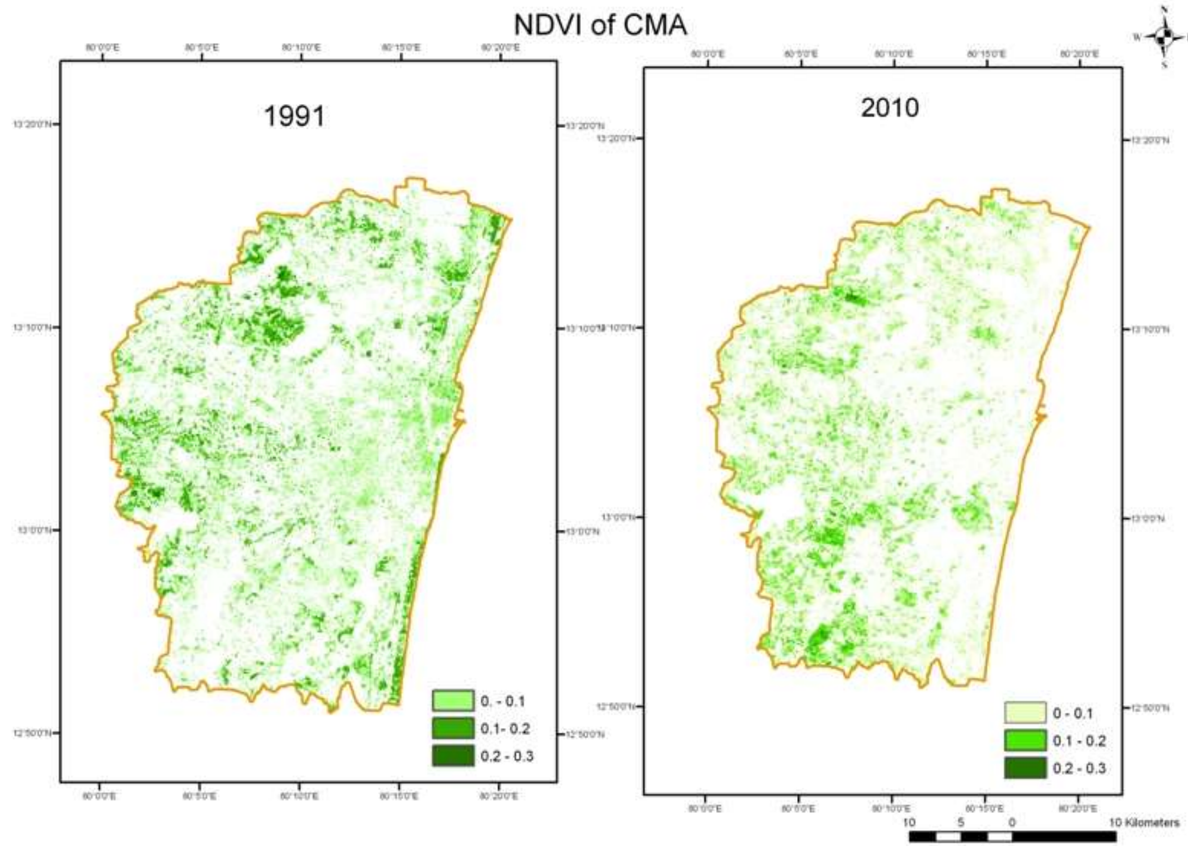

Figure 3: NDVI map of CMA in 1991 and 2010.

4.3 Seal level rise and coastal inundation

4.3.1 Observed mean sea level trend

The mean sea level trend of the Chennai tide gauge station during 1916 to 2015 has downloaded from Tides and Currents products of Center for Operational Oceanographic Products and Services (CO-OPS) of National Oceanic Atmospheric Administration (NOAA) is shown from figure 4. The observed mean sea level trend for Chennai is +0.55 millimetres/year with a 95% confidence interval of +/- 0.34 mm/year based on PSMSL (Permanent Service for Mean Sea Level) monthly mean sea level data from 1916 to 2015 which is equivalent to a change of 0.18 feet in 100 years.

4.3.2 Inundation area in Chennai due to 0.5m sea-level rise

The quantitative estimation of the inundation areas of land use is tabulated in Table 1. The extent of 21.75 sq. km (nearly 1.83% of the total metropolis area) is under the threat of inundation to future 0.55m SLR. The sea-level rise would affect 38% of wetlands area in the said 21.75 Sq.km of total area affected due to inundation and flooding.

Chennai has gifted with natural wetlands adjoining to coastal region acts as a catchment of Chennai Basin. These wetlands are unique, helping improve groundwater potential in CMA and considerably prevent intrusion of salinity. The central wetland namely Pallikaranai wetland plays a vital role in the urban ecosystem with the rich biodiversity of both flora and fauna. It has identified now as more vulnerable to projected SLR of 0.5m—the area of 6.78sq. Km water bodies and nearly 1.6 sq. km of migrating settlement areas adjoining to coastal regions are also under threat of the sea-level rise of 0.5m (Fig. 5).

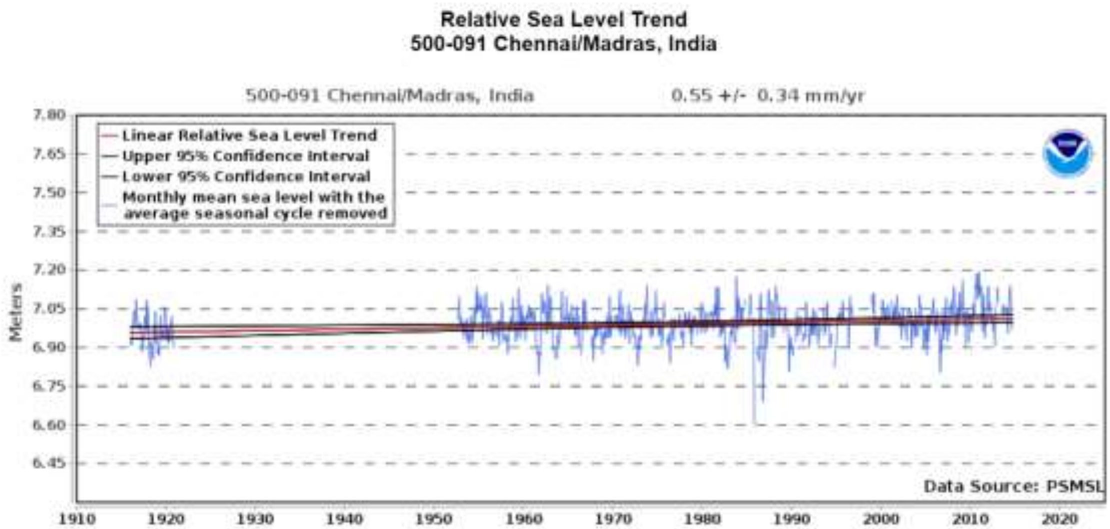

Figure 4: Mean Sea level trends in Chennai during 1916-2015.

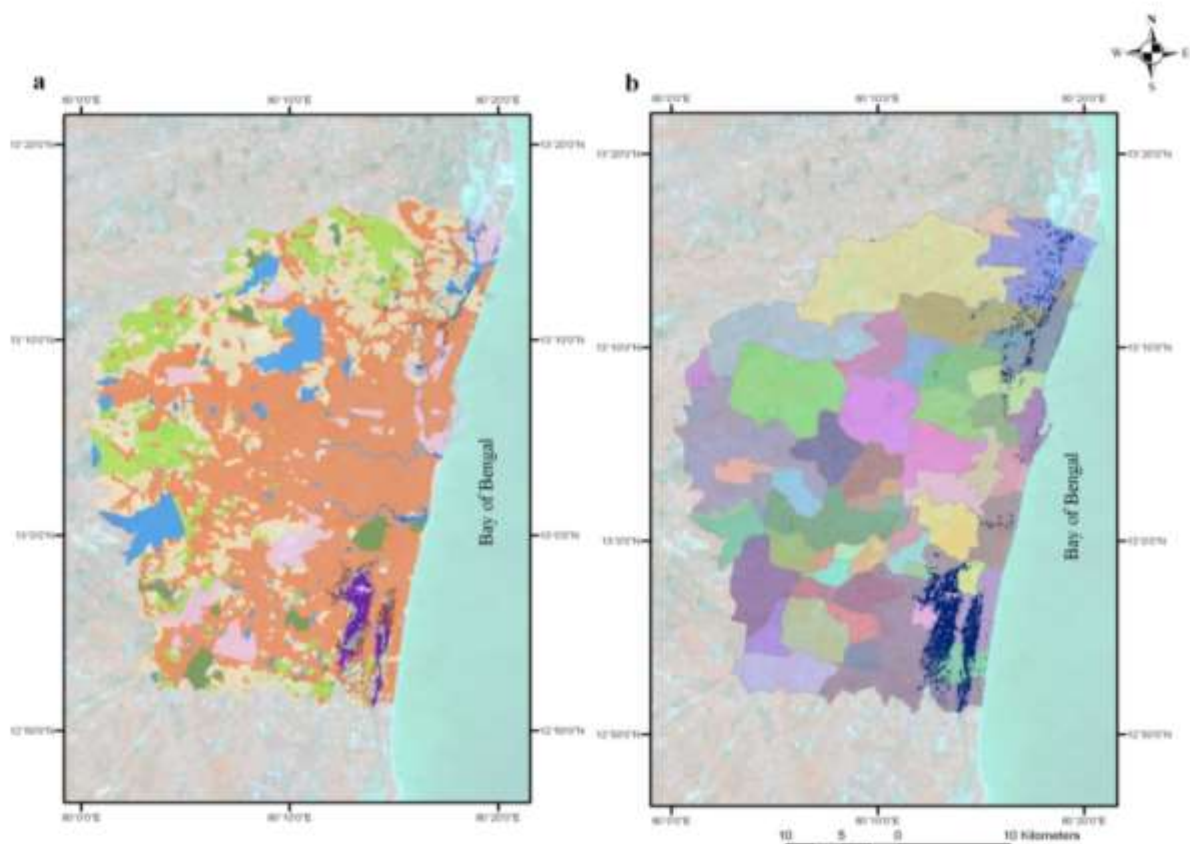

Figure 5: Superimposed spatial inundation map a. Area of land use under threat b. zone wise inundation.

Table 1: Inundation areas of land use for 0.5m sea level rise.

Land Use	Inundation Area in sq. km
Wetland	8.20
Water bodies	6.78
Others	3.30
Barren land	1.82
Settlement	1.60
Forest	0.05
Total area	21.75

Sea level rise would increase coastal populations and ecosystems' susceptibility through the permanent inundation of low-lying regions, amplification of episodic flooding events, and increased beach erosion and saline intrusion (McLean et al., 2001).

5. Conclusion

Urban system analysis reveals the pressure in behavioural aspects of the Chennai city; one of the fastest-growing economic centers in India and the South Asian region. The systematic assessment of land-use change analysis exposed that the study area has undergone tremendous changes in dimension urban land-use dimensions. The fast degradation of wetlands, green cover including agricultural and forest cover due to rapid urbanization, is a city's perturbing issue. As a coastal city, inundation due to sea-level rise is also a hazard to the city. Changing climates such as the increase in temperature, erratic rainfall, sea-level rise, and other climate extremities will affect the key sectors such as water, infrastructure, health, biodiversity, energy, and transport. A micro-level impact analysis is needed and to be addressed urgently. Drastic reduction in green cover, changes in land-use patterns, population growth, and changing climate are cumulative effects to develop the city's infrastructure, including climate-friendly policies to adopt and ensure the city's resilience. There will be challenges in every step towards making city resilience.

The challenges include technology, finance, system's behaviour, social aspects, and policymaking in every part of its development. There is a need to ensure that future land-use results do not worsen the current risk level, either through influencing the hazards themselves or affecting the urban system's future vulnerability and adaptive capacity. Green cover should be increase to mitigate the adverse effects of climate change. Increased research and analysis of projected local climate impacts and conditions of exposure will be needed urgently. To address the consequences of climate change in city, strong support and commitment to local government programs and community-based initiatives should be initiated. By combining local knowledge and global clearance to tackle climate change issues, cities can lead the successful adaptation and sustain those gains through proactive ‘climate-proof’ development policy and planning.

Acknowledgement

The authors acknowledge DST's financial support–SPLICE, Government of India (DST/SPLICE/CCP/ NMSKCC/ PR-63/Tamil Nadu /2016(G) dated 09.11.2016) and the Director, Department of Environment, Government of Tamil Nadu.

References

Anderson, J.R., Hardy E.E., and Roach JT, Witmer RE (1976). A land use and land cover classification system for use with remote sensor data. Geological Survey Professional Paper 964, United States Government Printing Office,

Anushiya, J. and Ramachandran, A. (2015). Assessment of Water Availability in Chennai Basin under Present and Future Climate Scenarios, Chapter 18 In. Environmental management of River Basin ecosystems, Ramkumar, M., Kumaraswamy, K. and Mohanraj, R. (Eds.). Springer Earth System Sciences Publications, pp. 397- 415, ISBN: 978-3-319-13424-6,

Bal, P.K., Ramachandran, A., Geetha, R., Bhaskaran, B., Thirumurugan, P., Indumathi, J. and Jayanthi, N. (2016). Climate change projections for Tamil Nadu, India: deriving high-resolution climate data by a downscaling approach using PRECIS. Theoretical and

Applied Climatology, 123: 523–535.
Besussi, E., Chin, N., Batty, M. and Longley, P. (2010). The Structure and Form of Urban Settlements', Book chapter in Remote Sensing of Urban and Suburban Areas, Rashed, T & Jürgens, C (eds.) DOI 10.1007/978-1-4020-4385-7_2, Springer Science+Business Media B.V., The Netherlands, pp. 13-31.
Boateng, I. (2012). GIS assessment of coastal vulnerability to climate change and coastal adaptation planning in Vietnam., J. Coastal Res., 16(1): 25-36.
Bull-Kamanga, L., Diagne, K., Lavell, A., Lerise, F., MacGregor, H., Maskrey, A., Meshack, M., Pelling, M., Reid, H., Satterthwaite, D., Songsore, J., Westgate, K. and Yitambe, A. (2003). Urban Development and the Accumulation of Disaster Risk and Other Life-threatening Risks in Africa, Environment and Urbanization 15(1): 193–204
Census (2011). Table 3- UA having 1 million and above population. In Provisional Population Total 2, Directorate of Census operations-Tamil Nadu, http://www.census.tn.nic.in/index.php?ppt2.php.
Cooper, M.J.P., Beavers, M.D. and Oppenheimer, M. (2005). Future sea level rise and New Jerky coast, Science Technology and Policy Program, Woodrow Wilson School of Public and International Affairs, Princeton University, http://www.princeton.edu/~step/people/Oppenheimer%20Future%20of%20Sea%20Level %20Rise.pdf.
Dasgupta, S., Laplante, B., Meisner, C., Wheeler, D. and Yan, J. (2007). The impact of sea level rise on developing countries: a comparative analysis, World Bank Policy Research Working Paper 4136: 51.
Demographia (2020). World urban areas: 16th annual edition. Demographia, pp. 1-94.
Forrester, J.W. (1970). Systems Analysis as a Tool for Urban Planning, IEEE Transactions on Systems Science and Cybernetics, SSC-6(4): 258-265.
Gesch, D.B. (2012). Elevation uncertainty in coastal inundation hazard assessments, in Natural Hazards, Cheval, S, eds. Vukovar, Croatia, in Tech, pp. 121-140.
IPCC (2007). Climate Change 2007: Synthesis Report, Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Pachauri, RK & Reisinger, A (eds.), Geneva, Switzerland, pp. 104.
IPCC (2014). Summary for Policymakers, In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution to Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change 31st March 2014.
Jeganathan, A., Ramachandran, A. (2013). Temperature trends of Chennai city, India, Theoretical and Applied Climatology, 111(3-4): 417-425.
Johnston, S. (2012). Technical Introduction to Satellite EO', Chapter 1 in Evidence from Earth Observation Satellites: Emerging Legal Issues, Ray Purdy, Denise Leung (eds.) Martinus Nijhoff Publishers, pp. 498
Kovats, S. and Akhtar, R (2008). Climate, Climate Change and Human Health in Asian cities, Environment and Urbanization, 20 (1): 165-175.
Krishnan, P. (2013). Pallikarani is 2,700 years old. Deccan Chronicle, 27 October, http://www.deccanchronicle.com/131027/news-current-affairs/article/pallikaranai-2700-years-old.
Leatherman, S.P., Nicholls, R.J. (1995). Accelerated sea-level rise and developing countries: An Overview. Journal of Coastal Research, 14(1-14).
McLean, R.F., Tsyban, A., Burkett, V., Codignotto, J.O., Forbes., D.L., Mimura, N., Beamish, R.J. and Ittekkot, V. (2001). Coastal zones and marine ecosystems. In: Climate Change 2001: Impacts, Adaptation, and Vulnerability. McCarthy, JJ, Canziani, OF, Leary, NA, Dokken, DJ, White, KS (eds.), Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, pp. 343–379.
Nicholls, R.J. (2003). Case Study on Sea Level Rise Impacts, Prepared for OECD workshop on the Benefits of Climate Policy: Improving Information for Policy Makers: December 12-13, 2002, Working Party on Global and Structural Policies, Organization for Economic Cooperation and Development, Paris.
Nicholls, R.J. (2007). Adaptation options for coastal areas and infrastructure: An analysis for 2030, Report to the United Nations Framework Convention on Climate Change, Bonn, pp. 33. http://unfccc.int/files/cooperation_and_support/financial_mechanism/application/pdf/nicholls..pdf.
Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E. (eds) (2007). Climate Change 2007: Impacts, Adaptation and Vulnerability.Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge: Camridge University Press.
Ramachandran, A., Saleem Khan, A., Palanivelu, K., Prasannavenkatesh, R. and Jayanthi, N. (2017). Projection of climate change-induced sea-level rise for the coasts of Tamil Nadu and Puducherry, India using SimCLIM: a first step towards planning adaptation policies. Journal of Coastal Conservation 21(23):1-12.
Ramachandran, A., Anushiya, J. (2015). Long-term rainfall trends of Indian urban station and its variation in different phases and seasons, International Journal of Global Warming, 7(3): 307–321.
Sekar, S.P. and Kanchanamala, S. (2011). An Analysis of Growth Dynamics in Chennai Metropolitan Area Institute of Town Planners. India Journal 8 – 4: 31 – 57.
SoER (2013). State of environment report of Chennai Metropolitan Area. ENVIS Centre, Department of Environment, Government of Tamil Nadu, http://www.indiaenvironmentportal.org.in/files/file/State%20of%20Environment%20Report%20of%20Chennai%20metropolitan%20area.pdf.
Thenkabail, P.S. and Gamage, M.S.D.N. (2004). The Use of Remote Sensing Data for Drought Assessment and Monitoring in Southwest Asia, Colombo Srilanka, International Water Management Institute, pp. 123.
Titus, J.G. (1988). Greenhouse Effect, Sea Level Rise, and Coastal Wetlands', U.S. Environmental Protection Agency, Washington, DC, pp. 186. EPA 230-05-86-013.
Tucker, C.J., Townshend, J.R.G., Goff, T.E. (1985) African land cover classification using satellite data. Science, 227: 369–375.
UN Habitat (2008). State of the world's cities 2008/09- Harmonious cities, Chapter 3.3 Cities at risk from rising sea level. ISBN:978-92-1-132011-4, pp. 140-155

UNPD (2001) World Urbanization Prospects: The 2001 Revision. Available online at www.un.org/esa/population/publications/wup2001.