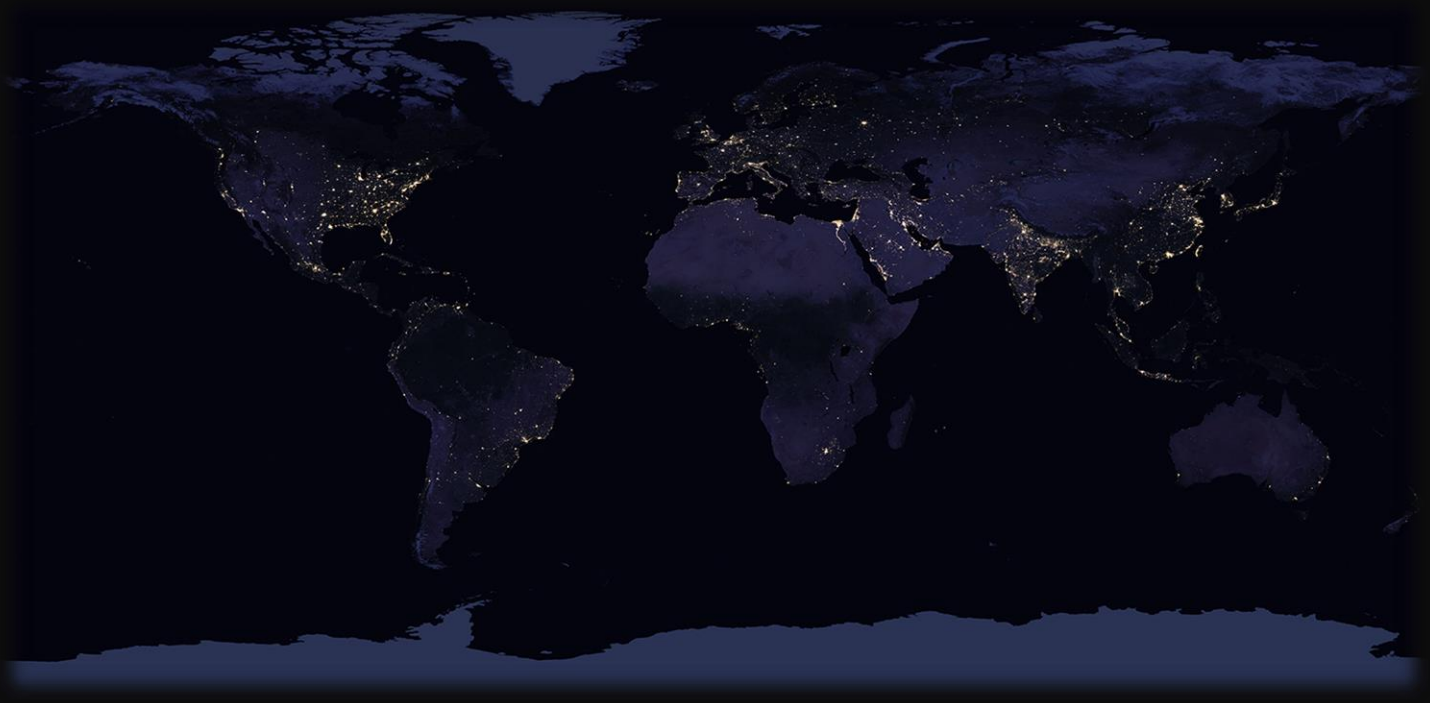

URBANIZATION & CLIMATE CHANGE

"ANALYSING THE CHANGE IN URBAN PATTERN FROM 1980 TO 2020 AND ITS IMPACT ON CLIMATIC VARIABLES IN BANGALORE, DELHI, INDORE, KOLKATA, PUNE."

AUTHOR:
NISHANT KUMAR UPADHYAY

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ABOUT ORGANIZATION:

The Comptroller and Auditor General (C&AG) of India is a Constitutional Authority appointed by the President of India to head the Supreme Audit Institution (SAI) of India.

SAI India has been conducting international training Programmes since 1979**. iCED is a designated Global Training Facility of Working Group on Environmental Audit (WGEA), as well as of the Working Group on Extractive Industries (WGEI) of International Organizations of Supreme Audit Institutions (INTOSAI),** since March 2011 and August 2016 respectively. iCED is also a premiere institution conducting training programmes on Environment Audit under Indian Technical and Economic Cooperation Programme sponsored by Ministry of External Affairs, Government of India. iCED embarked on its capacity building efforts in October, 2013. iCED has been set up near the historical city of Jaipur in India, located around 230 kilometers from Delhi, the capital of India. This facility seeks to harness India's expertise in conducting more than 100 environment audits in last 20 years to provide extensive training and to act as a forum for experience sharing and research for the auditors and government program managers.

Vision and Mission

We aim to be a global Centre of Excellence for improving accountability and governance in the area of environment and sustainable development.

We will develop high quality products in training and research to enrich environment audit through an inter-disciplinary approach enabled by valuable partnerships.

Area of Research: iCED conducted wide range of environmental research and numbers are going up with more value addition research. Each Research has been done in supervision of appointed Guide and data used in research are authentic.

DISCLAIMER:

Opinions and recommendations in the report are exclusively of the author(s) and not of any other individual or institution including iCED. This report has been prepared in good faith on the basis of information available at the date of publication. Data and methodology used in this research is mentioned inside. All interactions and data collection are transparent and conducted in an open, honest and independent manner as enshrined in iCED code of conduct for research.

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ABBREVIATIONS

LULC:	Land Use Land Cover
NDVI:	Normalized difference vegetation index
GIS:	Geographic Information system
USGS:	United states Geological Survey
NASA:	National Aeronautics and Space Administration
RS:	Remote Sensing
FCC:	False color composition
IMD:	Indian metrological department
Lat.:	Latitude
Lon.:	Longitude
N-	North, S- South, E- East, W- West
LCC:	Land Change classification/cover
SDM:	System Dynamics Modelling
CLD:	Causal loop diagram
UNCTAD:	United Nations Conference on Trade and development
ULBs:	Urban Local Bodies
NIR:	Near Infrared Wave
SWM:	Solid waste management

INTRODUCTION

"Ultimately, we need to recognize that while humans continue to build urban landscapes, we share these spaces with other species."

- David Suzuki

From the podium of Habitat III Conference, United Nation Chief called "New Vision for Urbanization." So, why do we need a new vision? Is the old vision unable to solve the urban problems?

The world is urbanizing at a very high rate, According to United Nations (UN) Population Division,[1] one-third of the world population was urbanized in 1950. This will increase to two-thirds of the world population in 2050.

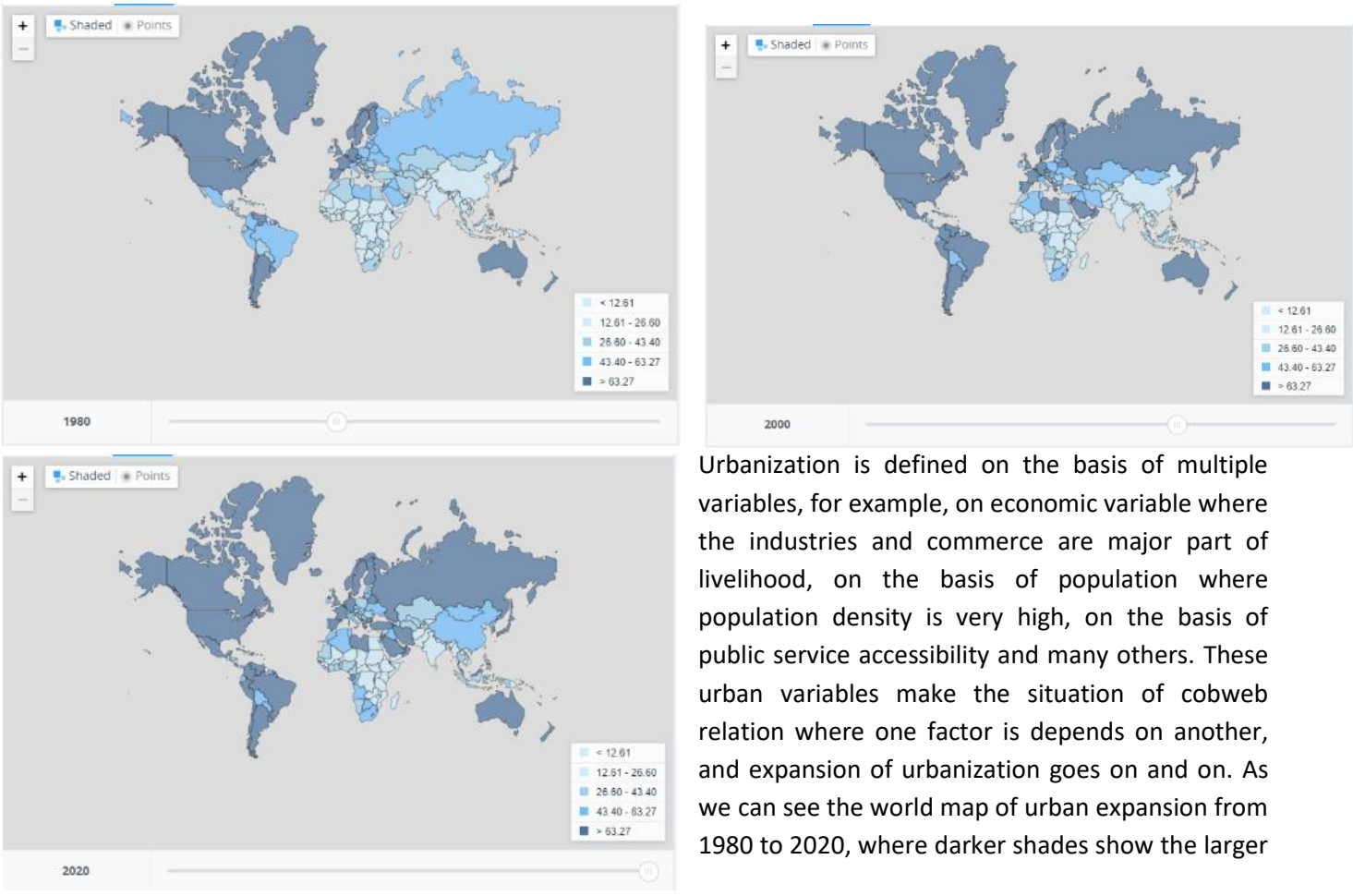


Figure 1 UN WORLD POPULATION

Urbanization is defined on the basis of multiple variables, for example, on economic variable where the industries and commerce are major part of livelihood, on the basis of population where population density is very high, on the basis of public service accessibility and many others. These urban variables make the situation of cobweb relation where one factor is depends on another, and expansion of urbanization goes on and on. As we can see the world map of urban expansion from 1980 to 2020, where darker shades show the larger population of that nation lives in urban cities.

[1] UN, Population Divison/https://www.un.org/development/desa/pd/themes/urbanization

India's scenario of urban pattern:

India with more than 1.3 billion population contributes around 17% of total world population. [2]As per the UNCTAD the urban population increased 51.1% in 2009 to 55.7% in 2019 just in ten years. Developing economies such as India has very high rate of growth in urban population, according to World bank 35% of total population lives in urban area in India.

Population Census 2001 and 2011

	Persons in million numbers				Decadal growth in population %
	2001	2011		1991-2001	2001-2011
Total	1029	1210		21.5	17.6
Rural	743	833		18.1	12.2
Urban	286 27.81%	377 31.16%		31.5	31.8 +0.3%

Table 1 POPULATION CENSUS

[3] As per the above census 2011 data table of housing ministry 31.8% decadal growth of urban population in India forced us to think, When such a large population lives in urban area and rate of urbanization increases day by day then it is very essential to understand the challenges associated with it like climate challenges such as Heat stroke, heavy rainfall and water logging, Unsustainable housing pattern, slums, worst Quality and shortage of drinking water, bad Air quality, unsustainable waste management system and many more. These challenges not only make human lives vulnerable but impacted climate in long run.

Sustainable urbanization is not only for climate perspective but it is very important to human perspective also, for example slums in city is not a way of living, sustainability has multiple factors from climate to infrastructure. Which is well defined in upcoming chapters of this research with causal inferences in between the sustainability and its variables.

[2] UNCTAD/ https://stats.unctad.org/handbook/Population/Total.html

[3] https://mohua.gov.in/cms/urban-growth.php

RESEARCH OBJECTIVE:

Analysis of urban pattern and its sustainability is the main objective along with different sub-objective mentioned below:

- Finding the extreme weather situation and degree of its impact on different research sites to comparatively analyze the situation, and draw the sustainable option to tackle the problem.
- Changing pattern of urban area of research sites through LULC and NDVI methods. Observe and analyze the nature of urban expansion.

RESEARCH SITES: The scope of the study is to focus on the mega cities and its level of sustainable urban pattern.

- Delhi, Kolkata, Bangalore, Indore, Pune
- Site Selection: Research is basically focused on the diversity of megacities to conduct a comprehensive study of their urban pattern and sustainability so selection of these cities is based on the previous performance in different sustainability index, population and other extreme climatic frequency in that city.

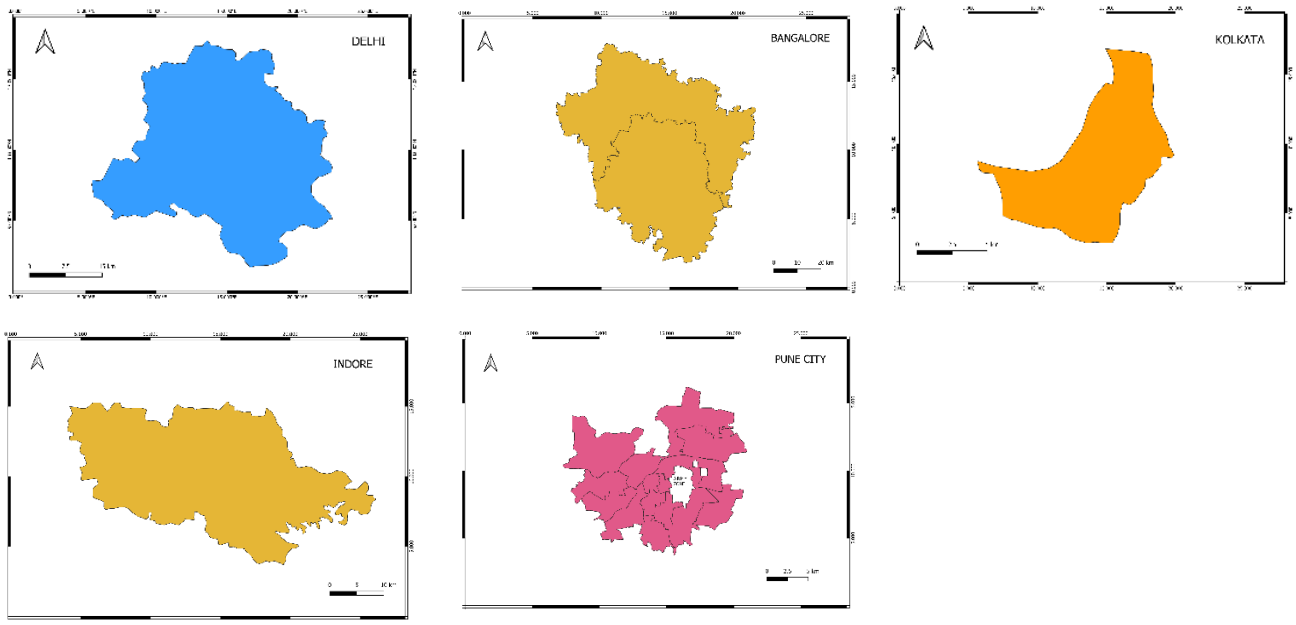


Figure 2 RESERACH SITE MAPS

SAMPLE SELECTION: Landsat satellite image is major sample of the data collection to analysis the urban LULC pattern of these cities. Rainfall data is taken from IMD which is mentioned in ANNEXURE-1, Temperature data is taken from Power NASA portal which is mentioned in ANNEXURE-2 and Real time satellite based data is taken from Landsat of NASA USGS according to research area and study.

CITY	AREA(in sq Km)
BANGALORE	4496
DELHI	1502
KOLKATA	91
PUNE	251
INDORE	1025

Table 2 RESEARCH AREA (IN SQ KM)

RESEARCH METHODOLOGY

Qualitative findings are not possible without quantitative supports, similarly in this research analysis supported by the data from different official sources and literature review as mentioned below. The objective of the research to analyze the unsustainable urbanization and its impact is well derived from the methods of SDM (System dynamics modelling) and Green Nudge. This research primarily uses GIS tools like Q-GIS and USGS NASA satellite data to finding the degree of unsustainability and pattern of expansion of Urban area.

WHAT IS GIS AND HOW IS IT USED IN THIS RESEARCH?

GIS (geographic information system) has already defined by the two components of its name, first one is geographic and another one is information, which means analysis, interpretation and mapping of different types of data or information of any geographical region is defined as GIS. GIS has broad horizon in this modern time, where technology has multiple roles to solve the problem. In this research GIS used to map the changing pattern of urbanization, LULC and NDVI of mentioned research sites. Through this we can understand the land cover and spatial pattern of urban area and try to find out the problems associated with it.

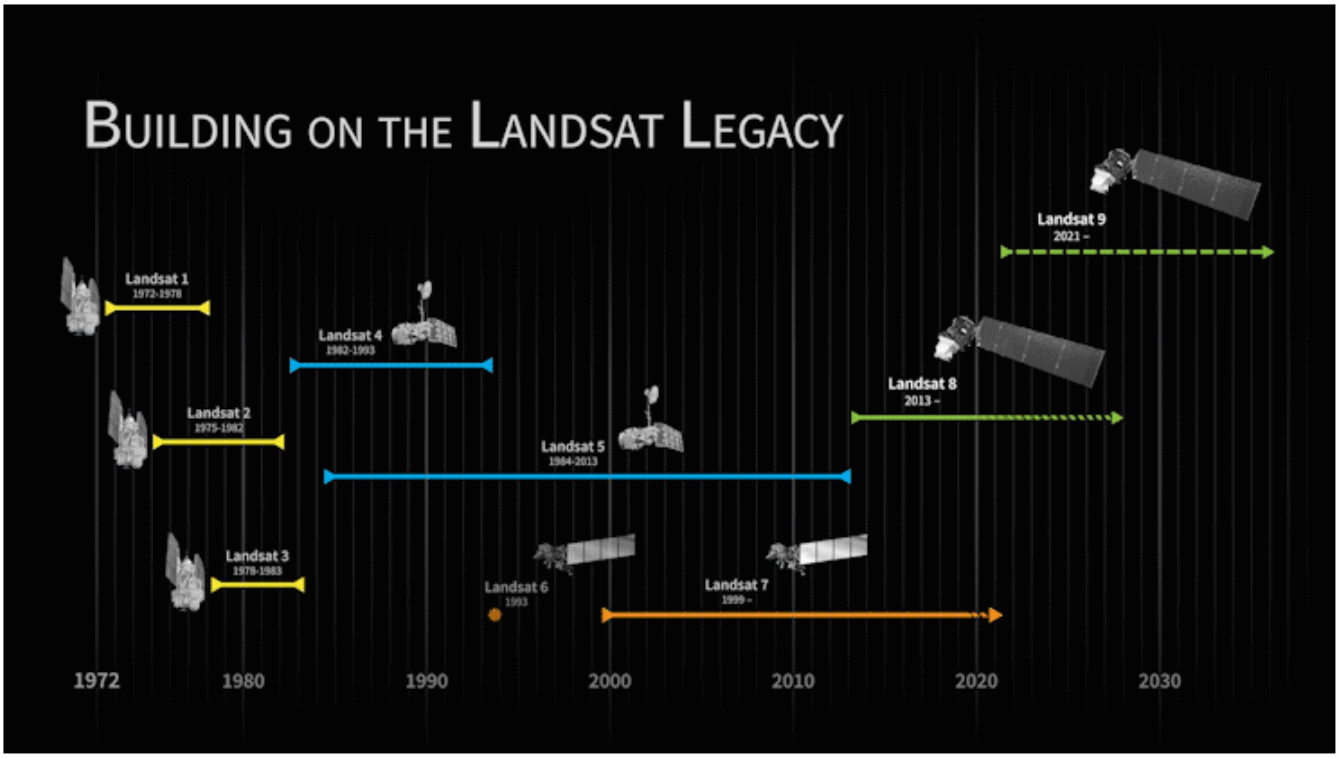


Figure 3 LANDSAT LEGACY

Landsat is series of satellites which are sent by USGS NASA, government of United states of America for the purpose of collecting geographical high-resolution data which is used in different developmental, planning and decision-making process. Landsat is the longest running earth observatory satellite which was started from 1972 as Landsat-1. Now it has latest launched in 2021 which is more accurate and frequent known as landsat-9. The above picture talks about the different phase of Landsat satellites. Landsat-1 from 1972 to 1978, Landsat-2 from 1975 to 1982, Landsat-3 from 1978-1983, Landsat-4 from 1982 to 1993, Landsat-5 from 1984 to 2013. Unfortunately, Landsat-6 was crashed and some sensors are not placed well which was failure for Landsat-6. Landsat-7 which was sent in 1999 still working, along with Landsat-8 which was sent in 2013 and Landsat-9 which is in 2021.

Method of converting geographical Information from Landsat data into Map of our interest:

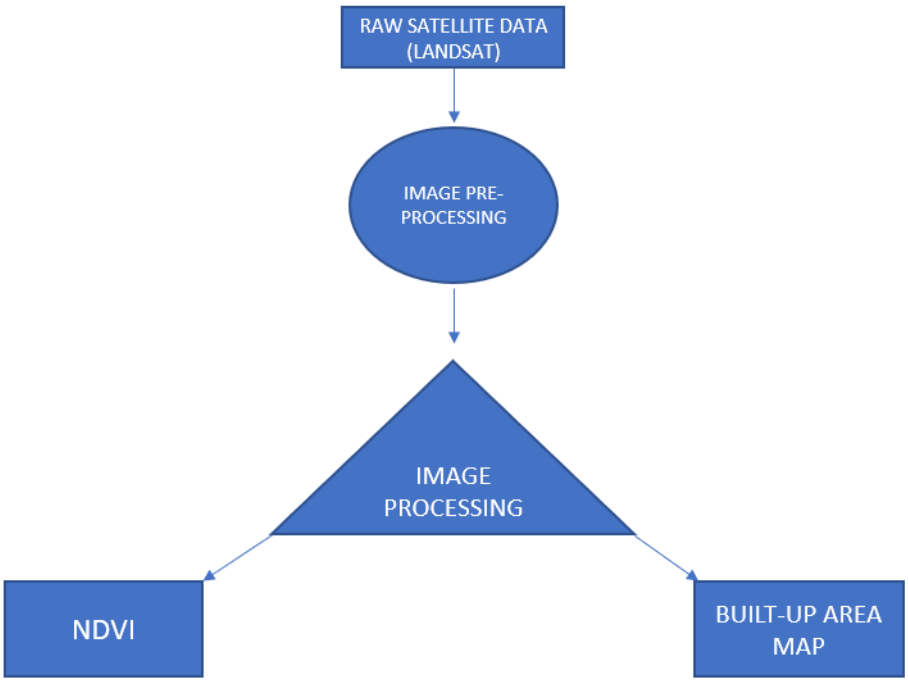


Figure 4 METHODOLOGY FLOW

Step.1. Downloading Landsat Data from USGS Earth Explorer (NASA): https://earthexplorer.usgs.gov/ data on USGS is real time data cover 180*185 KM with 30 m resolution. Which has several bands according to landsat data time frame.

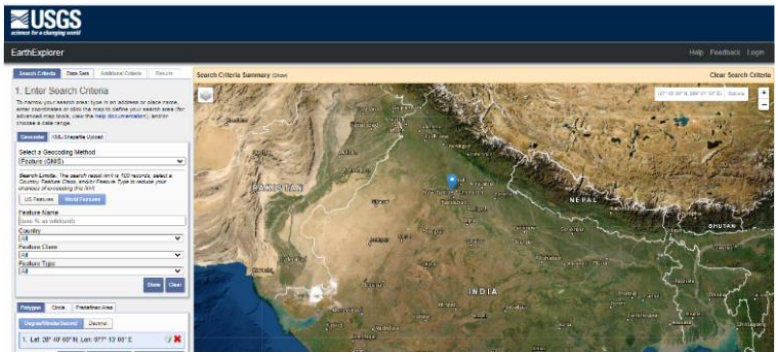


Figure 5 METHODOLOGY STEP.1

Step.2. Making Reflectance of bands and creating virtual band: downloaded Landsat data from Earth explorer imported in QGIS software to convert the bands into FCC (false color composition) which helps to understand the different land use pattern

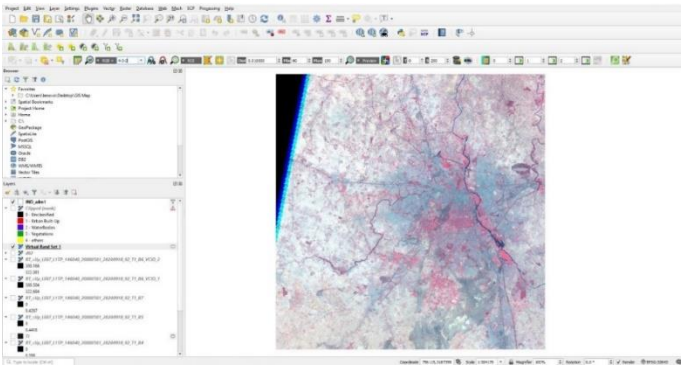


Figure 6 METHODOLOGY STEP.2

like urbanization looks in gray, vegetation looks into dark red, water bodies in blue and black and others like barren lands, sands, agricultural lands etc. looks in yellow and white.

Step.3. Classification of reflectance raster data into our area of study (LULC, NDVI) using QGIS Software: According to research interest and findings we then classify the FCC virtual band into supervised classification pattern which is look like the image given in the left side. Where the classification of urban area converted into red, water bodies into blue, vegetation into green and others into yellow.

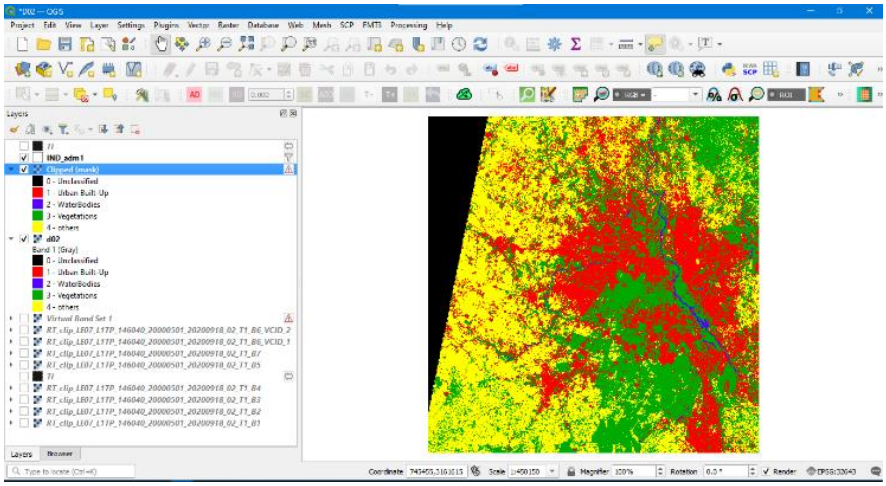


Figure 7 METHODOLOGY STEP.3

Step.4. Importing final Map in QGIS software: Final import has been done in the left side which has zebra grids with coordinate's values on it, defined legend, and map title with North arrow for direction of the map.

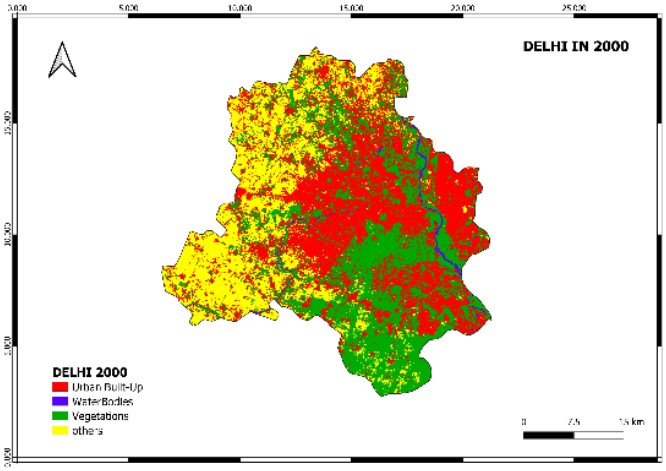


Figure 8 METHODOLOGY STEP.4

METHOD FOR CLIMATIC DATA OF RAINFALL AND TEMPERATURE:

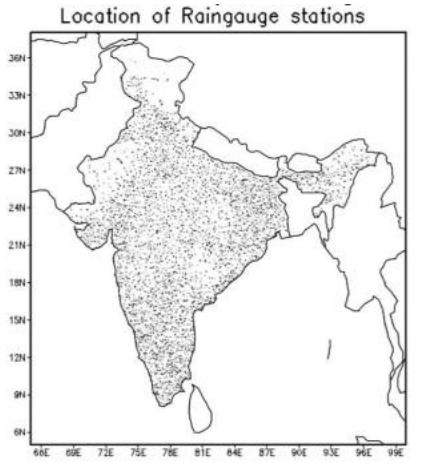
RAINFALL

[4]Data for rainfall is taken from the IMD (Indian metrological department) of India as below mentioned coordinates of cities.

To analyze the rainfall of different cities, the above coordinates are taken, which are the nearest raingauge stations to those cities, to get more accurate result.

City	Coordinates	
	LAT(N)	LON(E)
Bangalore	13	77.5
Delhi	28.75	77
Indore	22.75	75.75
Kolkata	22.5	88.5
Pune	18.5	73.75
Jaisalmer	27	71

Figure 9 CITIES AND COORDINATES



ig. 1. Network of 6955 rain gauge stationsused for development of IMD4

Step.1. Downloading data from IMD website which is in gridded form which means data is saved in divided grid of these raingauge stations in form of .grd file.

Step.2. Converting .grd files of different year into csv form.

Step.3. Extracting the data of each day of each year of these coordinates from big data of rainfall for each year from 1980 to 2020.

TEMPERATURE:

Data of Temperature is taken from [5]NASA Power data Access portal which is open portal with large climatology data available. Temperature data is taken directly by mentioning cities coordinates and time period from 1981 to 2020. Maximum temperature and wet bulb temperature is taken in account to study the extreme impact of climate on the mentioned urban cities which further impacted human life at large.

What is wet bulb temperature?

Wet bulb temperature is the temperature which is recorded if the bulb of the thermometer is wrap by wetted cotton. [6]Wet bulb temperature is the lowest temperature to which air can be cooled by the evaporation of water into the air at a constant pressure.

[4] https://www.imdpune.gov.in/Clim_Pred_LRF_New/ref_paper_MAUSAM.pdf
[5] https://power.larc.nasa.gov/docs/methodology/
[6] https://www.sciencedirect.com/topics/engineering/wet-bulb-temperature

Why we need to consider wet bulb temperature rather than dry bulb or normal air temperature in this study? It is because of humidity and wind speed which is considered in wet bulb temperature. Let's understand this by some useful example, our body temperature is generally at 37 degree Celsius but we can live and survive in 45 degree Celsius, it is because of humidity of surrounding and mechanism of human body. Human body works as an engine which means it breaking food into energy and body get heated as similar as engine gets heated but in human body it release sweat which evaporates into surrounding and body become maintain its temperature. Now think if the humidity is high which means surrounding around the body has already much water in its air then sweat evaporation rate get reduced and our body feel more heat at the same air temperature.

Heat Stress Category (WBGT)	Moderate Work		Hard Work	
	Work/Rest Cycle	Water Intake Per Hour	Work/Rest Cycle	Water Intake Per Hour
White ≤76.9°F (≤24.9°C)	60/15 MINUTES	300 ml (1/3 qt)	40/20 MINUTES	500 ml (1/2 qt)
Green 77-81.9°F (25-27.7°C)	60/15 MINUTES	750 ml (3/4 qt)	40/20 MINUTES	1000 ml (1 qt)
Yellow 82-84.9°F (27.8-29.4°C)	40/20 MINUTES	1000 ml (1 qt)	30/30 MINUTES	1000 ml (1 qt)
Red 85-88.9°F (29.5-31.6°C)	30/30 MINUTES	1000 ml (1 qt)	Exercise is forbidden. Very high risk for heat casualties.	
Black ≥89°F (≥31.7°C)	Exercise is forbidden. Very high risk for heat casualties.			

Figure 10 WBT AND WORK RELATION

This phenomena is called heat stress and can be cause for death. So considering wet bulb temperature is one way to look out the real temperature which any human body can feel and burden.

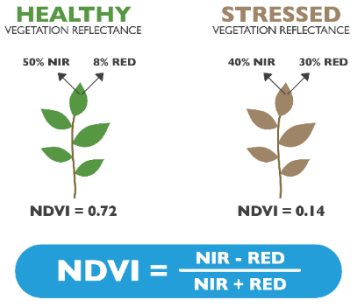
The maximum wet bulb temperature for human body is ranged between 30- 35 degree Celsius. Which is extreme and above this can cause heat stroke. Some countries mentioned the work duration for those work which is in direct sunlight at high humidity to reduce the casualty due to heat stress.

WBGT AND WORK RELATION TABLE: In the above table the relation between work nature, duration and permissible wet bulb temperature for that work is mentioned. Where above 29 degree Celsius has red zone which means high risk of heat stress casualties.

NDVI:

[7]NDVI is used to quantify vegetation greenness and is useful in understanding vegetation density and assessing changes in plant health. NDVI is calculated as a ratio between the red (R) and near infrared (NIR) values in traditional fashion:

NDVI= (NIR - R) / (NIR + R)



In Landsat 4-7, NDVI = (Band 4 – Band 3) / (Band 4 + Band 3).

In Landsat 8, NDVI = (Band 5 – Band 4) / (Band 5 + Band 4).

[7] https://www.usgs.gov/core-science-systems/nli/landsat/landsat-normalized-difference-vegetation-index?qt-science_support_page_related_con=0#qt-science_support_page_related_con

NDVI values are classified into different categories in between -1 to +1 where negative values represents the water bodies, barren land, urban built-ups and other land use pattern except healthy plants, positive value above 0.3 represents the healthy plants. It also depicts the density of vegetation. Healthy and densely vegetative shows greater values of NDVI above 0.6.

Figure 11 NDVI VALUE

RAINFALL PATTERN OF INDIA

India is a country which has good rainfall and drainage system. Monsoon in India is lifeline for some non-perennial rivers and agriculture, but due to climatic variation and changes in between some decades the pattern of rainfall varies accordingly.

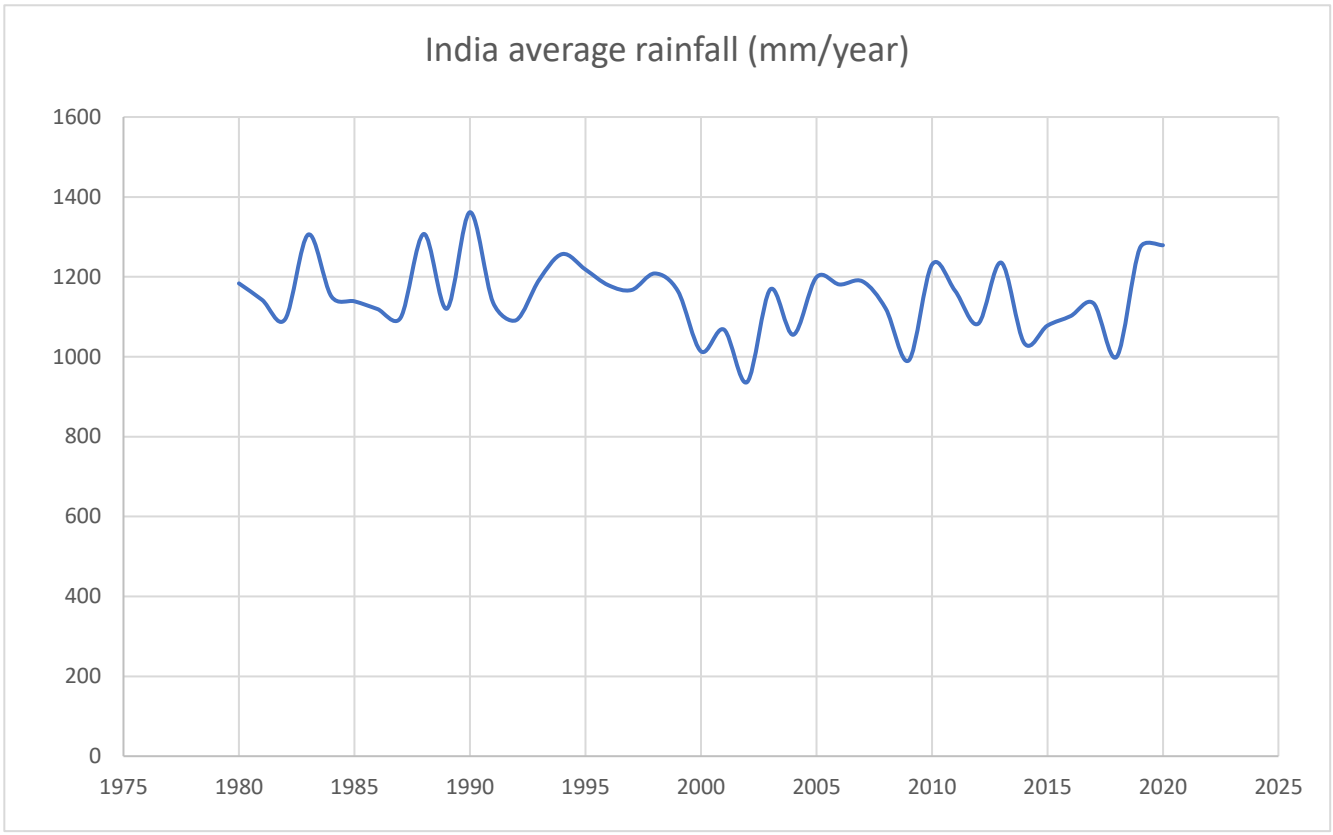
Rainfall variation in India: In analysis from 1980 till 2020, as shown in graph the mean value of 40 year rainfall is 1150 mm and normal distribution curve is inclined more towards central. In Deviation curve the 75% values lies in between 100mm differences from the mean in both tailed graph.

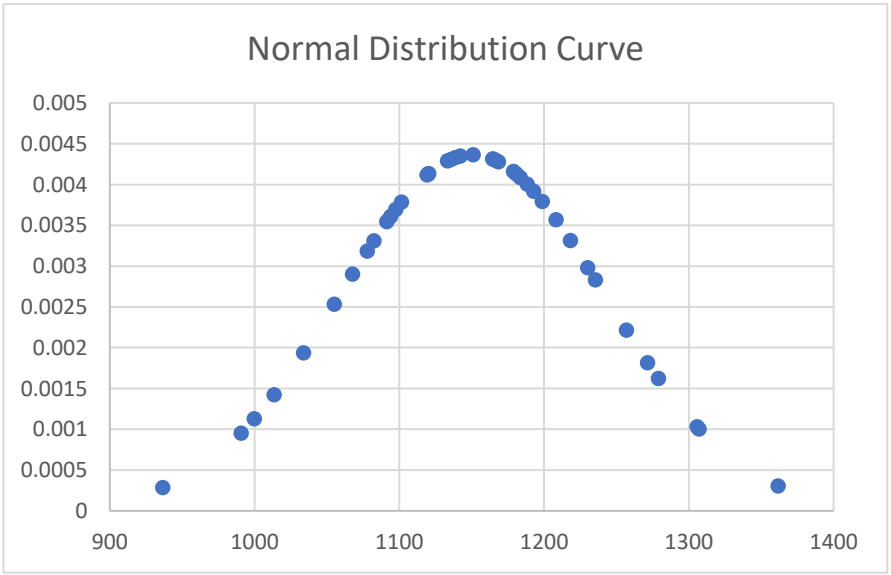
This means 75% of total 40 year rainfall data, the deviation lies between 100mm from the mean. The rainfall of overall India has well in the graph but further in this research we analyze the city wise rainfall in details and compare those with the overall deviation and distribution which tell us the real picture of rainfall in those cities with comparison to overall rainfall.

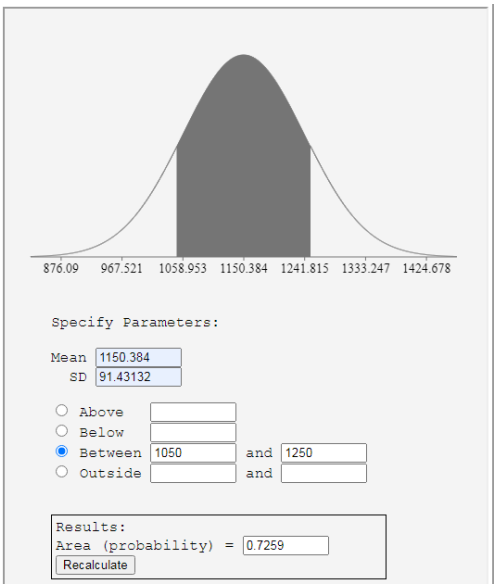
Difference between Tradition and Trend: Indian rainfall tradition has not changed at large in the past forty year of our study, it is very interesting that it is still deviates around 1150 mm/year but the problem is in trend. In our study we found that the rainfall trend in India is changing at very high rate.

What is Indian Rainfall Trend?

Trend is a instrument of pattern that can predict the future while tradition is history of that trend. Rainfall trend is based on changing time zone of monsoon and rainfall, change in regional or decentralized rainfall, and role of Vegetative index or forest cover at large shape the Indian rainfall trends, since past 10 years the trends of rainfall changed. For example, unpredicted rainfall in Chennai in 2021 after rain havoc of 2015, Mumbai and Pune flood in 2005 and many more.







Graph 1 INDIAN RAINNFALL DISTRIBUTION

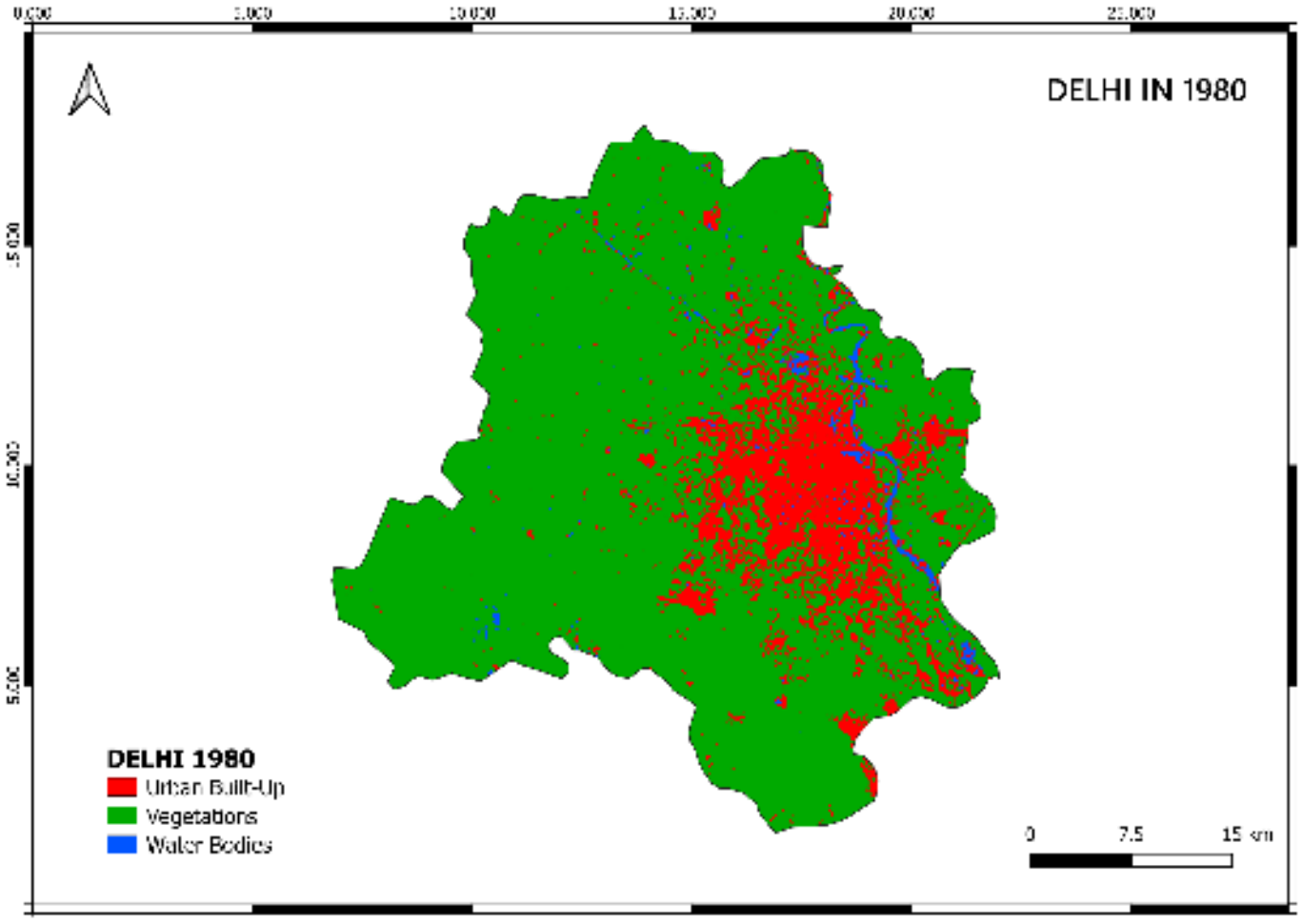
CHAPTER. I URBANIZATION AND CLIMATE VARIABLES

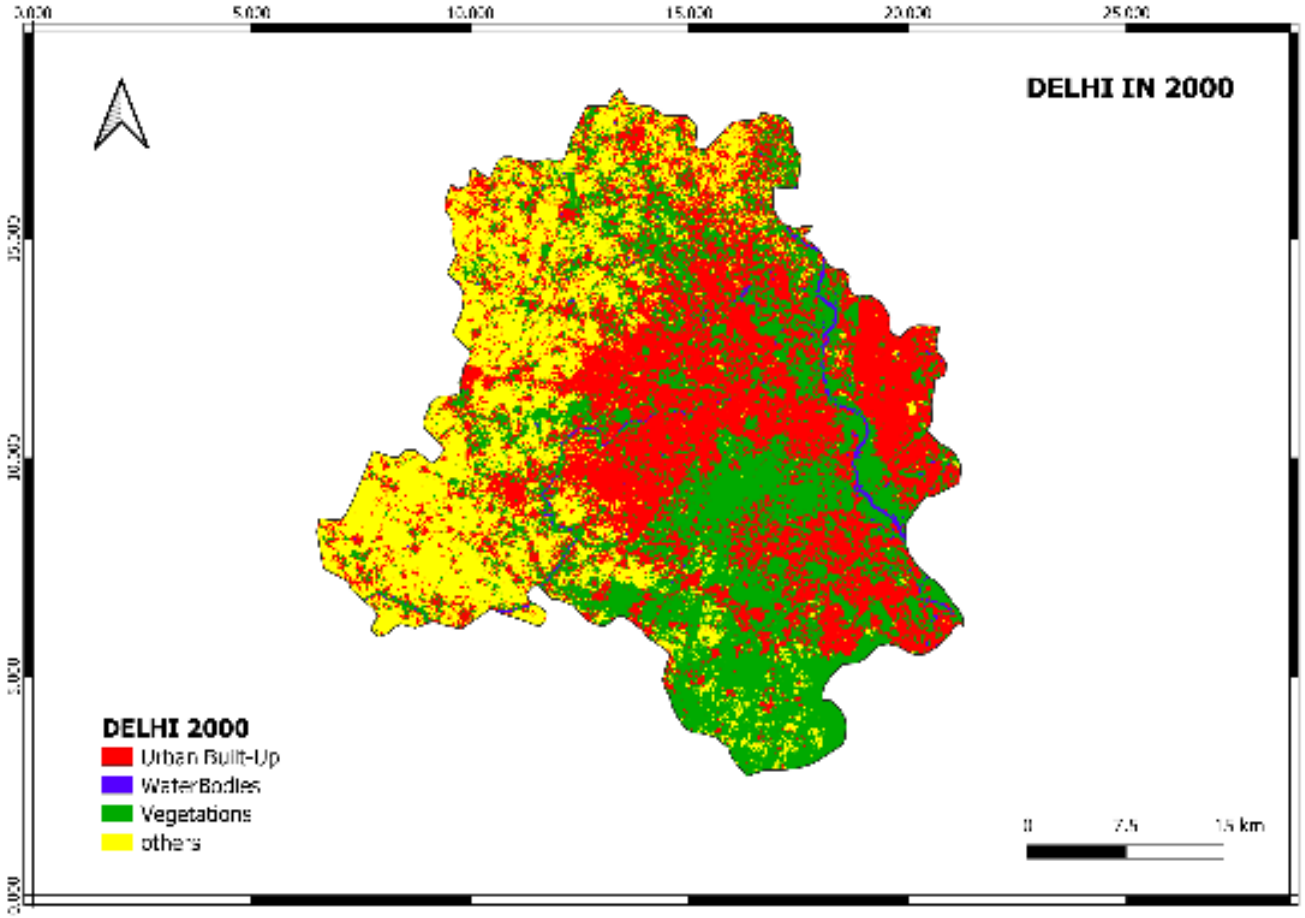
Understanding the Urban pattern and spatial analysis is one of the major keys of planning and governance. Sustainability should be the core concern of this governance. Analyzing the urban pattern is not enough, it is best only when all variables of sustainability should be considered. Precipitation, temperature, vegetative index and water quality and quantities etc. are the core of this which makes city more sustainable and climate friendly. Here we are analyzing the cities and their climatic variability.

In urban areas, presence of vegetation is essential for reducing the effects of environmental pollution and maintaining the ecological balance. In the wake of excessive growth of population, the urban vegetation with parkland, especially in developing countries, are diminishing rapidly to provide additional space to various other types of land use. However, such reductions can have serious future implications. Therefore, an assessment of the vegetation cover of urban areas is essential. other factor which is associated with vegetation as mentioned above like temperature and precipitation, in this paper we are analyzing the cumulative effects of all.

DELHI:

UNDERSTANDING THE URBAN PATTERN





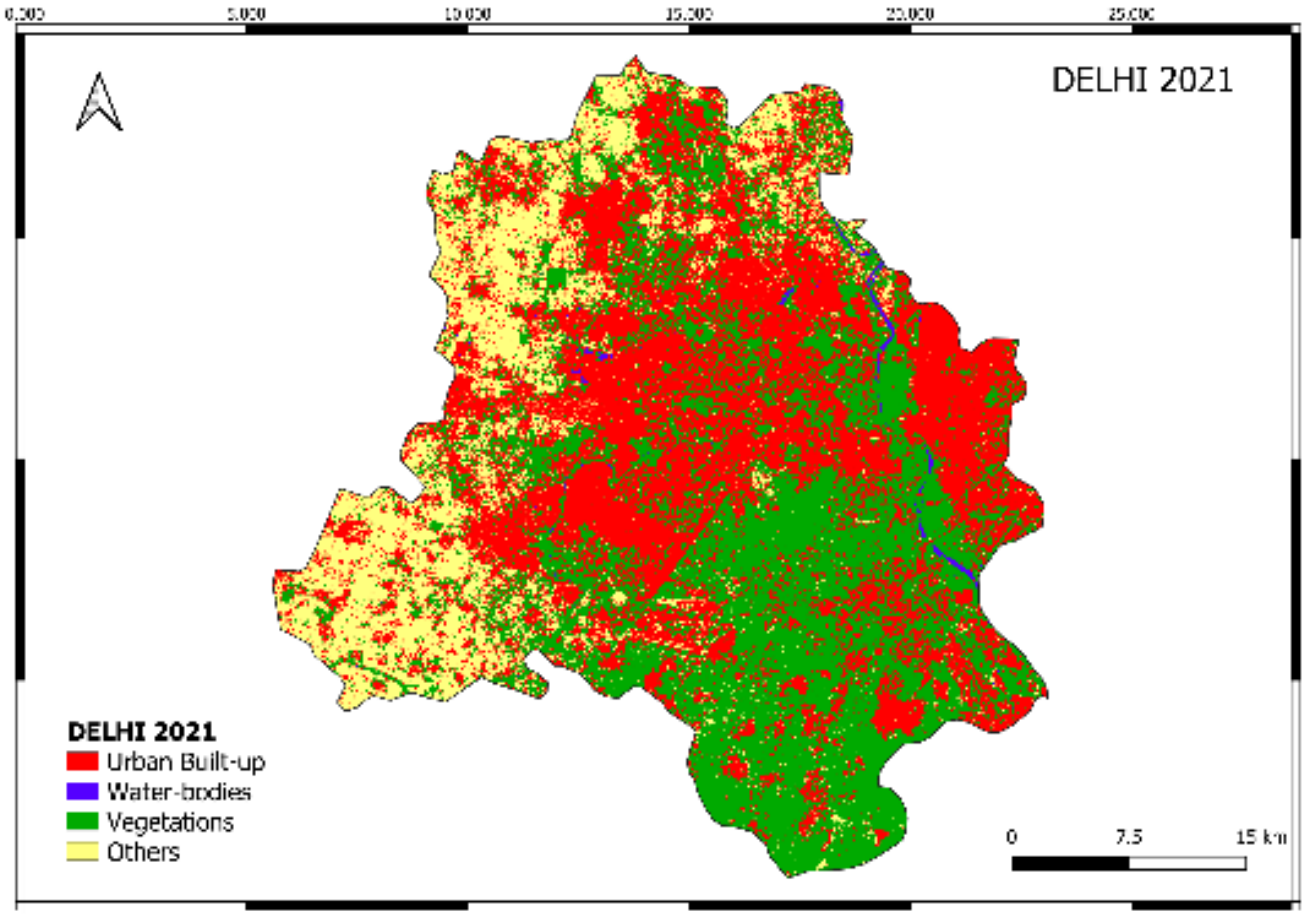


Figure 12 DELHI: URBAN PATTERN

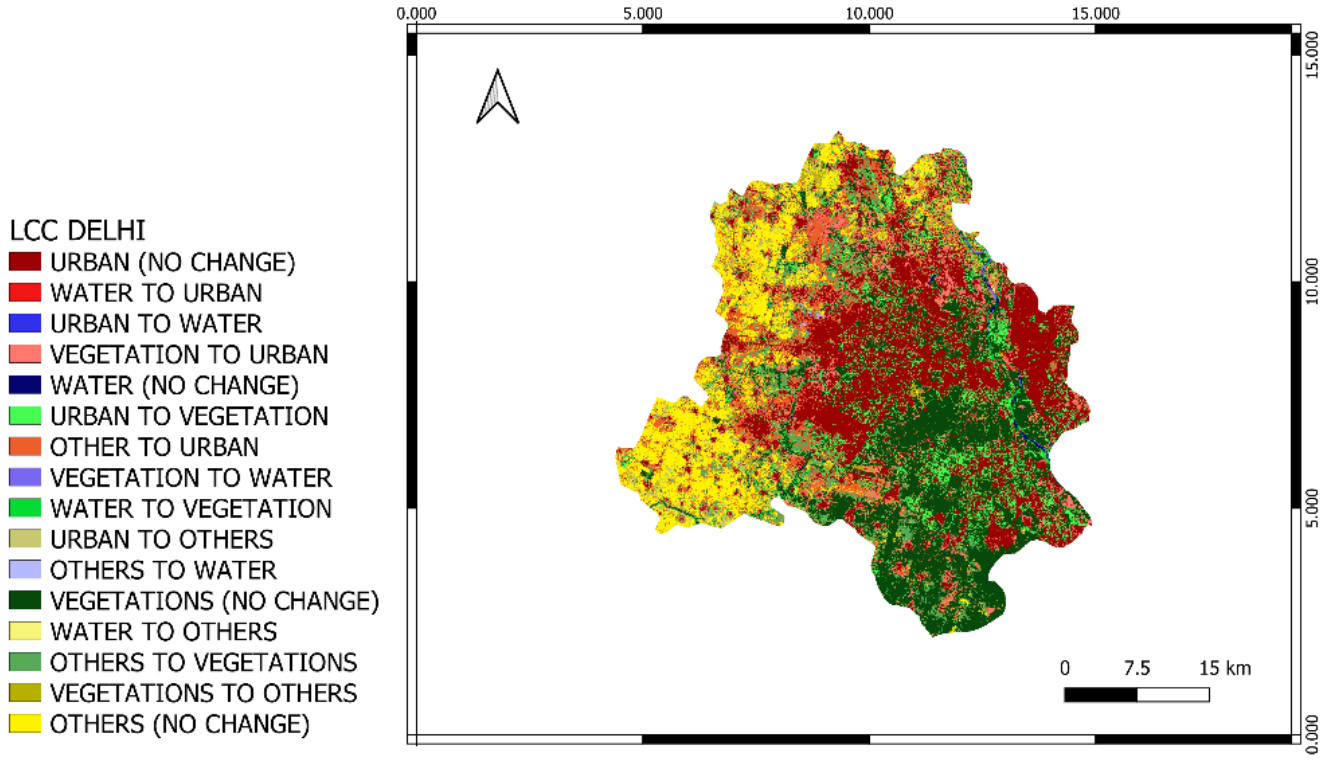


Figure 13 DELHI URBAN LULC MAP

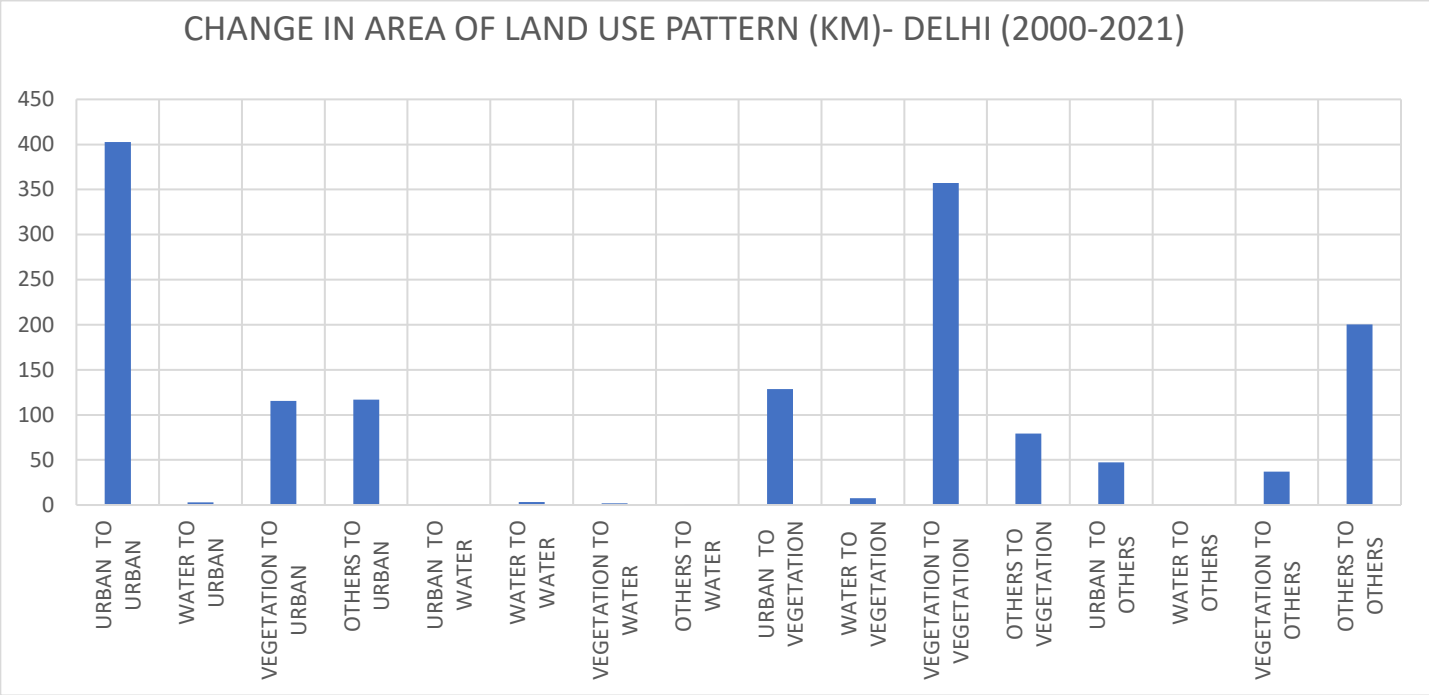
Delhi is 2nd most populous city after Mumbai, population of Delhi as per 2011 census is 1,67,87,941 which is around 1.68 crores. From the above LULC map of Delhi the urban expansion is clearly visible in the red pattern from 1980 to 2021 in three different maps. Expansion of urban pattern in Delhi followed urban sprawl and urban agglomeration which is connected via roads and metro transportation. As we can see in the above graph the north, south-west and west side of Delhi has major expansion in 2021.

For more detailed understanding of urban expansion and changes, here we are comparing the land change pattern of 2000 and 2021 in which we can see the expansion in north, south and south-west from vegetation to urban and others to urban built-ups.

From the below bar graph of land change classification we can see the amount of land change pattern from different area like agricultural or barren land converted into urban area has large proportion. Total 235.33 area is converted into urban area in between 20 years from 2000 to 2021, in which vegetative land and others land has major portion of conversion.

Other's land classification included barren lands, sands, agricultural crops, scrubs and some unhealthy vegetations. vegetative lands converted into others classification, which has large proportion after vegetation in

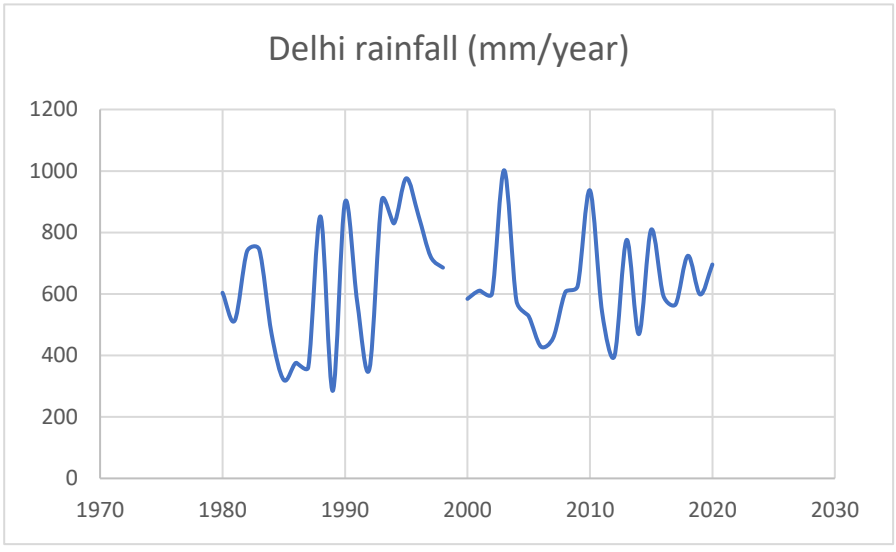
Delhi with area around 283 Sq km this land further converted into urban built-ups as we can further see in the comparison graph at the end.

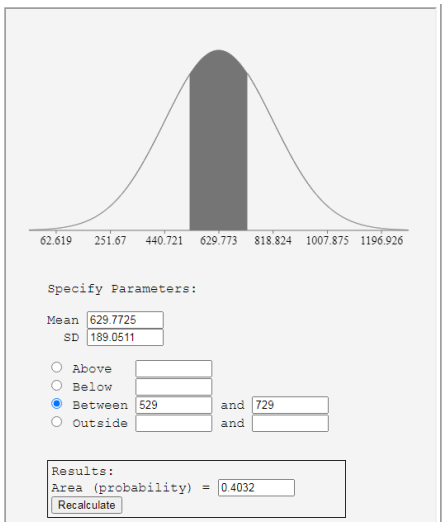


Graph 2 DELHI: LULC

CLIMATE VARIABLES AND UNSUSTAINABILITY

RAINFALL: rainfall pattern of Delhi is quite unique each year the variation in maximum rainfall a day is highly deviated from its previous year as you can see in graph below. The mean value of past 40 years rainfall is 629.77 mm/year.

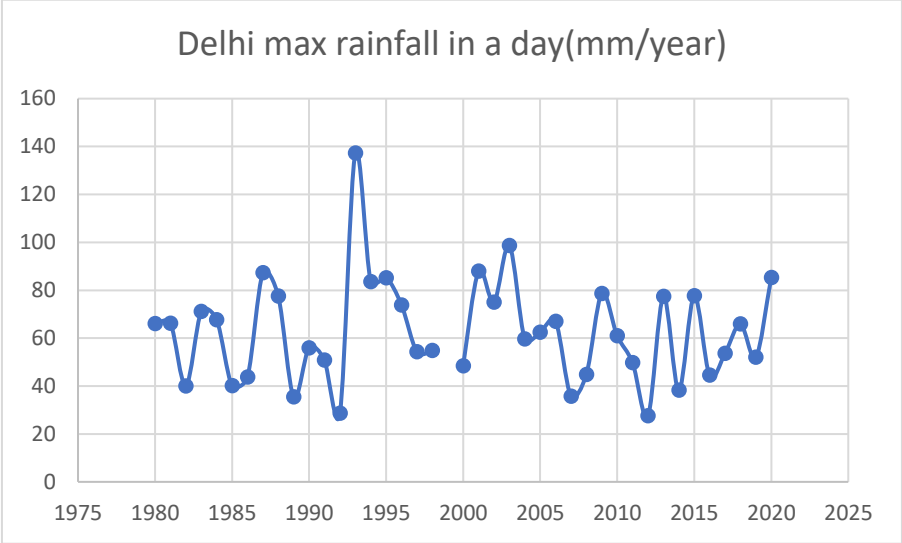




Graph 3 DELHI: RAINFALL

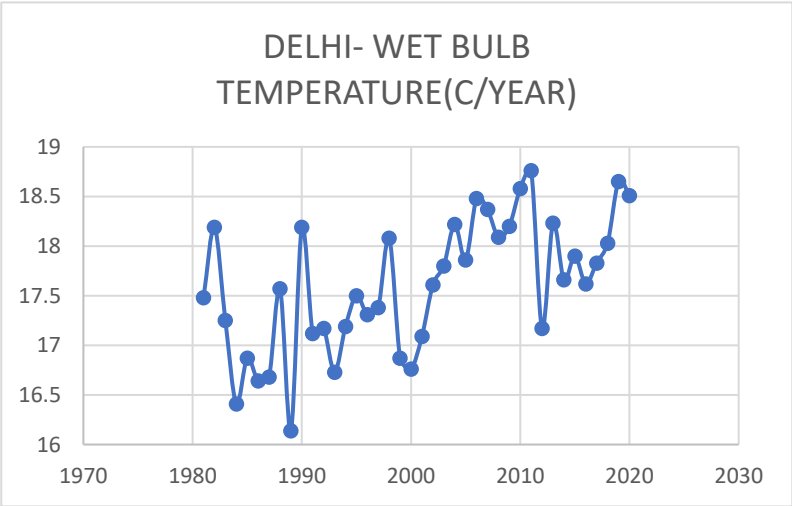
Since past 10 year the rain pattern of Delhi seem decreased and less deviated from the mean and can be seen 40% of the total 40 years mean rainfall lies in between the 100 mm deviation from the average mean. And from the past 10 years the rainfall pattern in Delhi is less deviated.

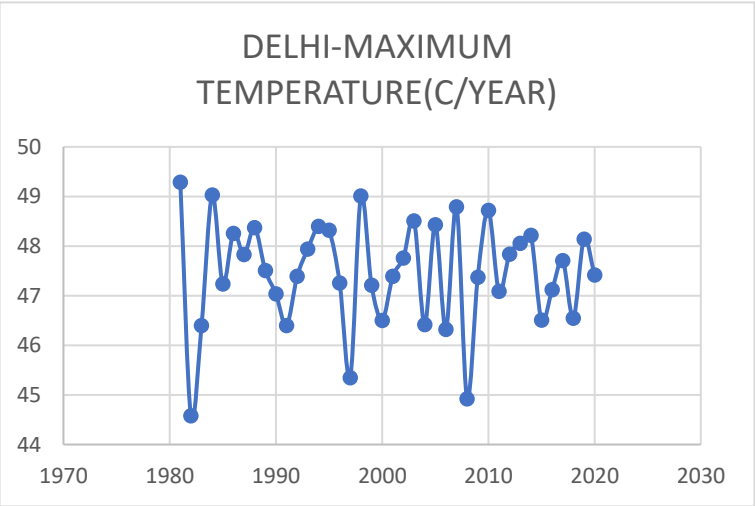
This means the extreme rainfall pattern of year in Delhi is decreased but still the urban flooding problem increased day by day during monsoon season in Delhi.



Cause of Urban Flooding: Unsustainable planning and Urban Sprawl, extreme weather conditions, Slums and illegal habitats, Poor drainage system and lacks of spatial engineering. These are the major cause of increased Urban flooding and unsustainability of urban structure. Further the urban flooding problem and solution will be detailed analyzed in upcoming chapter of sustainability with causal loop diagram.

TEMPERATURE:





Graph 4 DELHI: WBT

It is very interesting to see the graph of WBT here, which shows constant positive growth since 1980, it shows a positive trend in the WBT while the maximum temperature in a day map has less deviated and constant flat graph. This all means the Delhi usually faces a big problem of heat stroke and heat dome. In WBT graph 16.75 in 2000 to 18.5 in 2020 shows an increasing trend of temperature which means with constant high temperature, humidity also increased and cause positive slope of WBT.

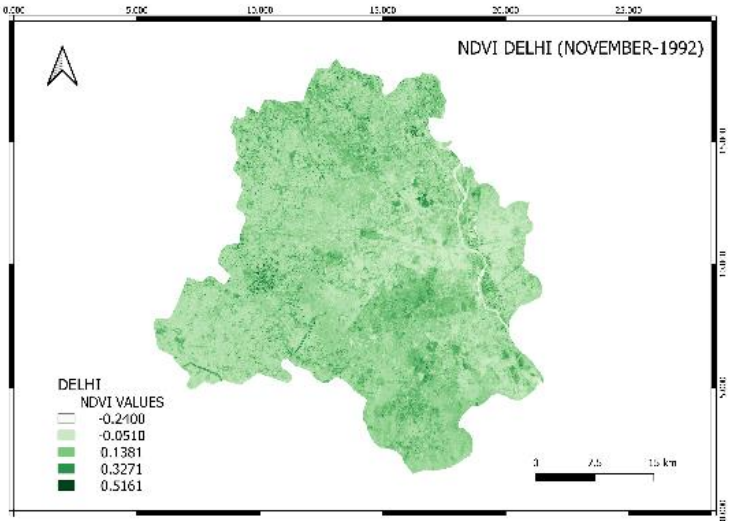
[8]The India Meteorological Department and the Indian Institute of Technology-Madras collaborated in 2017 to find that Delhi's heat index grew at a faster rate than the national average. During the summers, the heat index in Delhi has climbed by 0.6 degrees Celsius every decade, while during the monsoons, it has increased by 0.55 degrees Celsius per decade.

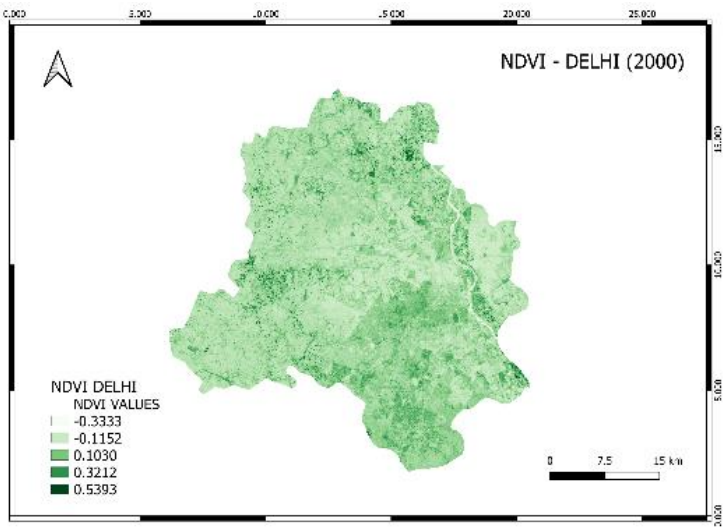
Summers and monsoons in Delhi are 3.6°C and 3.3°C hotter on the heat index than they were in the 1950s. The Centre for Science and Environment, a non-profit based in New Delhi, examined weather data from 2010 to 2017 and they also found that the average heat index for both seasons has been steadily rising.

Challenges caused by Increasing WBT:

High humidity and high temperature are responsible for heat stress and death in summer season, this is not only environmental problem but it creates economical losses also due to high WBT the industrial and outdoor work hampered during summer season and loss of workers and work hours causes economical losses also. So, we can say environment concern is not only related to ecology and human but it is core of all developments.

NDVI





[8] https://www.downtoearth.org.in/news/environment/indian-cities-are-simmering-in-their-own-waste-heat-65084

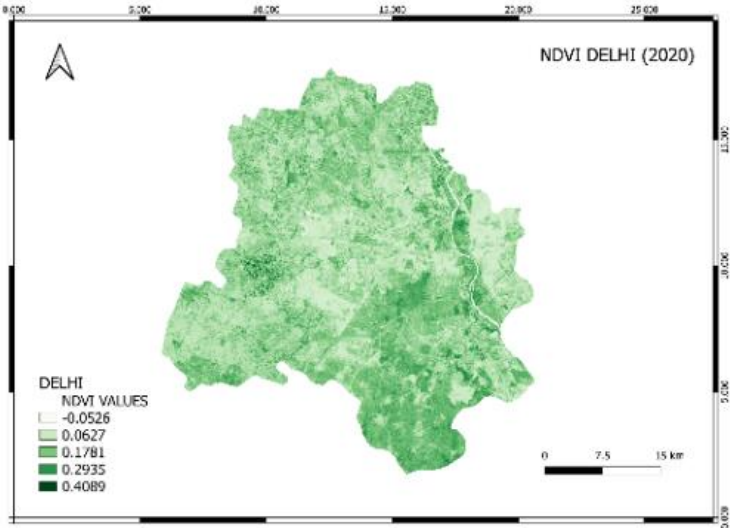


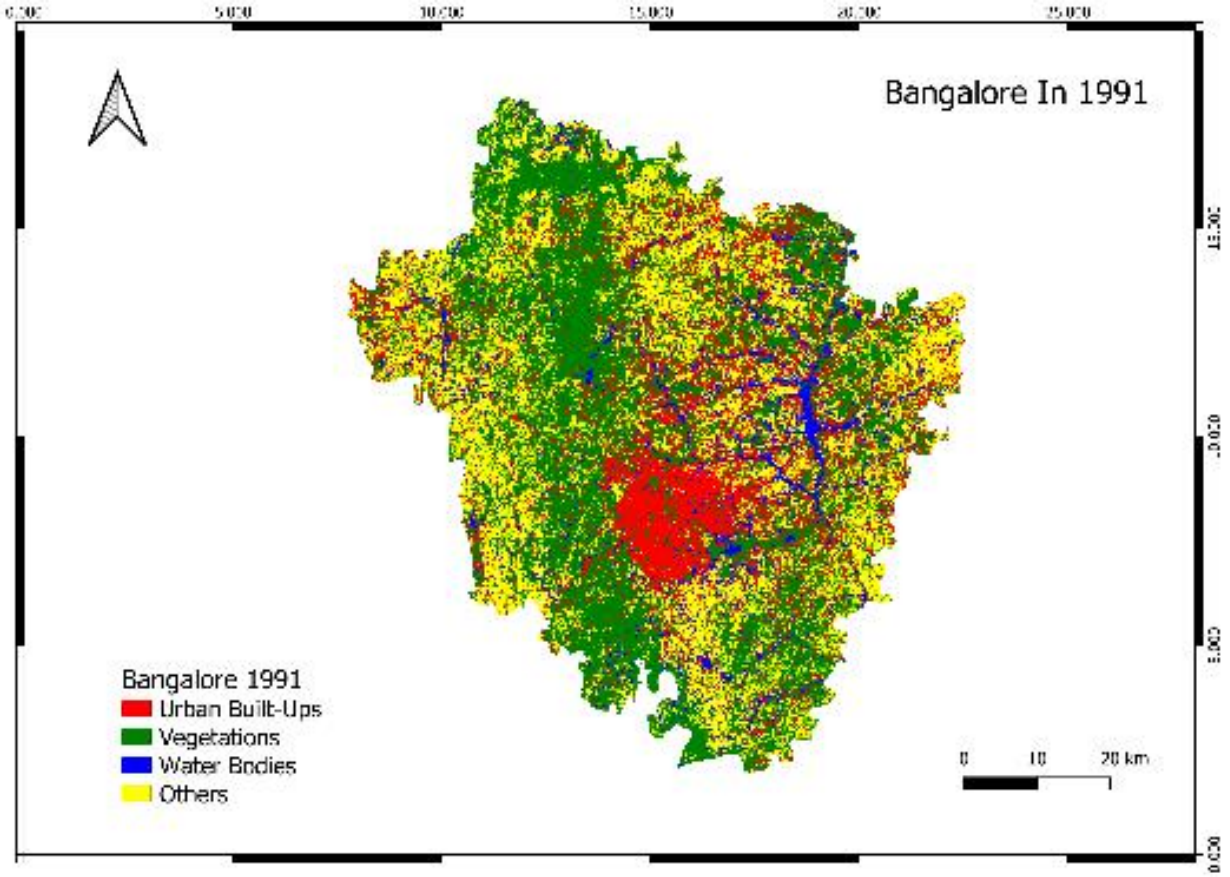
Figure 14 NDVI: DELHI

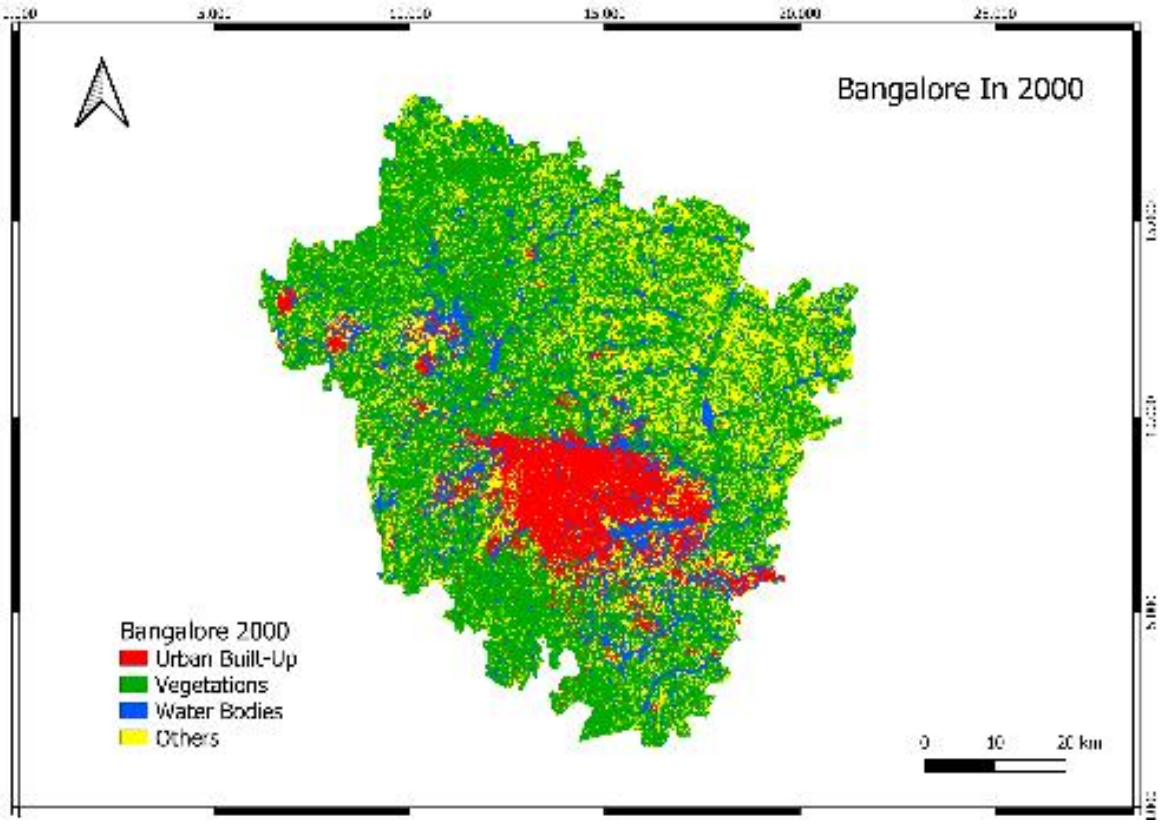
NDVI of Delhi is classified into five categories as shown in the map, negative value of NDVI shows the water bodies and built-ups areas while positive value more than 0.3 has shown the vegetation. NDVI Value from 0.3 to 0.4 has moderate and above 0.4 means densely and healthy vegetations pattern. Here in Delhi, we can see the highest value of NDVI in 1992 is above 0.5 and similarly in 2000 the value is above 0.5 but in 2020 the value is decreased to 0.40 which shows the reduction of densely and healthy vegetation.

In Delhi the green cover increased as we can see in the map but the densely forest and healthy vegetations decreased at very large rate from NDVI value 0.54 in 2000 to 0.4 in 2020. This means the reduction and conversion of Densely vegetations into moderate vegetations and no vegetation or Urban built-up as we discussed above in LCC graph around 115.60 Km of land converted from vegetation to Urban give significant indication of environmental exploitation and deforestation due to urban expansion.

BANGALORE

UNDERSTANDING THE URBAN PATTERN





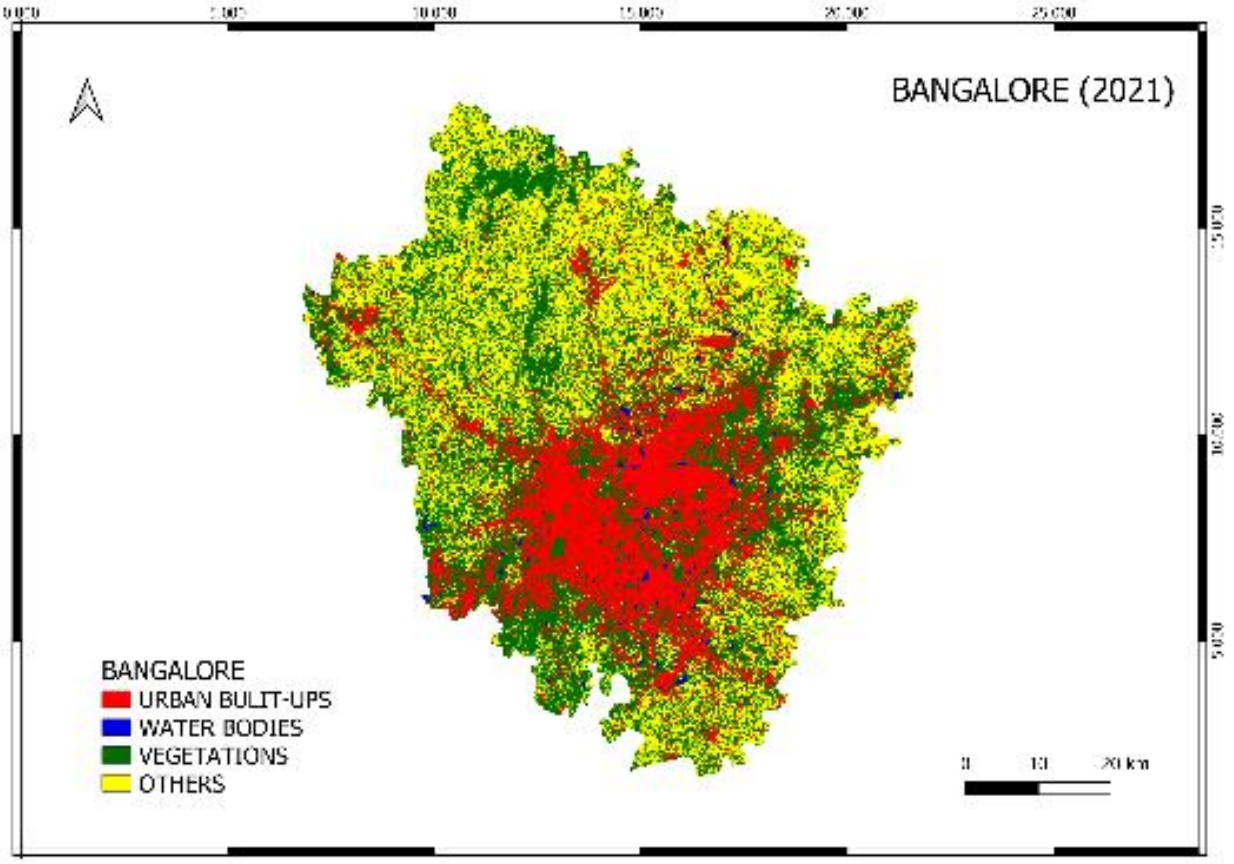


Figure 15 BANGALORE: URBAN PATTERN

Bangalore is 3rd most populous city with total 8,520,435 urban population, Urban expansion in Bangalore is more like Linear development expansion in map we can see that from 1991 to 2000 the urban sprawl and infillings occurred and then linear expansion from 2000 to 2021. This implies that, from 1991 to 2000 the expansion of urban pattern is scattered or sprawl and then from 2000 to 2021 the sprawl and scattered urban pattern connected through linear urban expansion, which means it is connected via Transportation and urbanization expand around that linear transportation system (i.e., roads, highways and metro etc.).

if we analyze the Land change pattern of Bangalore since past 20 years, we can see that more than 1000 km of lands are converted into others categories (barren, agricultural etc.) from vegetations and further in the same year 262 Km of others categories land converted into urban space. Even direct conversion of vegetation into urban is also very high (358 Km). This leads a very unsustainable growth of Bangalore city and further creates huge problem to the urban climate.

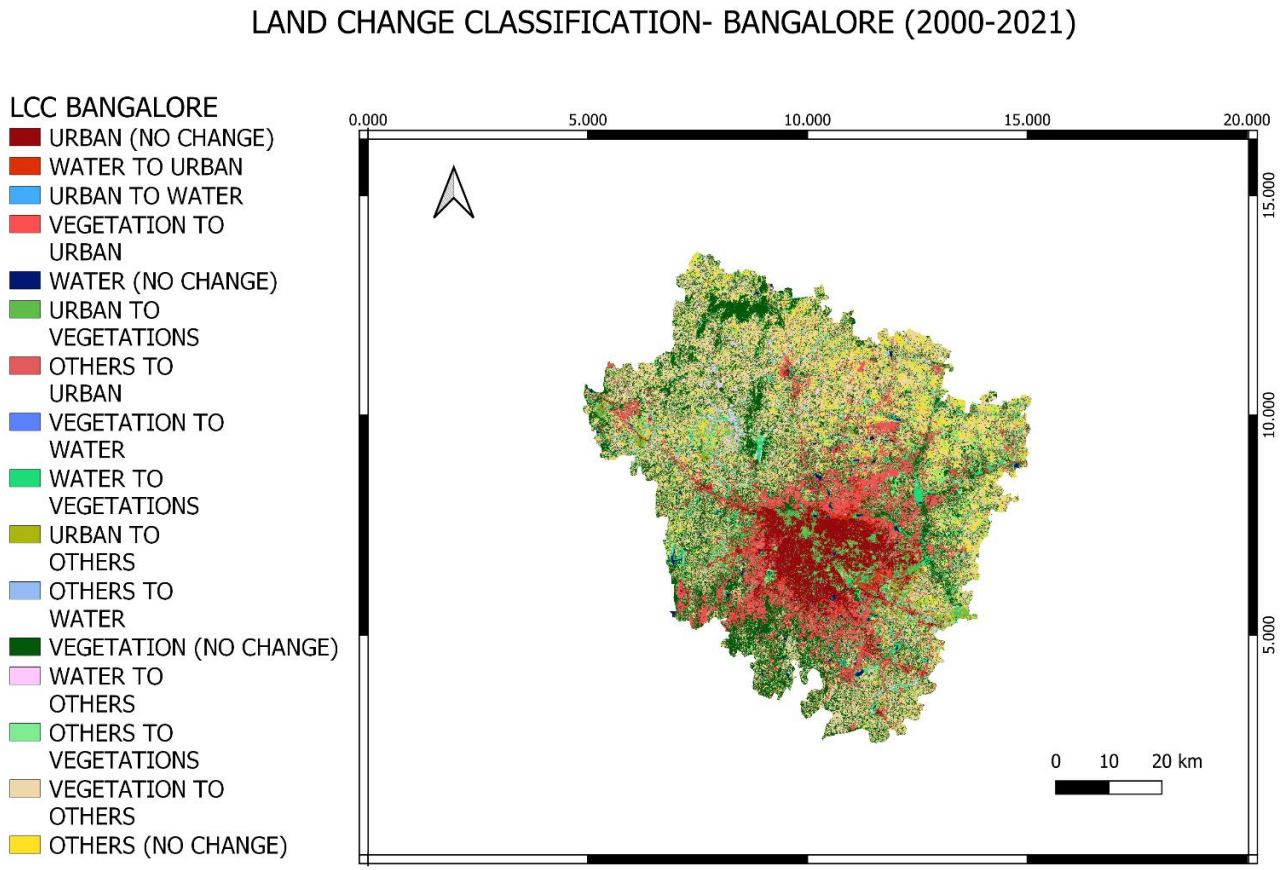
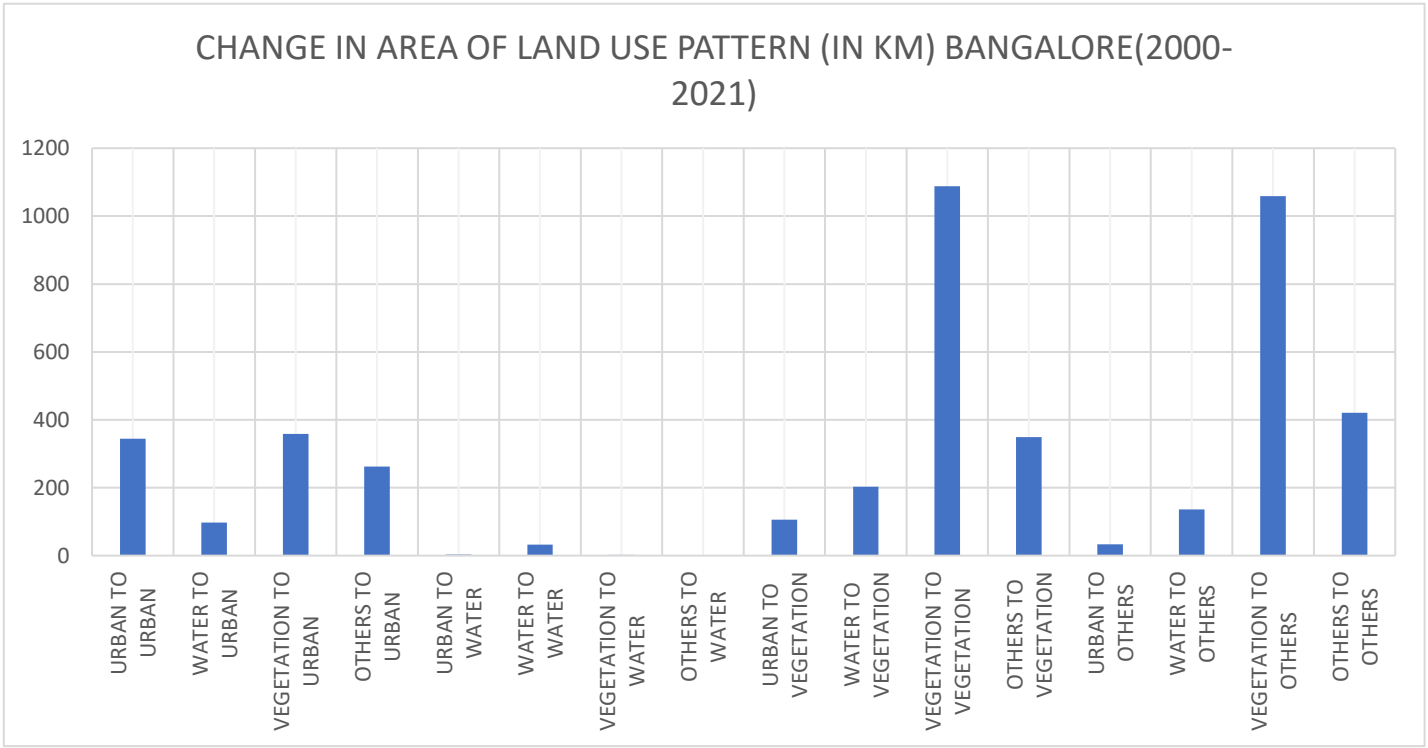


Figure 16 BANGALORE: LULC MAP

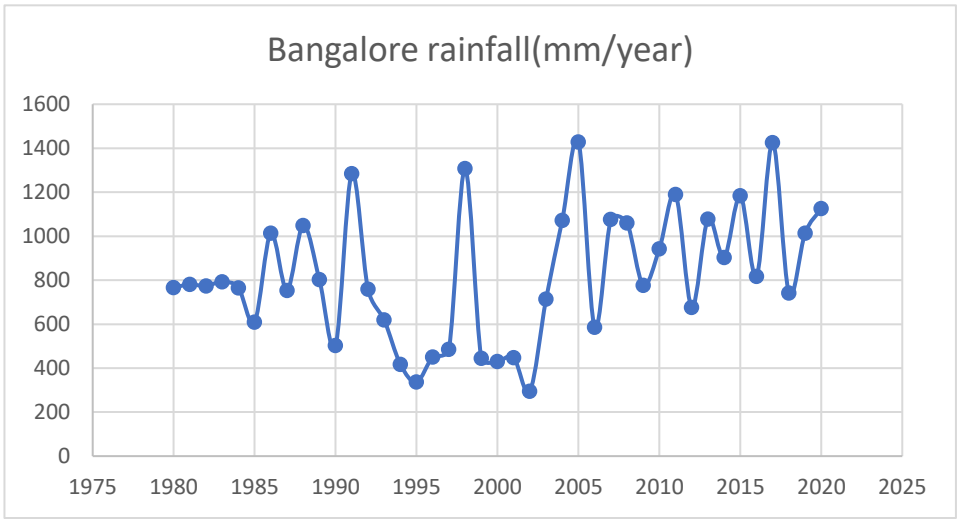


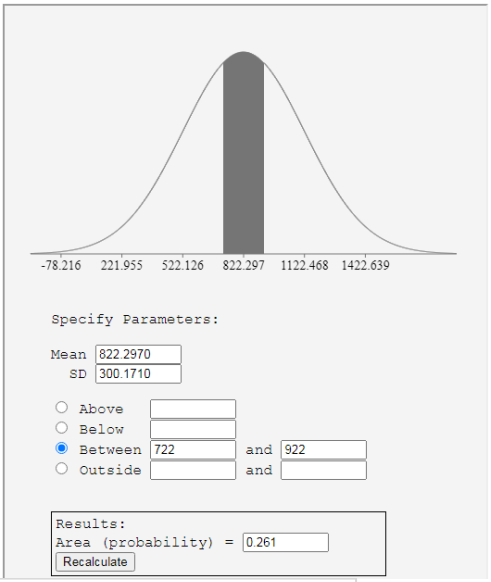
Graph 5 BANGALORE: LULC

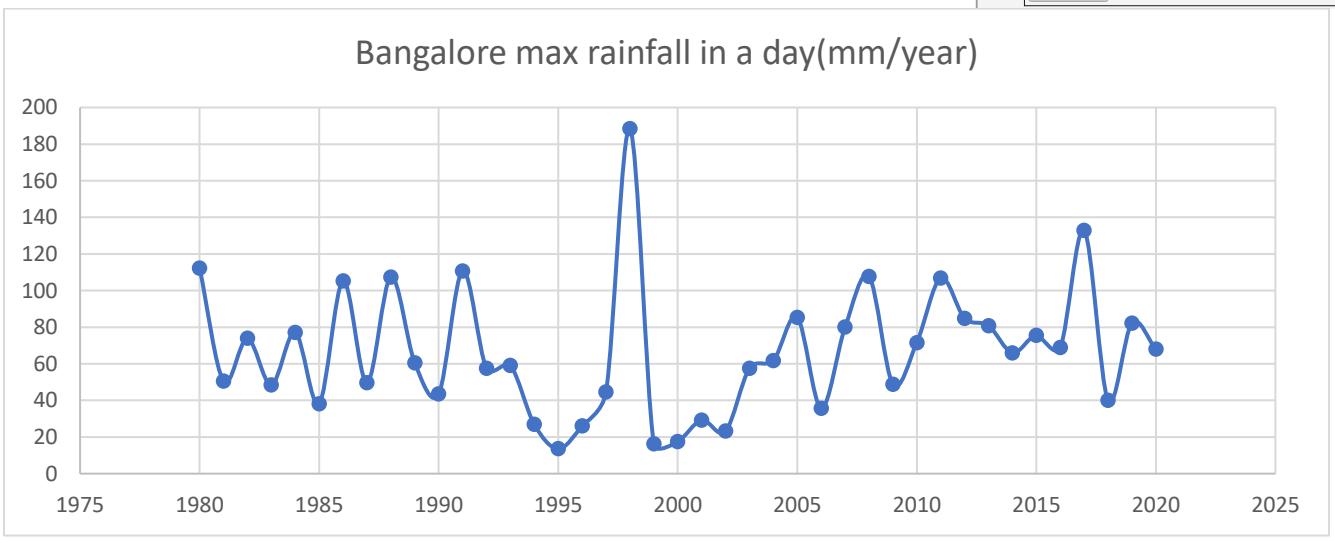
CLIMATE VARIABLE AND UNSUSTAINABILITY

RAINFALL

Rainfall pattern of Bangalore first decreased from 1980 to 2000 and then it is increasing since 2000 as we can see in the graph of total rainfall. The extreme events in rainfall pattern are increased from 1990, where large deviation in between the consecutive years can be seen.



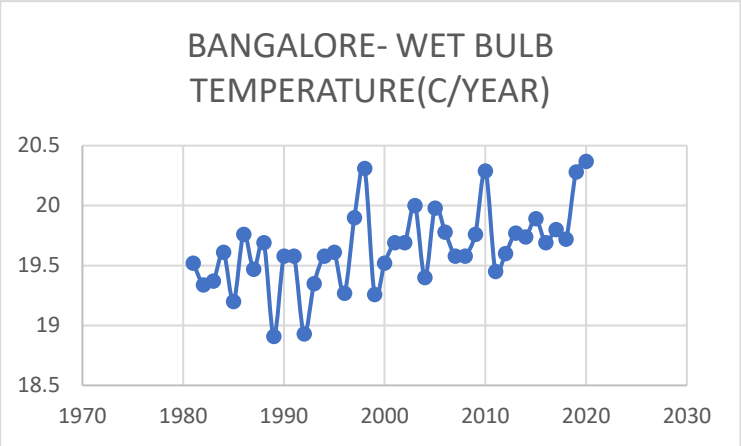


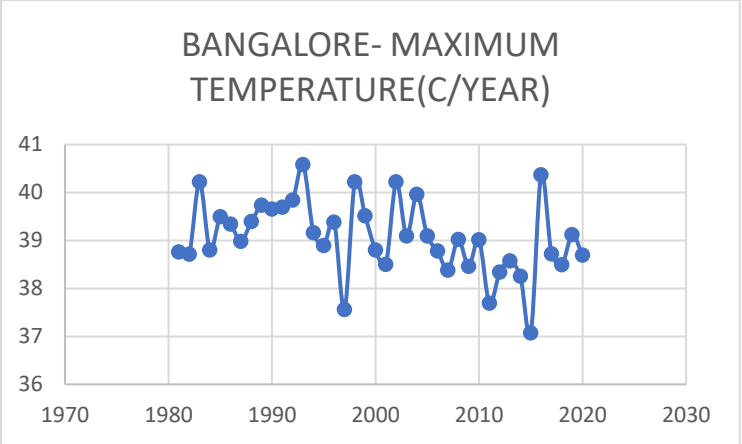


Graph 6 BANGALORE: RAINFALL

From standard deviation or normal distribution curve we can see the mean value of rainfall is 822 mm/year but only 26.1% of 40 years rainfall lies in between 100 mm deviation from both tailed ends. This means the extreme weather condition is very high in Bangalore in consideration to rainfall, from graph of maximum rainfall in a day we can see a positive trend in that in which more than 70- and 80-mm rainfall in a day. This cause unsustainability and frequent urban flooding situation in Bangalore and it will more frequent in upcoming year as data and graphs could predict.

TEMPERATURE



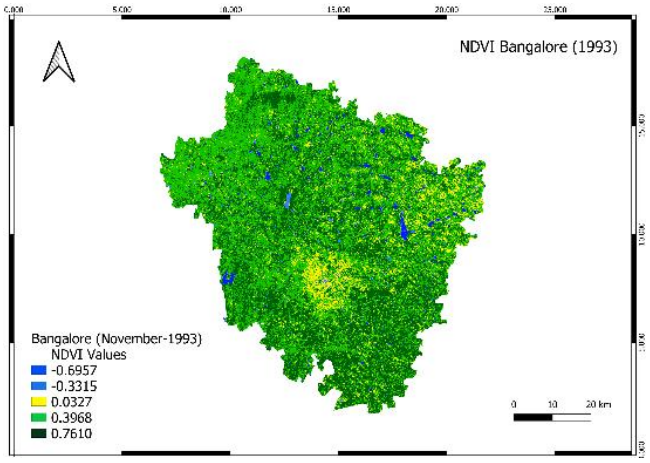


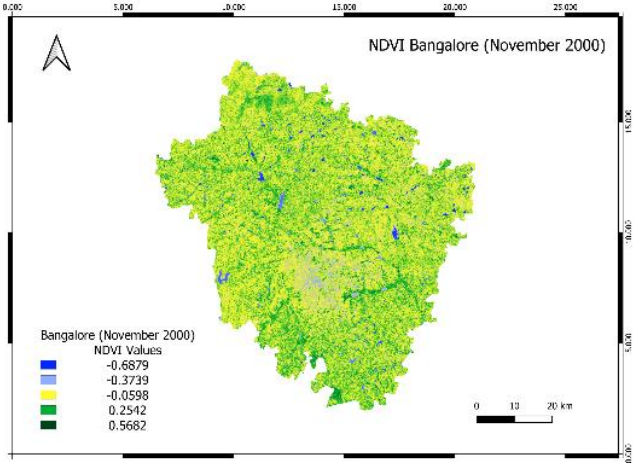
Graph 7 BANGALORE: WBT

Increasing trend of WBT at the same time decreasing trend in maximum temperature implies the greater role of humidity and wind speed variables which means even maximum temperature decreasing but still the humidity increasing and wind speed in cities gets decreases and cumulative effects of all this cause for increasing trend of WBT, and the deviation is very high from 19.5 to 20.25 in between 20 Years of time period.

As per the Paris agreement 1.5 degree Celsius from pre industrial level is our maximum limit or goal, but in a recent released report of IPCC tells that around 0.9 degree Celsius we already reached. So, limiting the temperature within the permissible range is vey important because it has multiplier and domino effect, not only on human health or environment but economical and sustainable development also.

NDVI





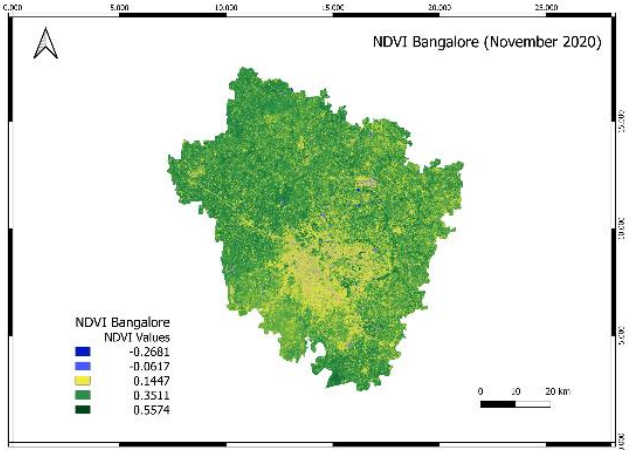


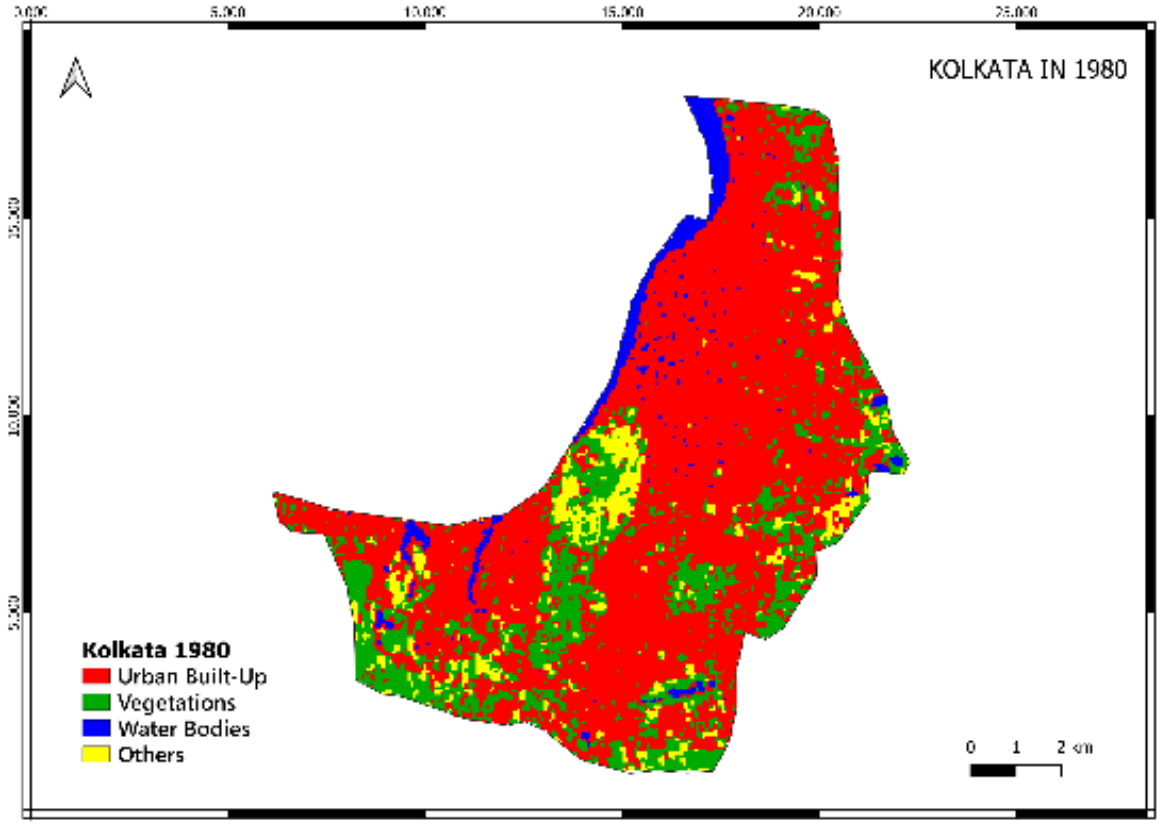
Figure 17 NDVI: BANGALORE

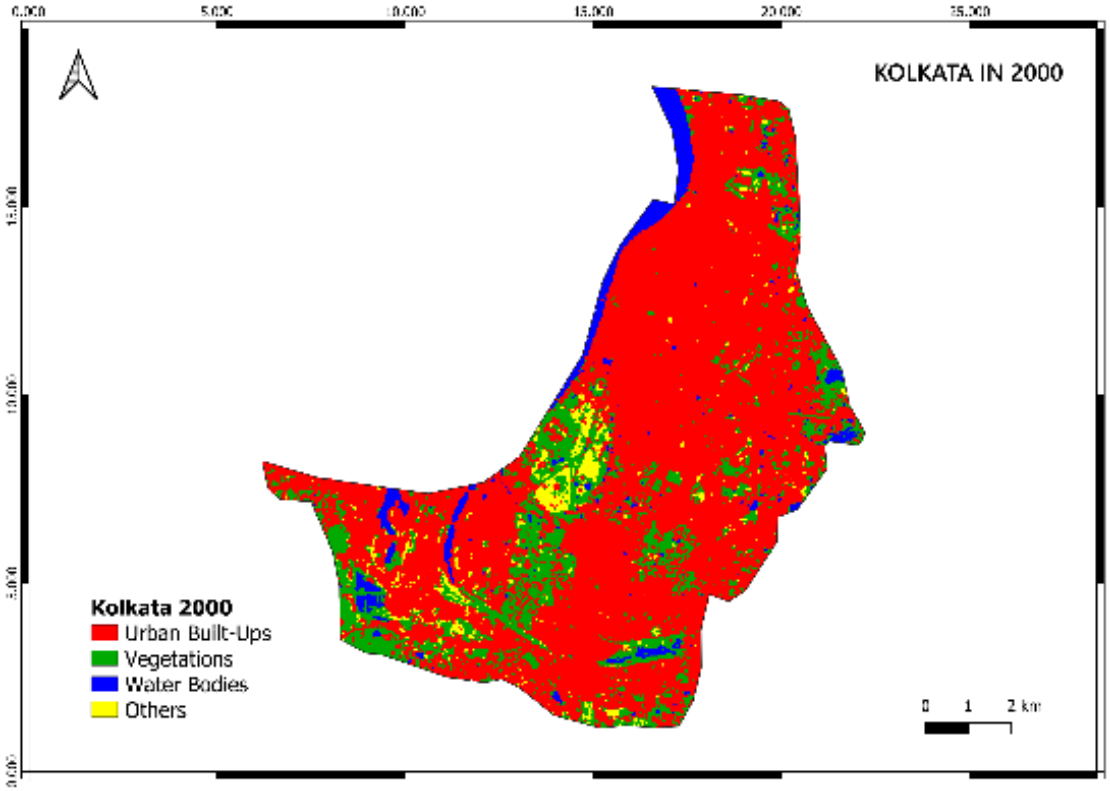
In Bangalore, we can see the decreasing trend of maximum NDVI value from 0.76 in 1993 to 0.56 in 2000 while in 2021 the value is 0.55.

This trend of NDVI means between 10 years of 1990 to 2000 the rate of decreasing of densely vegetation of Bangalore is very high but between 20 years of 2000 to 2020 the decrease rate of densely vegetation is low. This implies that in the recent years Bangalore performed well to reduced deforestation rate, we can see that in LCC map the Bangalore increased its urban vegetation which means in between the urban pattern there is dense scrubs, plants, trees and gardens which can be called as Urban Forest. This helps to make a city more sustainable and ecofriendly.

KOLKATA

UNDERSTANDING THE URBAN PATTERN





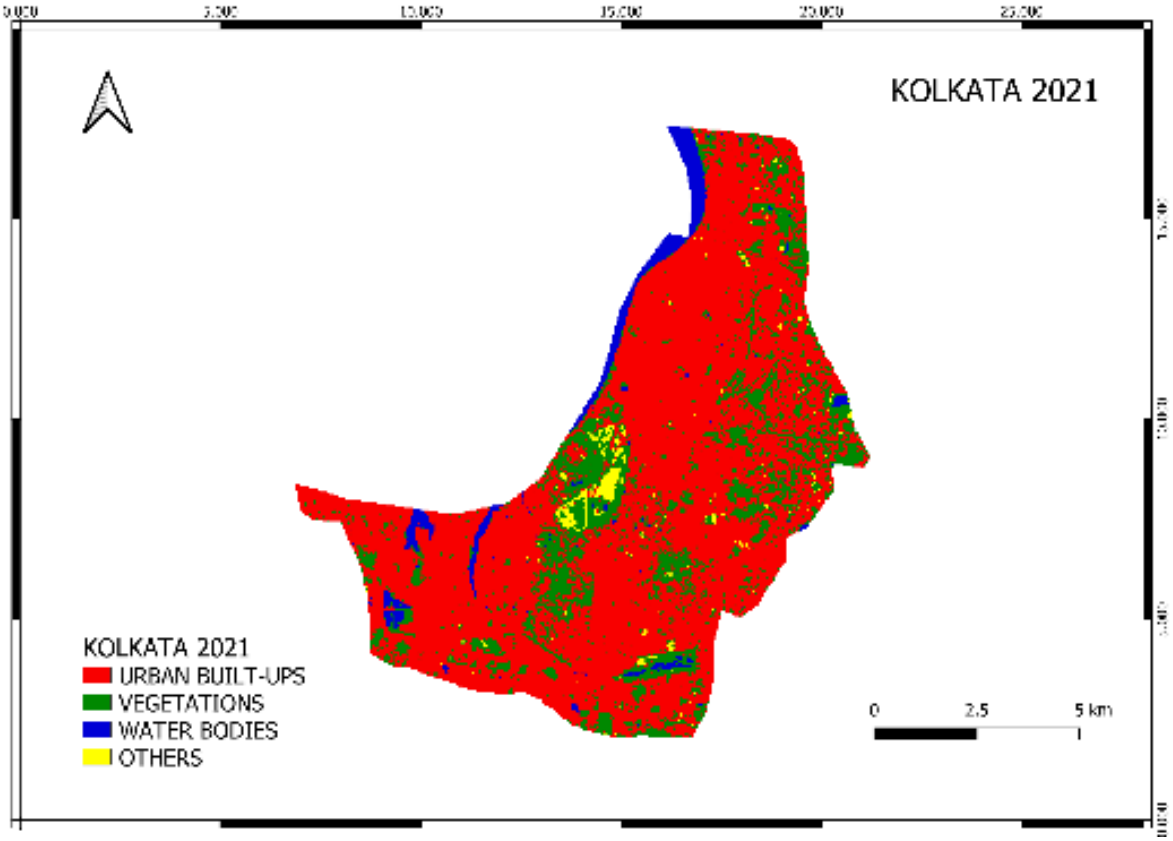
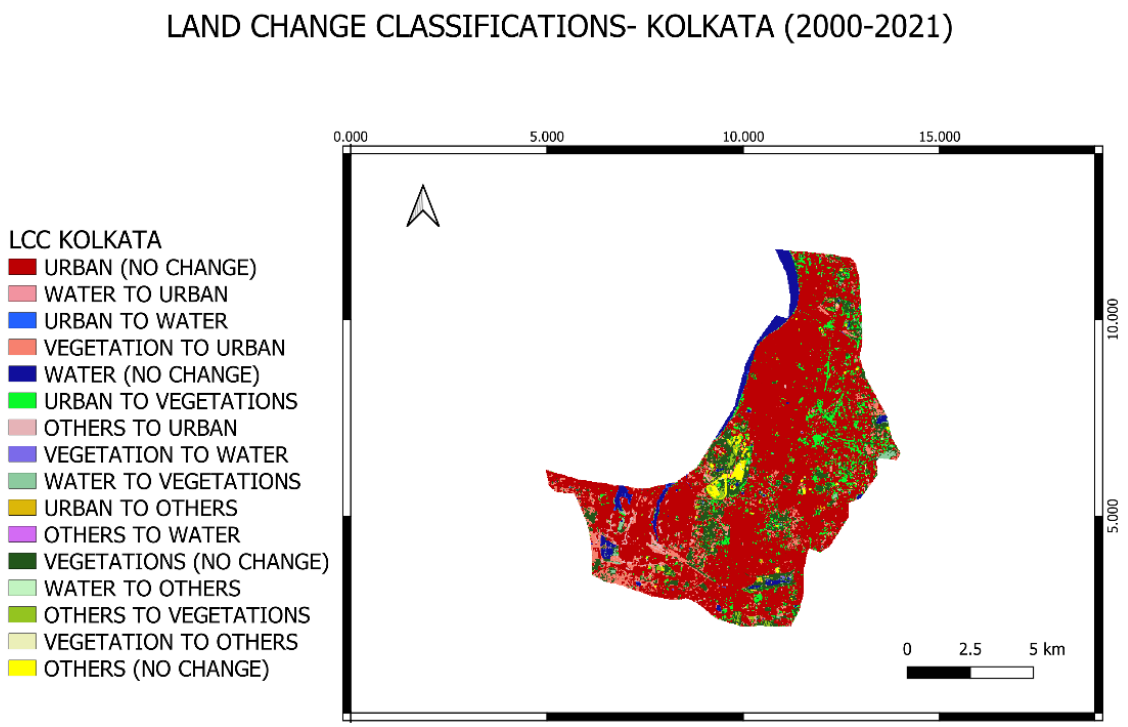


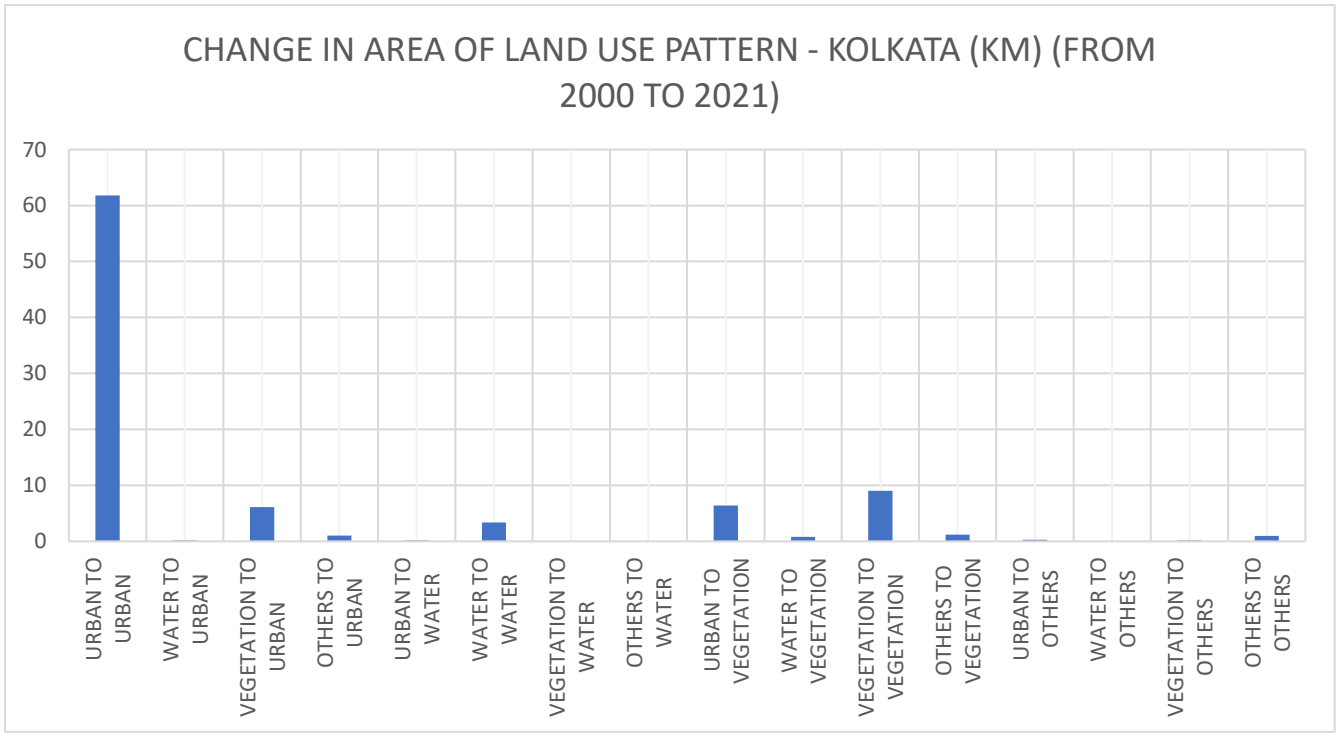
Figure 18 KOLKATA: URBAN PATTERN

Kolkata is one of the oldest cities of India, and population is 4,49,6694 which makes Kolkata at 7th rank in population but 3rd in population density. which is urbanized from the colonial period. Here in the pattern, we can see the densely urbanized since 1980. Urban agglomeration pattern in Kolkata is combined pattern, which means pattern of Urban sprawl with infilling pattern. One of the reasons to develop dense Kolkata is better and affordable transportation system from its early ages, which further helps to connect these sprawl and infillings.

Here in map of LCC and graph of changes from 2000 to 2021 we can see the largest proportion of area is preoccupied Urban pattern that is 61 Km in 2000 and 69 Km in 2021. With total area of 91 Km of Kolkata. This means 76% of the total area is covered with the urban built-ups and only 10 km land has vegetation this number of ratios is very critical for the environment and human health of that cities.

Due to such increased unsustainable and dense population problem, Kolkata initiated “Operation Sunshine” in 1996 to remove hawkers and illegal setters which was not a good decision and again 2003 Kolkata initiated removal of illegal slums and beautification of city but still the core problem is sustainability and urban engineering.

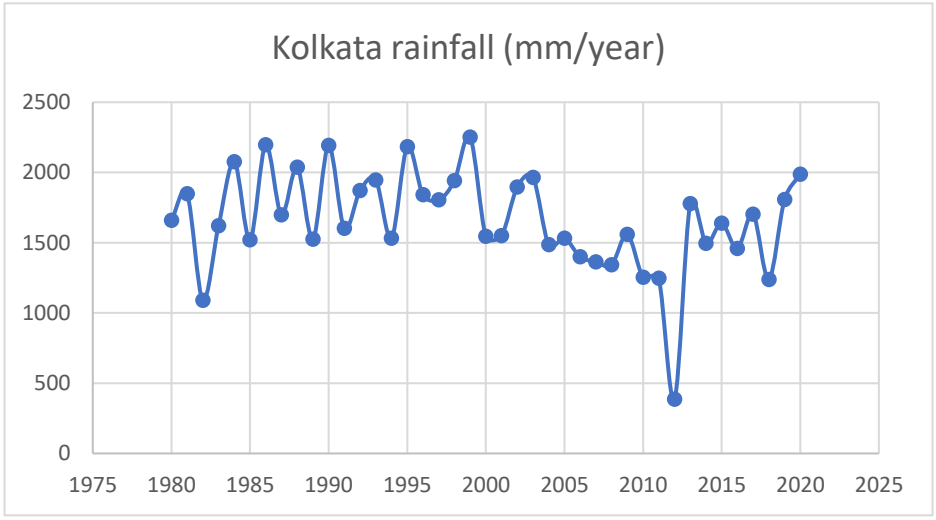




Graph 8 KOLKATA: LULC

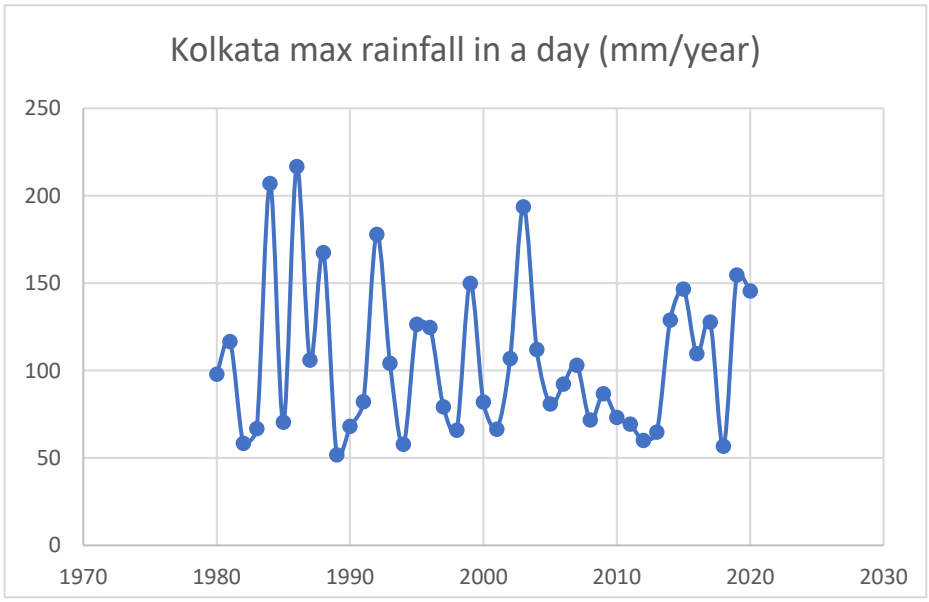
CLIMATE VARIABLE AND UNSUSTAINABILITY

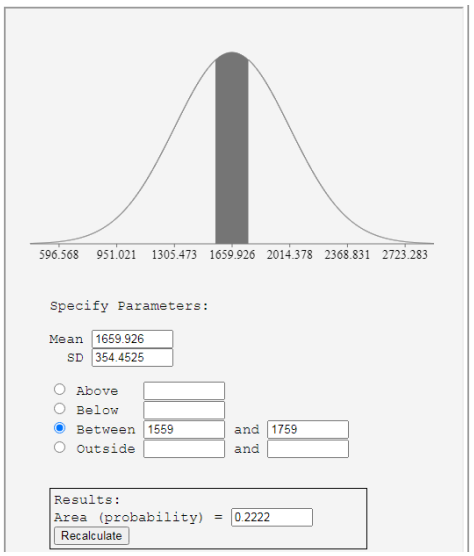
Rainfall



Kolkata in between 2003 to 2012 experienced decreasing trend of rainfall and again from 2013 it experienced highest after 10 years. Kolkata is experienced high rainfall due to monsoon, ganga River and near costal zone area. If we analyze the past 5-year data of rainfall we can find the high deviation. From the SD and normal distribution graph Kolkata witnessed low deviation and less extreme rainfall condition only 22% of 40 years rainfall data, and in last 5 year the deviation is very high which cause for extreme rainfall condition and further cause urban flooding and many other problems.

[9]Urban flooding may be caused due to various physical, social or infrastructural factors, of which intensive precipitation is the most dominant. Kolkata's drainage system is very old and regular siltation has reduced its carrying capacity; hence, heavy precipitation often leads to urban flooding. This paper attempts to critically assess urban flooding.

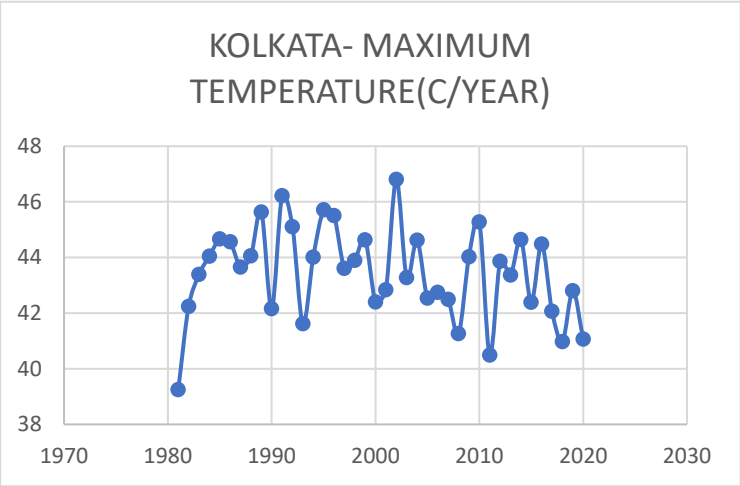


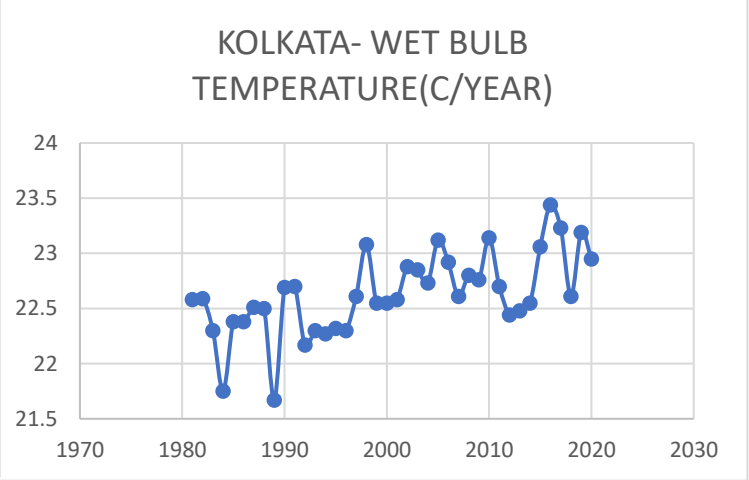


Graph 9 KOLKATA: RAINFALL

[9]https://www.researchgate.net/publication/324056002_Precipitation_Trends_in_the_City_of_Kolkata_and_Its_Implication_on_Urban_Flooding/figures

TEMPERATURE





Graph 10 KOLKATA: WBT

There is strong correlation between the temperature and Humidity in case of Kolkata urban pattern where WBT is way more than all other cities of this Research sites.it is increasing since 1990 with large deviation 2010 onwards. While at the same time the maximum dry bulb temperature shows decreasing trend in another graph.

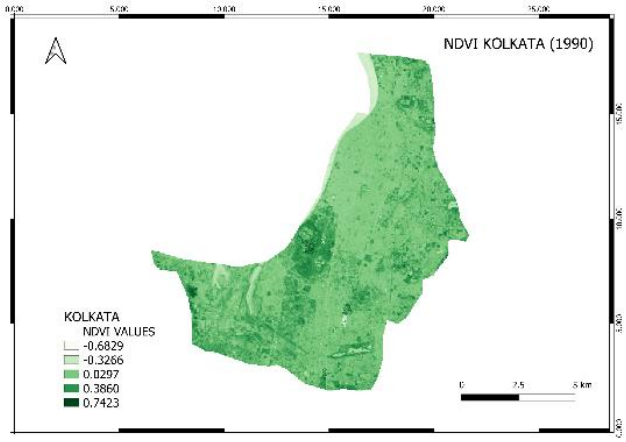
Recently IPCC released its AR 6 report in which Kolkata is more heat stressed and worst temperature rise in between seven decades. More than 2 degree Celsius is risen and it is one of the most heated urban in the world.

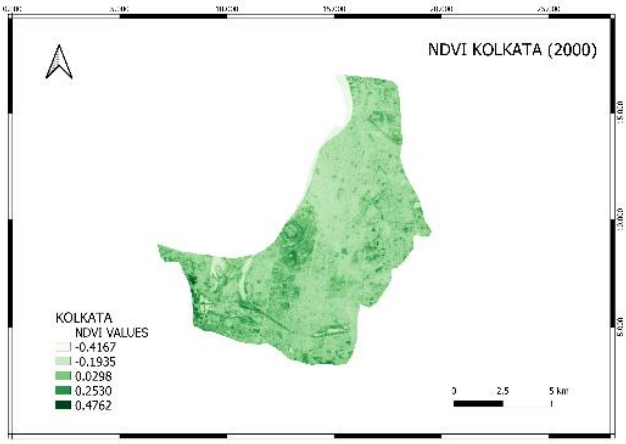
[10]The IPCC report (IPCC AR 6 WG1) explains that "urban heat island effect results from reduced ventilation and heat trapping due to close proximity of tall buildings, heat generated directly from human activities, the heat-absorbing properties of concrete and other urban building materials, and the limited amount of vegetation".

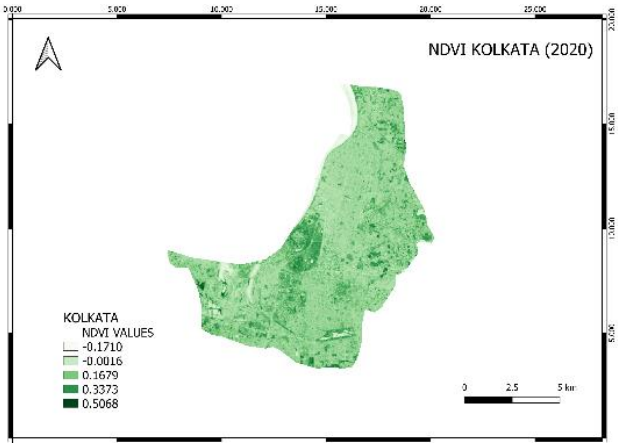
Urbanization also contributed to a rise in the city's temperature, with more than 80 per cent warming being generated within the city itself, the report said. It added that "urban centers and cities were warmer than the surrounding rural areas due to the urban heat island effect".

[10] https://www.telegraphindia.com/my-kolkata/news/kolkata-heat-rise-worst-in-world-ipcc-global-warming-report-finds/cid/1828694

NDVI





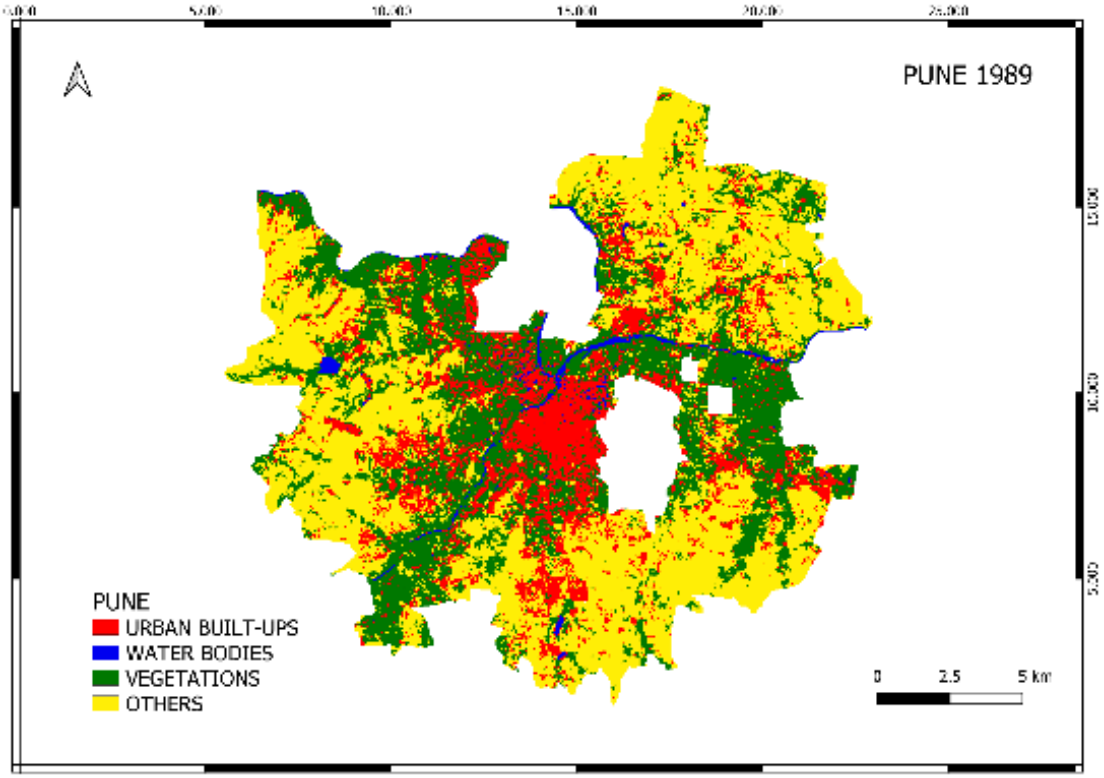


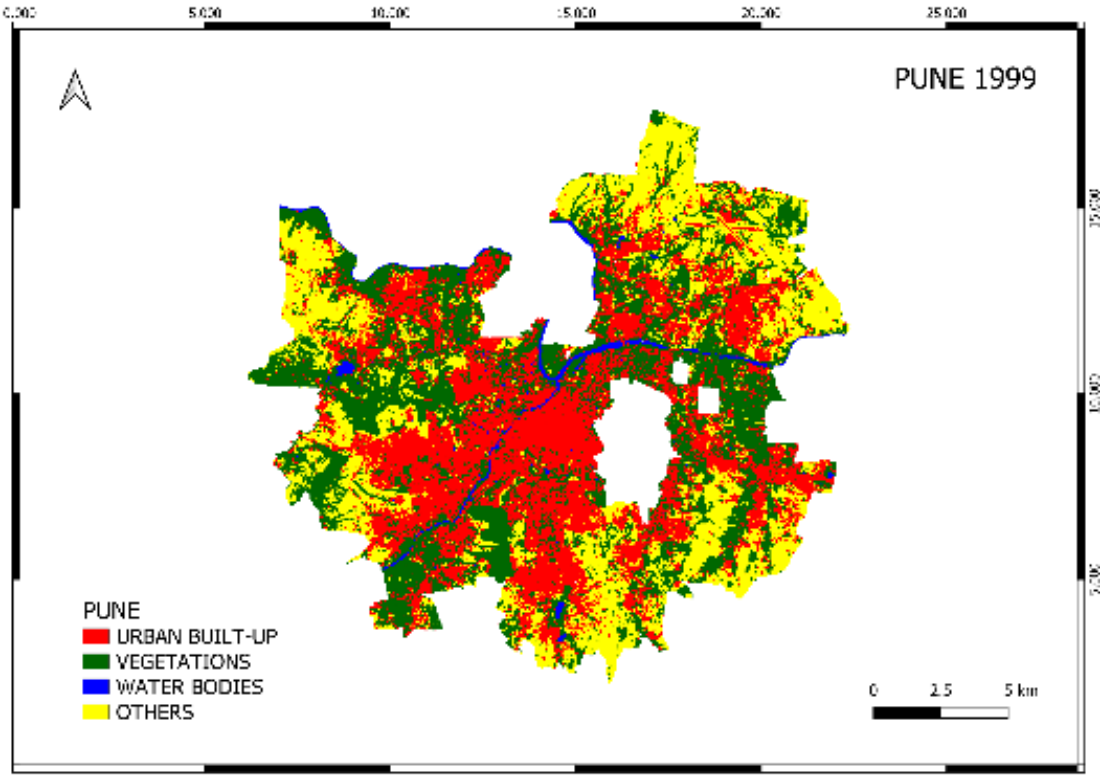
NDVI value is affected at both ends, either in minimum NDVI or Maximum NDVI, minimum NDVI value is reduced from -0.6 in 1990 to -0.17 in 2021, which means the water bodies is also affected during this time period. if we talk about vegetation then maximum NDVI value in 1990 is 0.74 which tell about dense vegetation zone which further reduced to 0.47 in 2000 and then from 2000 to 2021 we can see little improvement 0.5 in 2021. But small improvement cannot benefit the day by day increased urban population.

Figure 20 NDVI: KOLKATA

PUNE

UNDERSTANDING THE URBAN PATTERN





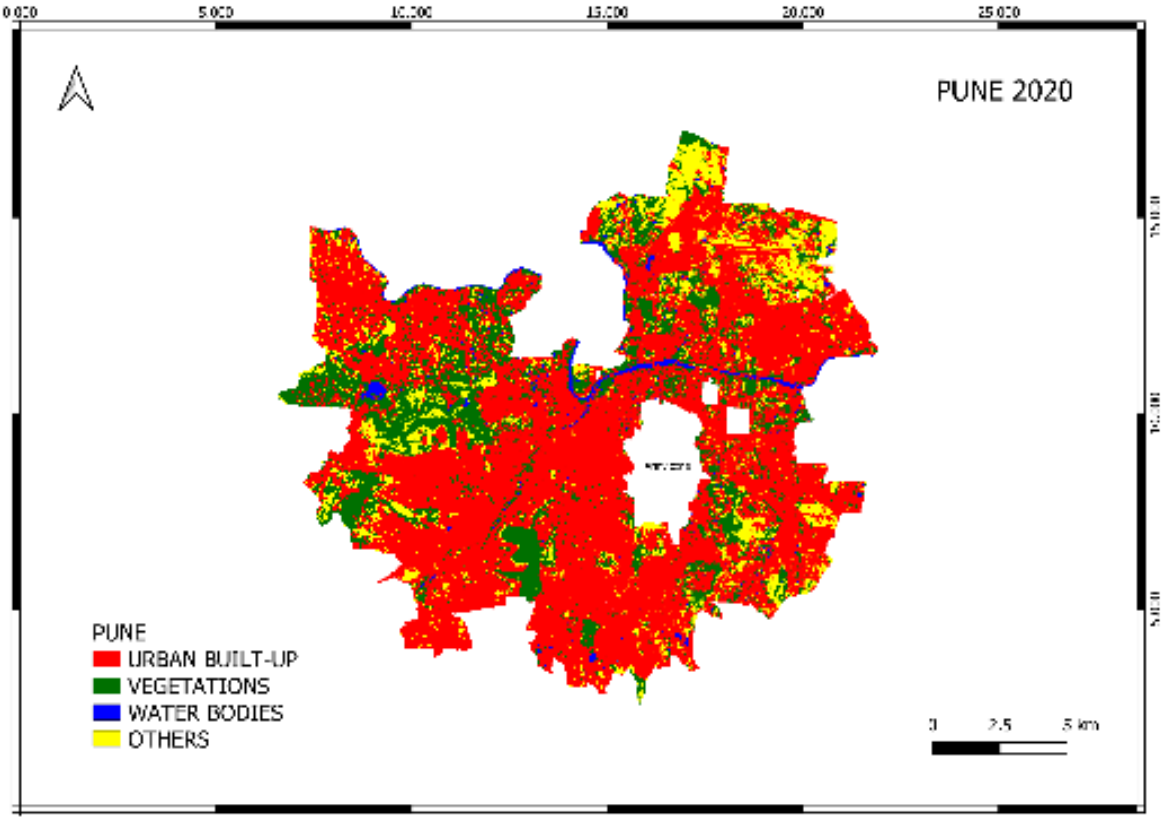


Figure 21 PUNE: URBAN PATTERN

Pune is seventh most populous city of India with population of 3,124,458.

Urban pattern of Pune is urban agglomeration with central radial pattern, this implies that transportation plays a great role to connect the urban sprawl.

From 1980 to 2020 the change in built-ups area is very huge as we can see in the urban graphs above.

To analyze little deeper to the change pattern between 2000 to 2020, from graph we can see that 41.5 km area of vegetation land converted into urban built-ups in between 20 years, while in same time period 42 km land of agriculture and barren land converted into Urban built-ups. And total change in urban built-ups from 82.79 km in 2000 to 167.25 km in 2020, which is doubled in 20 year of time period.

change pattern of other to urban is very common where barren land and agricultural land converted into urban-built-ups easily this is why usually, vegetation converted into others first and then into urban built-ups but here in Pune we can see the large portion of vegetation is directly converted into urban pattern rather than others than urban. It is because of Pune had large area of vegetation rather than barren and agricultural land so direct conversion of vegetation can be seen here in Pune. This change pattern suggests that the weak and low level of governance in Pune to regulate and protect the vegetations. [11]In between these years Pune district loss its 30000 acre of forest land and large urban forest.

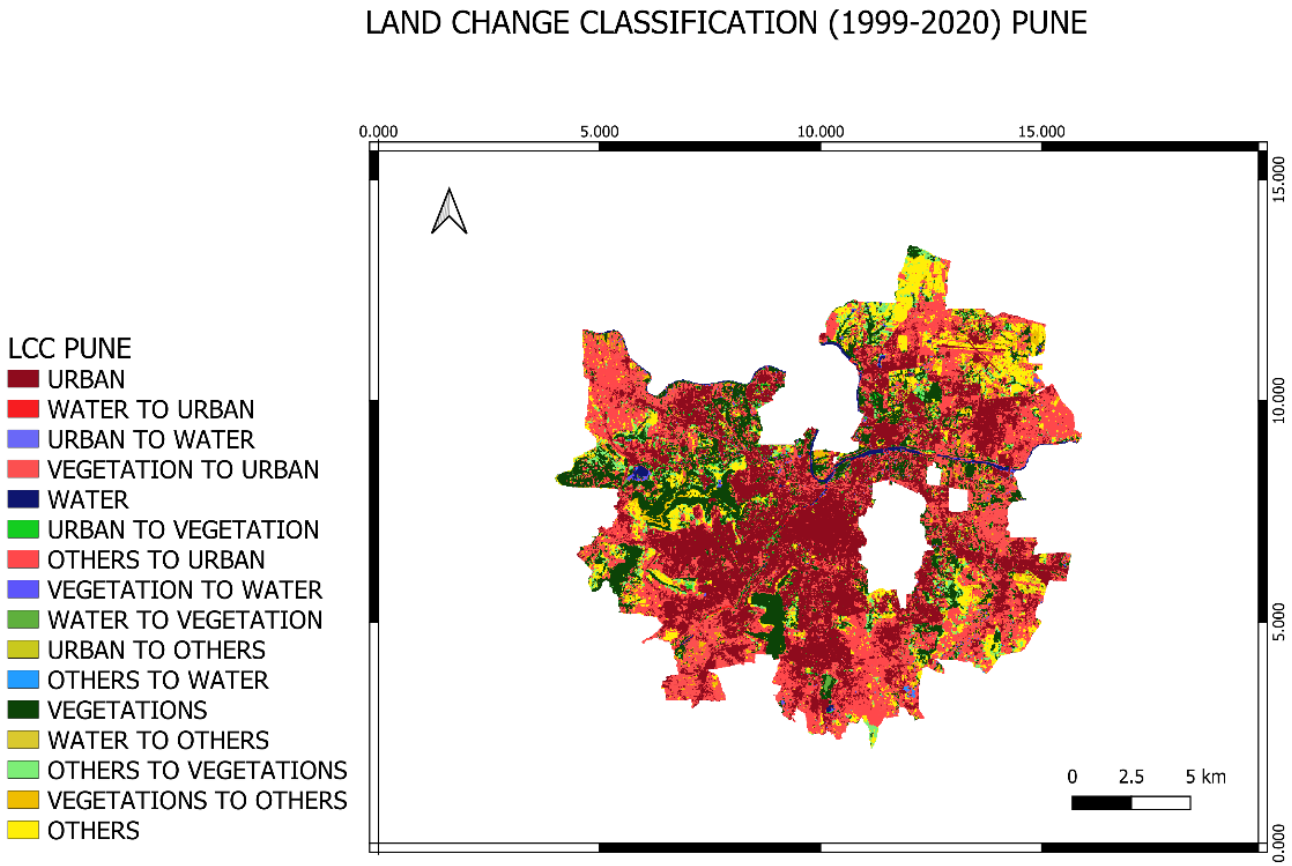
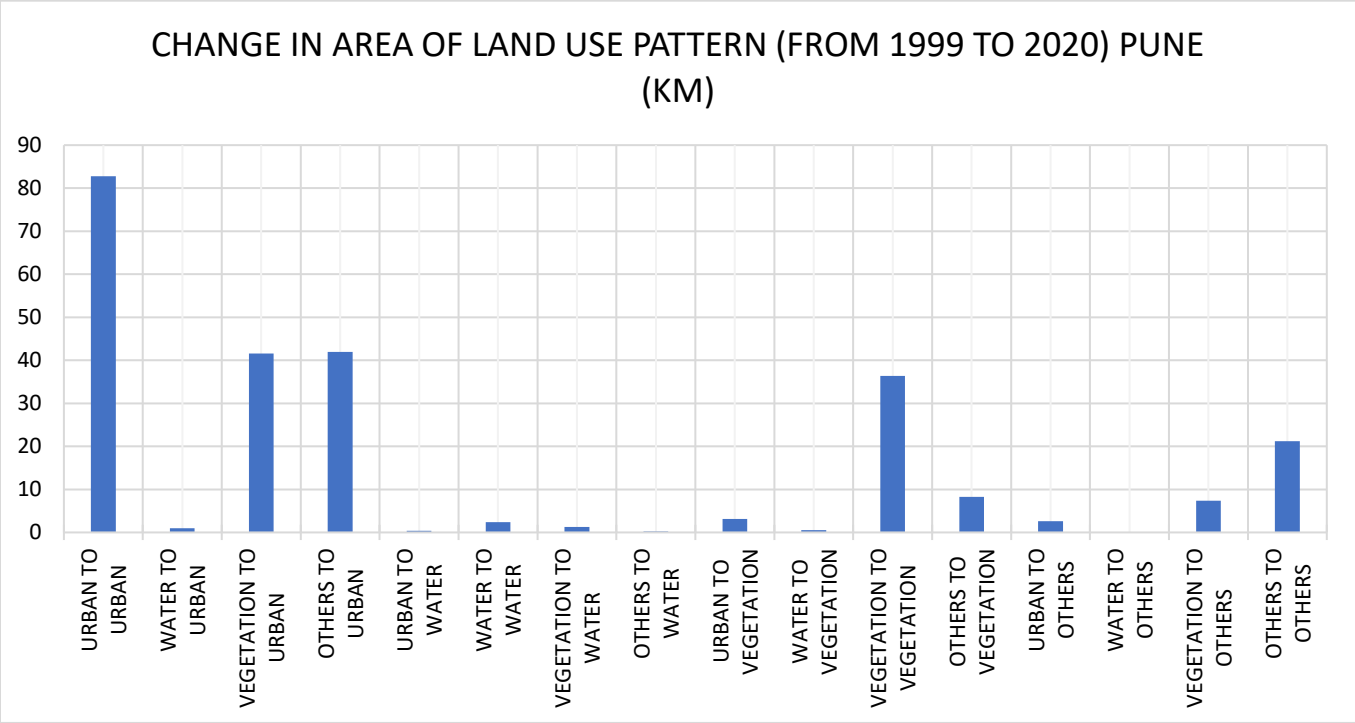


Figure 22 PUNE: LULC MAP

[11] https://www.hindustantimes.com/pune-news/pune-has-lost-30-000-acres-of-forest-land-says-deputy-conservator-of-forests/story-lQmGdORB9C3MYBNL2AFWxJ.html



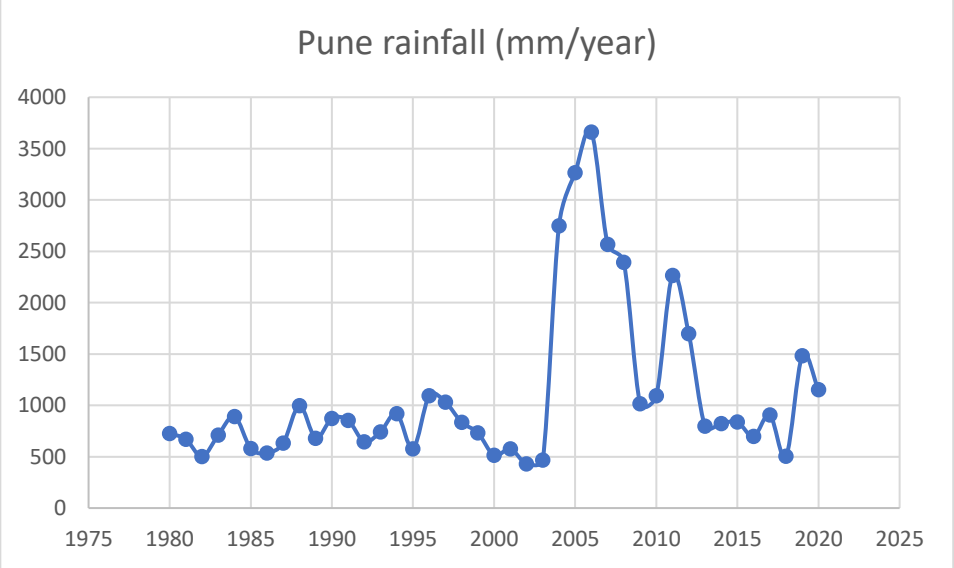
Graph 11 PUNE: LULC

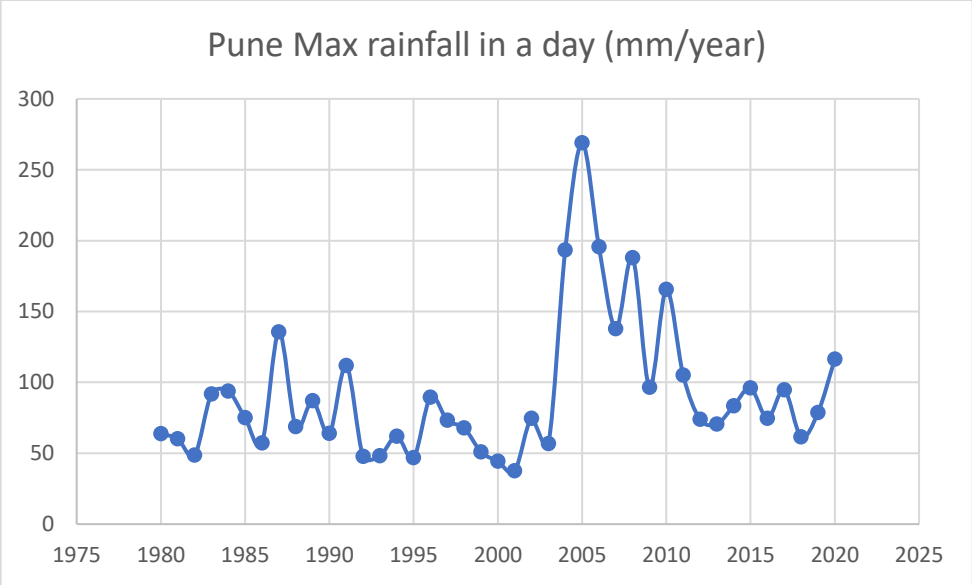
CLIMATE VARIABLE AND UNSUSTAINABILITY

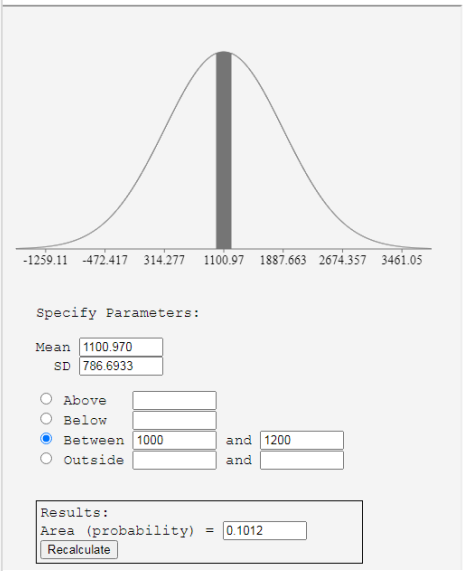
RAINFALL

Rainfall pattern of Pune is deviated from 500 mm to 1000 mm between 1980 to 2000 but rainfall tremendously increase from 500 to 3500 mm just in 2 years between 2003 to 2006, This is very disastrous 7 times more than its usual average rainfall.

The deviation is very high in Pune city which shows only 10% rainfall lies between the deviation of 100 mm from its mean value of 1100 mm average rainfall.



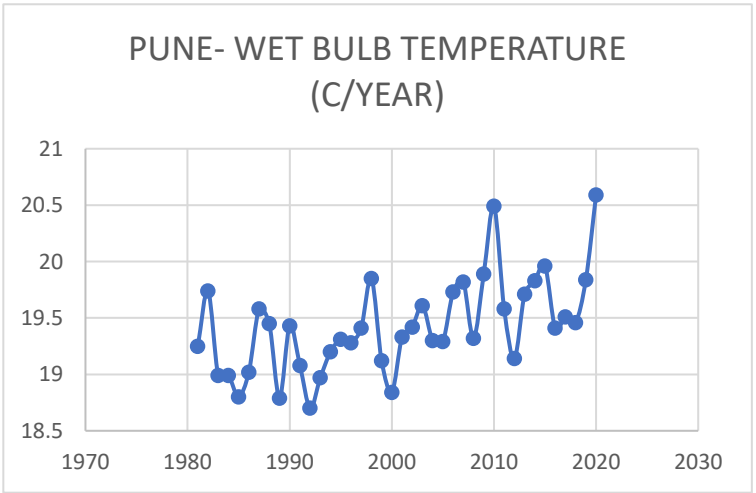


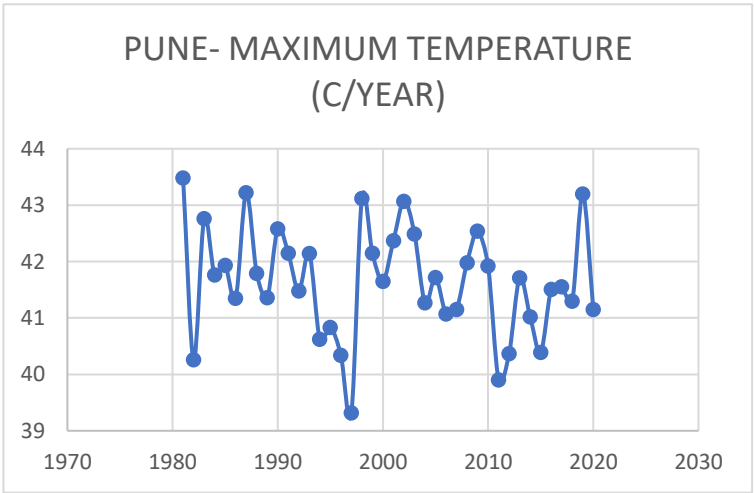


Graph 12 PUNE: RAINFALL

The deviation is very high and change in between year of 2004 to 2012 is very high this means extreme rainfall condition in Pune, as we can in one day the maximum rainfall is more than 200 in 2004, 2005 and 2006 which means in one day this much amount of rainfall occurred which is very high and unsustainable for any cities to sustain the carrying capacity of drainage system of city, this cause severe problems of Urban flood in all case Pune in these year faced very severe urban flood condition. Maharashtra state faced flooding in 2005 due to this large deviation in rainfall in one day, this cause death of more than 1000 people.

TEMPERATURE:



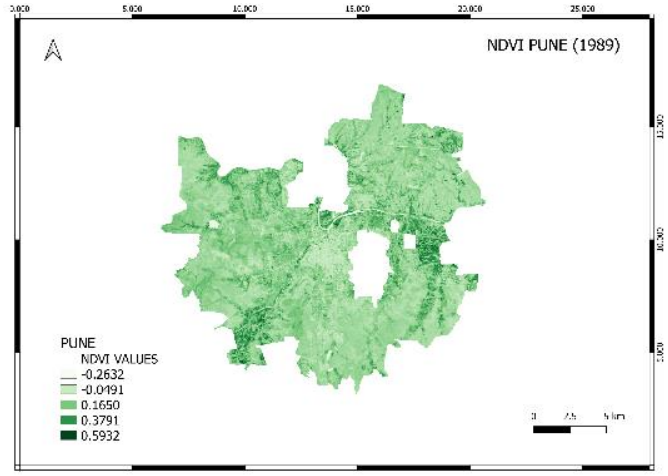


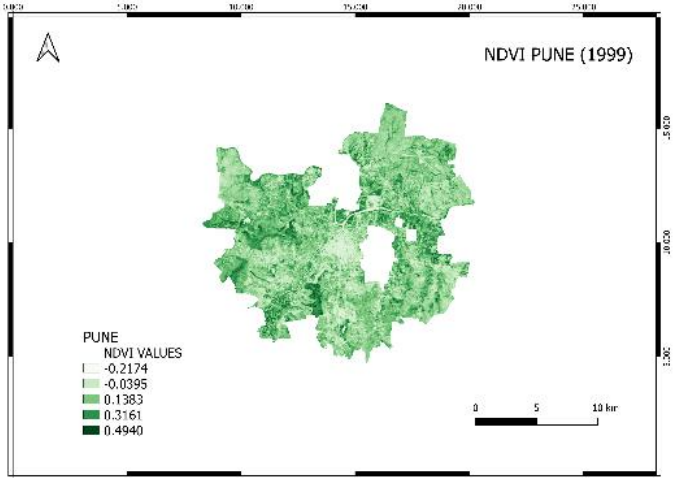
Graph 13 PUNE: WBT

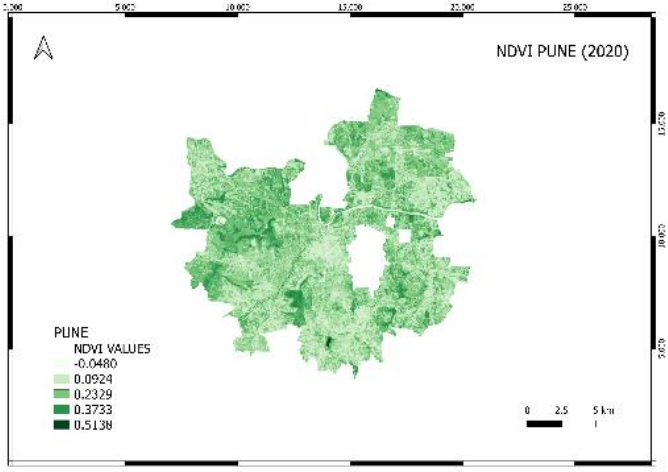
Similar to all cities, WBT of Pune has positive trend and in recent 5-year WBT increased more than 0.5 Celsius which is not sustainable at all. As in graph of WBT the temperature from 19 Celsius in 1991 to 20.5 in 2020 which

means 1.5 Celsius change in between three decades. After 2012 the change pattern is positive increasing trend and non-reversal increase

NDVI:







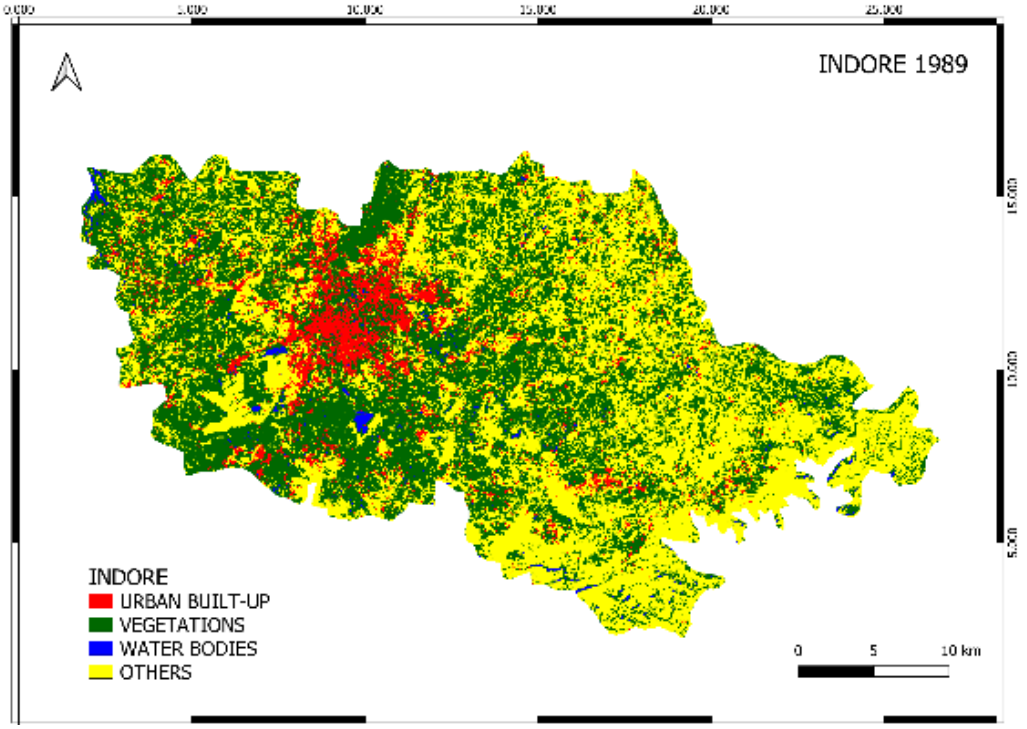
Vegetation index of Pune has decreasing trend from 1989 to 1999 and increasing trend from 2000 to 2020, the densely vegetation is increased from 2000 to 2020.

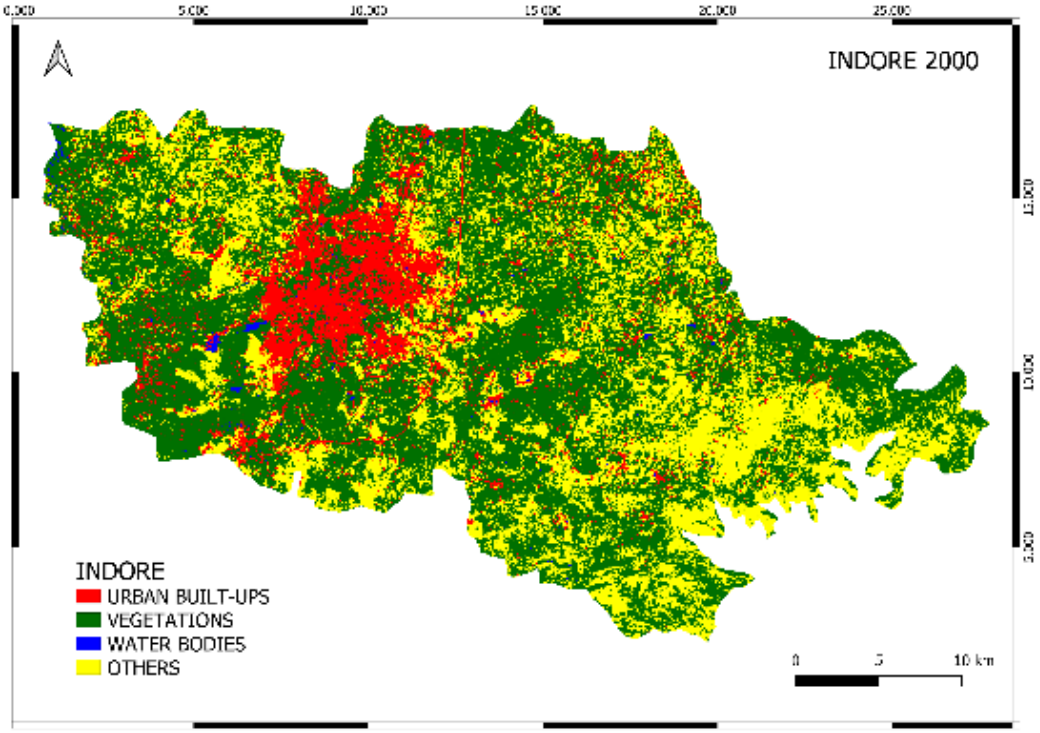
While vegetation in Pune is impacted largely because of increasing Urban agglomeration, more than 41 km of vegetation is directly converted into urban built-ups.

Figure 23 NDVI: PUNE

INDORE

UNDERSTANDING THE URBAN PATTERN





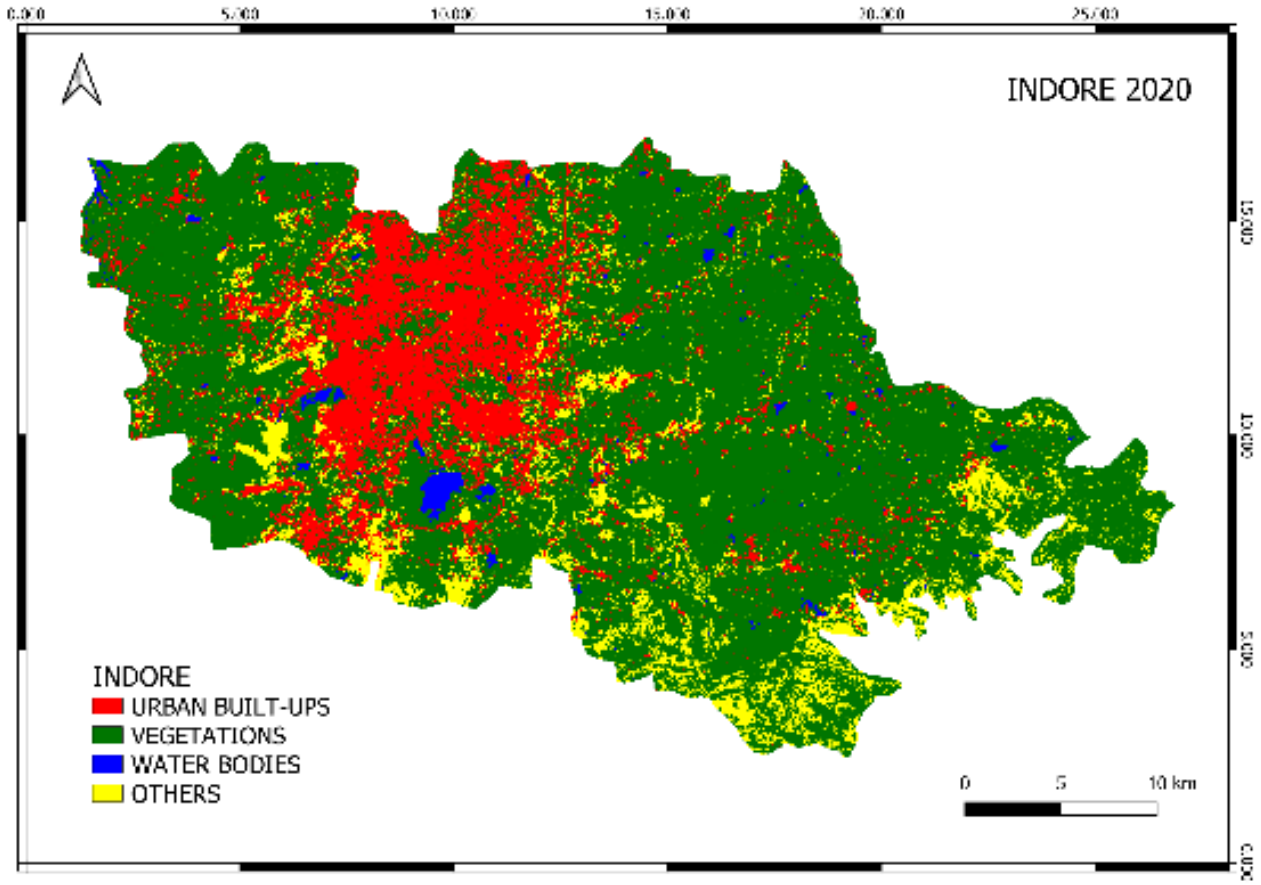


Figure 24 INDORE: URBAN PATTERN

Indore as per census 2011 has 1,964,086 urban population. Urban pattern of Indore is similar to Bangalore urban sprawl and agglomeration, where Indore has some scattered pattern also as we can see in the map, these scattered patterns of urban are mostly small settlements similar to town which acts as connection between main urban or city to village, we can see the increasing trends of these scattered town. Urban agglomeration of sprawls is clearly visible from 1989 to 2000 and further expansion of these agglomeration through linear development expansion can be seen in between 2000 to 2020.

Here in the second LCC map we can the degree of change between 2000 to 2020 which shows the change of vegetation to urban is 58.6 sq km area, and 41 sq km of others area converted into urban area. This shows that area of Indore changed from 77.97 sq km in 2000 to 179.16 sq km in 2020 more than 200% growth of urbanization occurred in between 20 year time period is very high. To understand the problems associated with this amount of growth further in next chapter we discussed the challenges of unsustainability and their consequences.

Rate of urbanization in Indore is high but still the proportion of Urban built-ups in Land use is 17% of total area and vegetation, water and agricultural land proportion is still high in Indore district, which makes Indore balanced and more ecofriendly urban city.

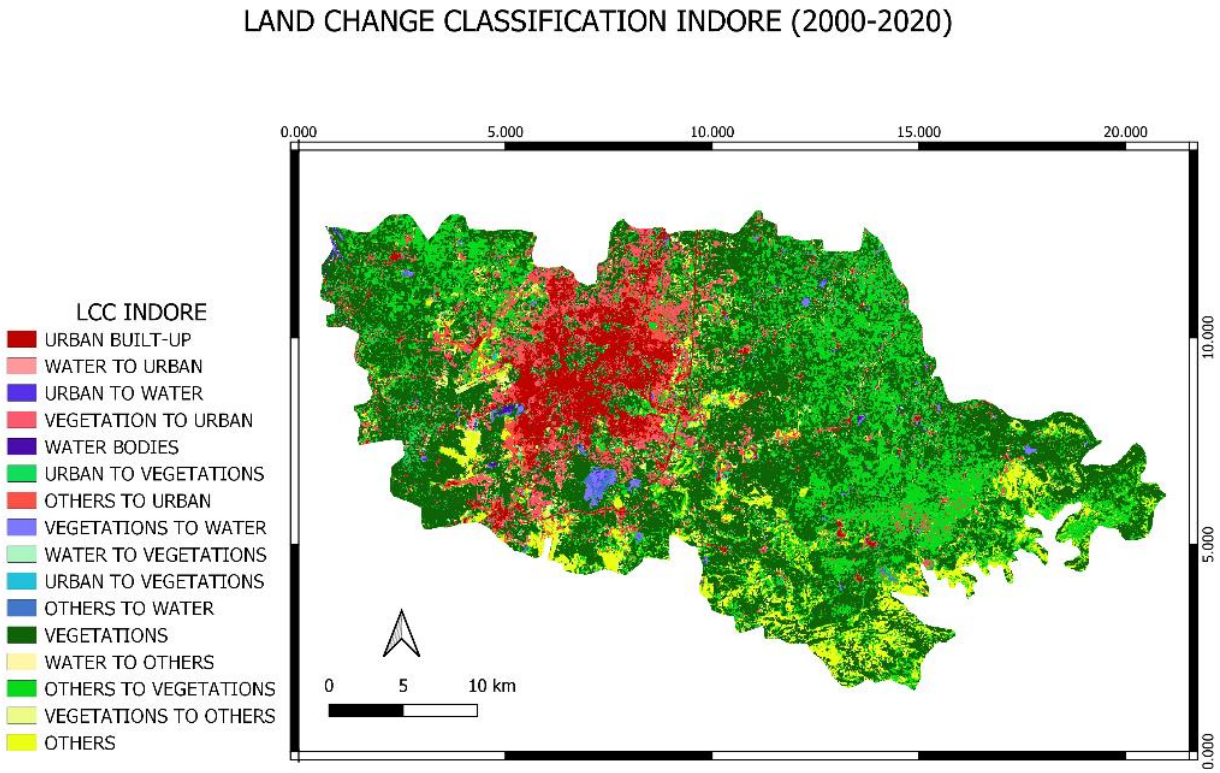
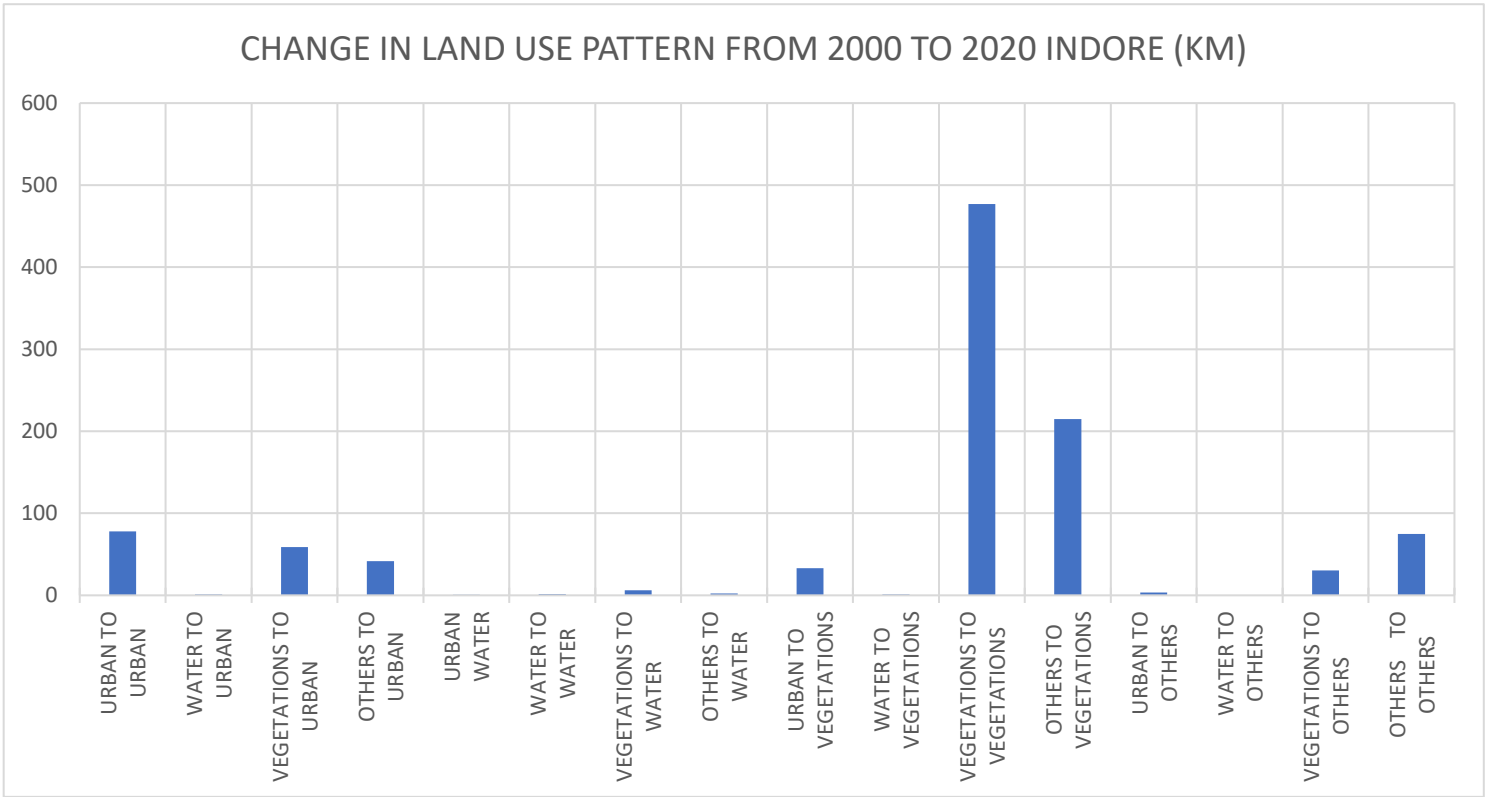


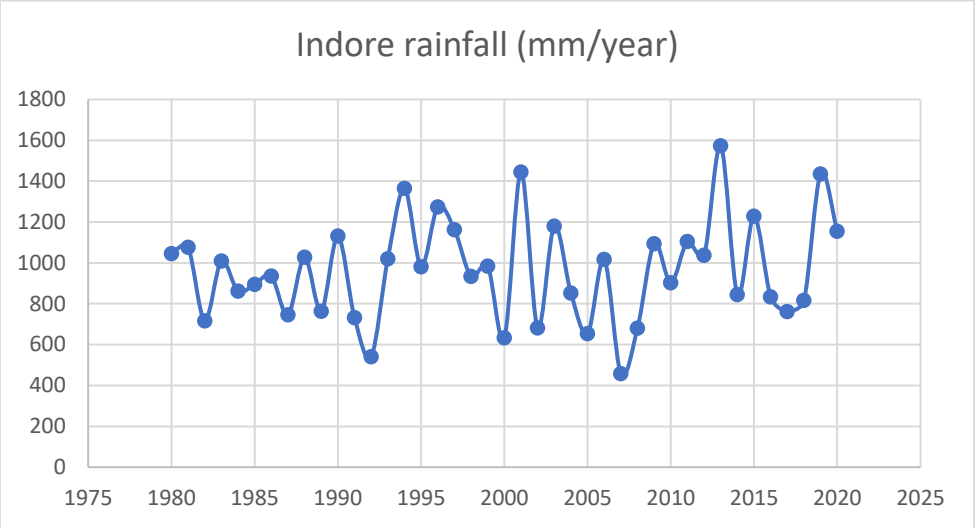
Figure 25 INDORE: LULC MAP

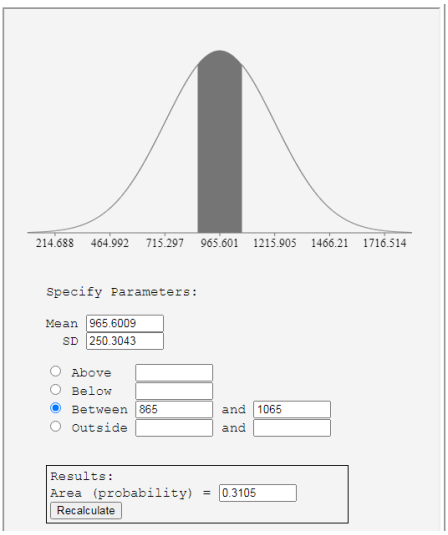


Graph 14 INDORE: LULC

Climate Variable and Unsustainability:

RAINFALL:

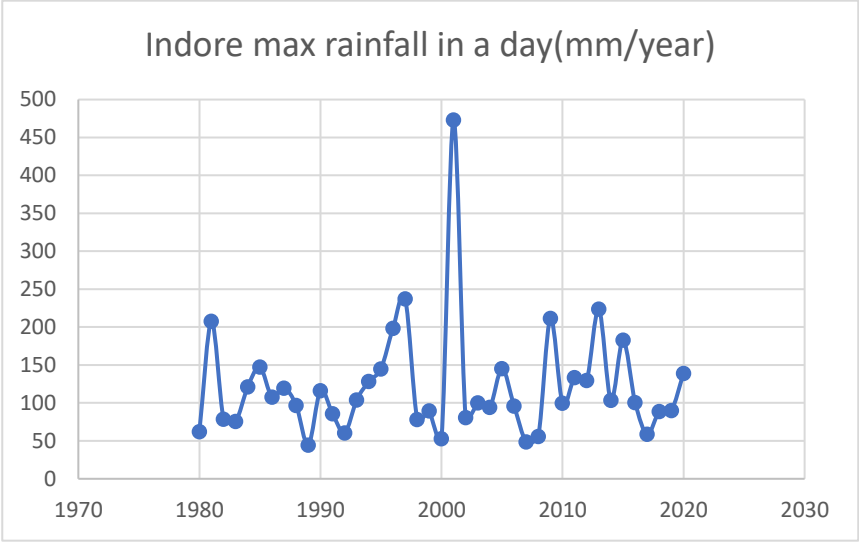




Rainfall pattern of Indore is mostly lies in between the 700 to 1000 mm average rainfall a year, mean of 40 year rainfall is 966 mm. 31% of the total 40 year rainfall data comes under the 100 mm deviation range which shows that the extreme rainfall condition in Indore is not as much high as Pune and Bangalore. But in recent years we can see the large deviation in 2019 and 2020 which shows more than 1200 mm average rainfall.

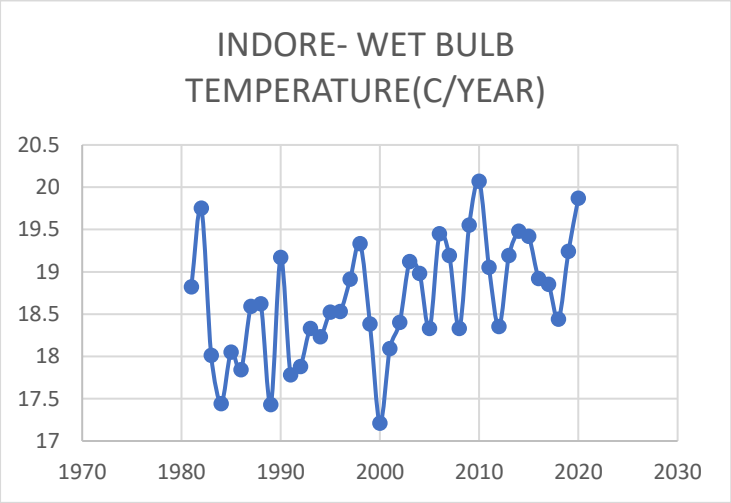
In 2001 the maximum rainfall in a day is more than 470 mm which is half of the total rainfall of a year, in one day this much amount of rainfall creates havoc for any city.

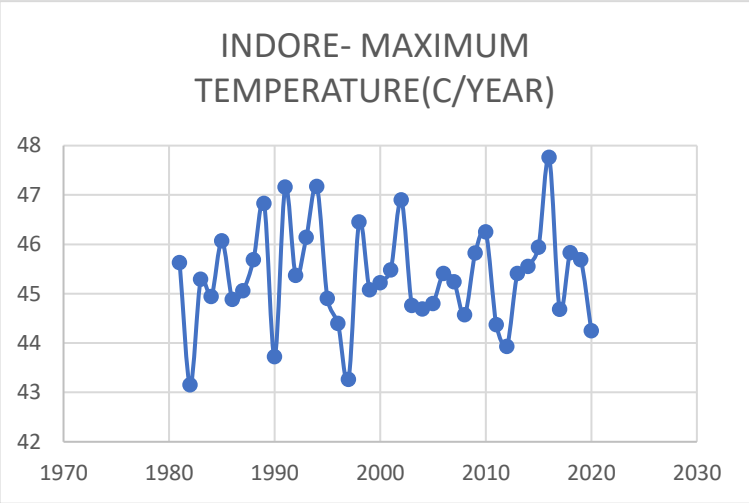
In recent year the increasing trends of rainfall amount in one day is increasing which is very dangerous for upcoming year and better to make better carrying capacity of urban drainage and sustainable infrastructure to overcome the upcoming urban flood disaster.



Graph 15 INDORE: RAINFALL

Temperature



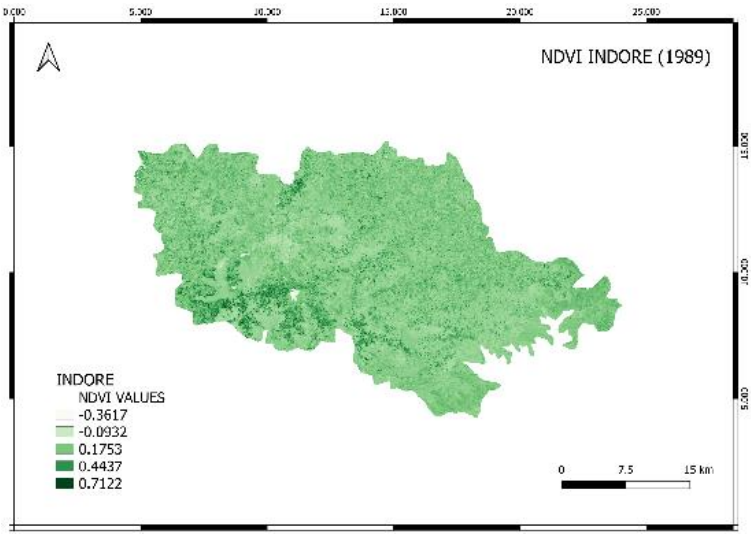


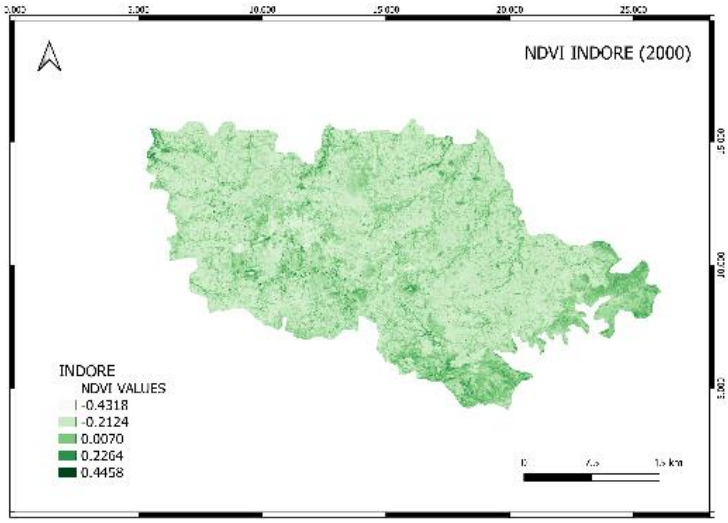
Graph 16 INDORE: WBT

WBT of Indore is deviated from 17.25 to 20 degree Celsius in between 40 years, but in 2020 the WB temperature is maximum at 20 while in same year the maximum dry air temperature is low in all 10 years, this implies that the humidity in Indore city is increasing and wind speed is decreasing due to dense and vertical Urban pattern.

In maximum temperature graph the deviation is very high from 43 to 48 degree Celsius, this much of deviation is further cause for heat stress and urban heat island.

NDVI





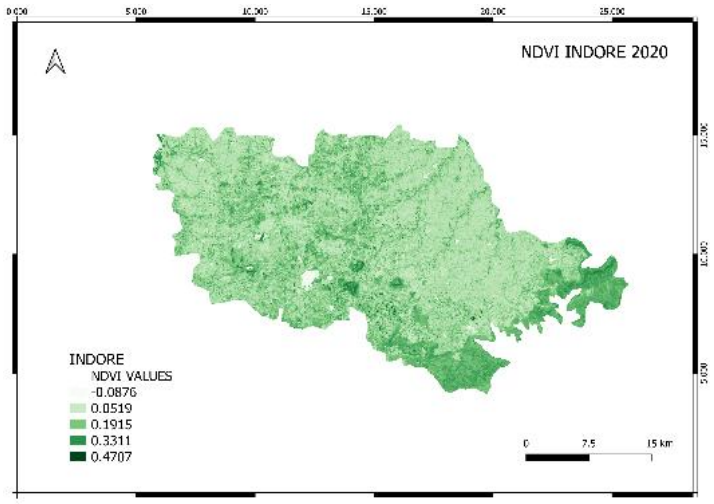


Figure 26 NDVI: INDORE

Decreasing trend of NDVI value from 0.712 in 1989 to 0.44 in 2000, implies the reduced vegetative area and specially the densely vegetations but further in 2020 the value increased to 0.47 which means improvement of 0.03 in densely vegetations area.

Indore has larger proportion of vegetation area in it total area, which balance the urban emissions and makes it better performing on the scale of sustainability.

LAND CHANGE CLASSIFICATION COMPARISON TABLE

City	Total Area (in sq km)	Urban Area (In sq km) 2000	New Urban Area (in sq km) 2021	Urban area change rate (sq km/year)	Percentage of urban area (in 2021)	Urban area Change pattern		
Delhi	1502	402.64	637.97	11.76	42.47	From	To	CHANGE AREA
						water	Urban	3.13
						vegetation	Urban	115.60
						others	urban	116.77
Bangalore	4496	344.65	1062.51	35.92	23.62	From	To	CHANGE AREA
						water	Urban	97.54
						vegetation	Urban	358.20
						others	urban	262.12

Kolkata	91	61.82	69.09	0.36	75.92	From	To	CHANGE AREA
						water	Urban	0.15
						vegetation	Urban	6.10
						others	urban	1.02
Pune	251	82.79	167.25	4.25	66.63	From	To	CHANGE AREA
						water	Urban	0.99
						vegetation	Urban	41.56
						others	urban	41.91
Indore	1025	77.97	179.16	5.05	17.47	From	To	CHANGE AREA
						water	Urban	1.06
						vegetation	Urban	58.67
						others	urban	41.46

Table 3 LAND CHANGE CLASSIFICATION COMPARISION

From the above table the best performing city in terms of percentage of urban area of total area is Indore. According to land change rate of urban area within 20 years Kolkata, Pune and Indore performed well but Kolkata and Pune are pseudo in this case because Kolkata is already urbanized to its 75% area and Pune is 66% of its area. While Indore is only 17% of its total area and its urbanization rate is also very low this is why Indore performed well in urban pattern rate.

Bangalore in this case has high rate of urbanization where 35 km area of total area is urbanized each year in within 20-year time period and vegetative area of 358 km is used directly in urban built-ups in between 20 year of time period.

Degree of Urbanization, Changes and Rank according to research findings:

I. **Ranking on the basis of Percentage of Urban area proportion to total land taken in research study (in 2021):** From reference year 2000 to 2021 (in 20 years) the change happened rapidly in all sector, increasing trend of migration, industrialization, and convergence of forest cover into unplanned and illegal urban expansion, in this section we are ranking the cities according to urban proportion percentage where maximum percentage ranked at 1 which means the cities has largest in urban proportion and densely urbanized, while rank 5 shows less urban proportion percentage of total land. (Follow column III of table. Mentioned below to see the rank, and the cause-effect behind the ranking)

II. **Ranking on the basis of urbanization rate (from reference year 2000 to 2021):** In this section we are dealing with the rate of urbanization in the past 20 years, in which the city which is ranked at 1

means the highest rate of urbanization while city which is on 5th means the rate is less. The cause and effect is also discussed in the section of below table. (Follow column IV of Table. Mentioned below to see the rank and the cause-effect behind the ranking)

Note: **Urban pattern** means **Built-ups** that is detailed explained in chapter.1 Urban pattern city-wise section and GIS Maps.

S.No.	City	Percentage of Urbanization(%) -(Rank)	Urban Area change rate (Urbanization rate)-(sq km/year) (Rank)	Cause and Effect
1	Kolkata	75.92 - **(1)**	0.36 - **(5)**	Kolkata urbanized from colonial time period and the reason behind the high proportion of urbanization is: • Port city • More livelihood opportunities leads to large migration. • Area taken under research is municipality region which comes under the border of Kolkata municipality and the area under Kolkata municipality is less and compacted in compare to other taken research cities. • Total area taken for study is only 93 sq km fo Kolkata which a way less in compare to other cities. • Kolkata ranked in 1st in percentage of urban area to total land use pattern which means the urbanization in Kolkata is more and the pattern as we discussed in the Urban GIS section of Kolkata in chapter 1, can be seen very irregular and compact. Kolkata urbanization rate is very less in past 20 years which is 0.36 (sq km in a year), reason behind the less rate of urbanization: • Kolkata has already urbanized at its utmost. • In chapter 1- urban pattern section we can the Kolkata has urbanized compact and densely even in 1980 and 2000 which has no place to urbanized more. • Emergence of other mega-cities and migration towards them is one other factor for less urbanization rate for Kolkata. For example in India the urbanization rate of Bangalore and Pune increased because of new trend of employment migration, where these cities have infrastructure as IT hubs attract tech service sector and employment opportunities. • Governance towards management of rural-urban migration and planning leads to decrease the urbanization rate in Kolkata.

2	Pune	66.63 - **(2)**	4.25 - **(4)**	Topography of Pune is different in compare to other cities, Pune is located near the western hill and it is located on the foot of hill and surrounded by hill range, but in past 20 year the trend of urbanization in Pune is very unique and interesting. Reason behind the 2nd rank on urbanization proportion of total land: • According to census 2011 the 99.09% of the population of the city comes under urban area. • Employment opportunities and increased IT sector after liberalization. • Better Transport facilities helps to not only Pune city but other nearby tehsil also urbanized at very high rate. • Area of Pune in our research site is less if we compare to other cities, Pune in this study according to area comes on 4th position which means the Pune city municipality are under our study is less. This can be as anomaly on comparison the value of land use. • Less area are under Pune city municipality leads to governance issue, larger area helps to sustain Pune make plan for its large population while less area in municipality leads to compact and densely planning of human habitat and industrialization at the same place which is hazards for human health. Pune is on 4th rank for the urbanization rate with 4.25% rate, which means each year urbanization rate of Pune in past 20 year 4.25 (sq km in a year), this is a good rate in compare to other cities. • Area of Pune is limited under the study which restrain the rate for urbanization, after 1991 Pune seen instant increase in urbanization and further stabilize at low rate due to land scarcity. • Increased governance and planning at decentralized level of urban planning leads to manage the urban expansion rate. • Pune used GIS and other technical tools to manage the urban planning. • According to NITI Aayog Behaviour regulation and ministry of housing and urban affairs ranked Pune at 2nd rank after Indore on best municipality performance index.
3	Delhi	42.47 - **(3)**	11.76- **(2)**	Delhi ranked at 3rd on urban proportion with 42.47% of its total land used for urban pattern (built-ups), reason for Delhi urbanization proportion: • One and major reason is capital of India, Delhi from colonial time acts as capital of India and attracts every stakeholder towards it.

				• Better Transport facilities, education services and employment opportunities cause for migration in delhi every day. • In a study of Demographia it is found that 700000 population comes to Delhi each year which leads to mess and densely urbanized and even illegal and unlawful colonies and slums. • Income divide is very high in Delhi which leads to unaffordable hounding and increasing trend of slums. • Delhi is at very high risk according to UNFCCC, climate variables in Delhi are deviated at very high rate and leads to high extreme events each year. i.e. air pollution, water stress, urban deluge: flood in monsoon and extreme heat stress in summer. Delhi ranked at 2nd in five studies megacities on urbanization rate. Delhi at 11.76 (sq km in a year) urbanized its area in each year which is above 10 sq km per year which is unsustainable for a city which is already urbanized at its full potential, this increasing trend means: • Construction and built-ups increasing day by day and this concretization leads to urban deluge such as urban flood and heat dome. • Dense and very unplanned • If Delhi already urbanized at its fullest then how even is it possible to urbanizes at this high rate: **i)** This means protected region like Aravali hills and other protected area now urbanizing and expanding. **ii)** Lack of governance and planning leads to irregular pattern of urbanization. • Transport facilities such as metro expansion in Delhi is very cause for rapid urbanization in its periphery, Faridabad, Gurugram, Gaziabaad etc. • Urban sprawl in Delhi is very high which leads to urban agglomeration in Delhi and cause increasing trend even it is already compact and densely urbanized. • Conversion of agricultural land in its periphery to urban built-ups is very high in Delhi and in 2021 agriculture activities in Delhi reduced to near zero.
4	Bangalore	23.62 - **(4)**	35.92- **(1)**	Urbanization proportion of Bangalore is 23.62% and ranked at 4th in five cities: • Bangalore after liberalization faces the urban expansion at very high rate. • Availability and suited Infrastructure which leads to growth of new industries leads to attract the new industries such as Tech companies.

				• IT hub similar to Pune, Bangalore expanded and attract the youth and other employment opportunities and leads to migration. • High quality Education and service utilities cause for factor for migration in Bangalore. • In case of Bangalore the transport facilities like metro and highways joins the periphery of rural Bangalore and leads to massive urban sprawl into urban agglomeration and proportion of urban built-up increased day by day. Urbanization rate in Bangalore is very high and ranked it at 1st position. Urbanization rate in Bangalore is 35.92 (sq km in a year) each year expansion of urban pattern, which is total havoc and unsustainable: • In our study the Bangalore is the city which is highest urban expansion rate where 360 sq km of vegetations were converted into urban built-ups in between 20 years, 262 sq km area of agricultural and other land converted into urban built-up. • It is very important to notice that in Bangalore the 97 sq km of water bodies were converted into urban pattern. • Lakes in Bangalore is reduced at very high rate in between 20 year of period. • According to ministry of urban affairs Bangalore ranked at 31st position this implies the lack of Governance perspective in Bangalore urban planning.
5	Indore	17.47 - **(5)**	5.05- **(3)**	Indore performing the best in all the studied cities as we can see here the rank of Indore in urban proportion is 5th which means Indore has low in urban built-ups if we compare to total studied land of Indore, reason behind the low proportion of urban built-ups: • Due to large area of municipality of Indore and the proportion is less but in compare to total land to Delhi, Indore has less than urban built-up and systematic planning. (Refer Indore section of chapter 1) • Indore performed well in planning and local governance as per the ministry of urban affair the Indore ranked at 1st position of municipality performance index and best city for all time. • Indore has large vegetation in compare to all cities but the conversion rate of vegetation into urban is still high which is 58 sq km of vegetation converted into urban space in 20 year of time period, on the other and Pune city in this only converted 41 sq km of vegetation land into urban built-ups in 20 years. Urbanization rate of Indore is sustainable and better after the Pune, it is 5.05 (SQ KM IN A YEAR) changed into urbanization

				each year: • Rate of urbanization in Pune increased after 2000 which can be seen chapter.1 Indore urbanization section. • Multi criteria decision making (MCDM) for selecting the cities for the development projects and smart city is one major cause to increasing the infrastructure development in all cities.

Table 4 RANKING ANALYSIS

CHAPTER.II: GAME THEORY AND BEST CITY

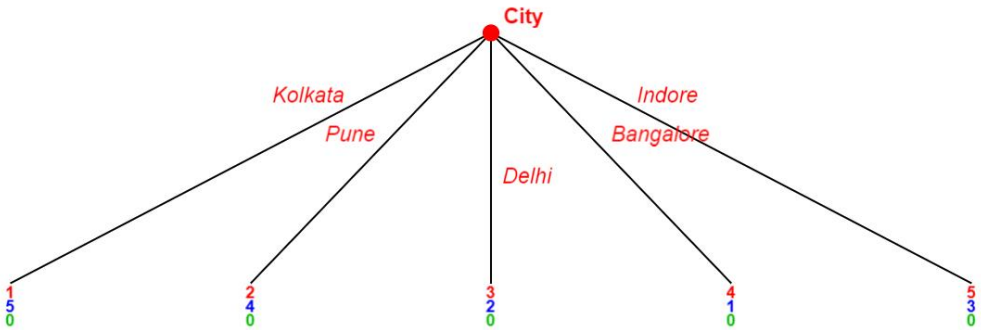
Game theory is method or instrument to explorer the optimum solution and gain, first it is used in economics and politics for better decision making but in modern world where multidisciplinary action is in core of every theory and action, where every variable and sector is interrelated to each other in very complex relation.

Game theory in environment sector is largely used in global and international decision making but here from our study of research data available we can find out the best city from the above data using game theory and **Nash equilibrium OR (SPNE) subgame perfect equilibrium Theory.**

Result of game tree from the Game theory explorer (GTE) tool: using the GTE software and data of above rank in matrix of 2*2.

Rank in urban proportion from 1 to 5 where 1 is very bad because of large proportion of dense urban built-ups and 5 is best which has less proportion of urban built-up as discussed in above table where Kolkata ranked at 1st in urban proportion and Indore ranked on 5Th . This is used as first entry for the first matrix.

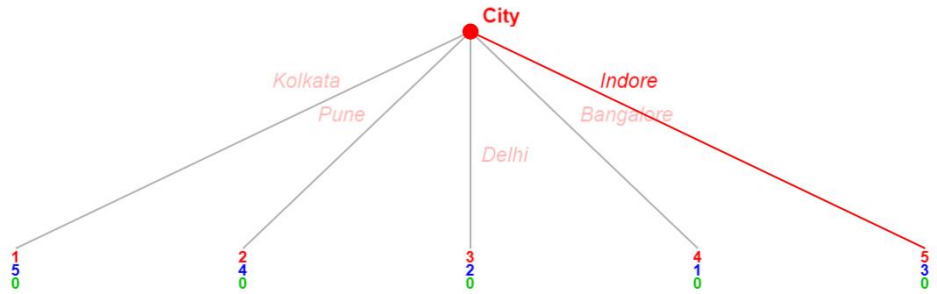
Rank in urban expansion rate used as 2nd matrix where 1st rank in urban expansion rate is very high expansion rate leads to unsustainable urbanization and very bad while on the other hand rank 5th makes it best and suitable for sustainable growth of urban pattern.



[12]**Game tree of cities:** in the game tree where the first matrix of payoff in red represent the urban proportion rank and payoff in blue represent the rate of urban expansion rank which is 2nd matrix. As we can see in the figure mentioned below.

SPNE Theory and Result: In game tree for best city according to given matrix of payoff and applying the SPNE Test, we can see the result for best cities according to payoff the Indore is the best among these five cities on the performance of urban proportion and rate of urbanization.

Result of the above game can be validating our study and result of our correlation and understanding of the performance.



Understanding the mathematics:

5 x 1 payoff matrix A:	5 x 1 payoff matrix B:
1	5
2	4
3	2
4	1
5	3

Table 5 GAME THEORY PAYOFF MATRIX TABLE

EE = Extreme Equilibrium, EP = Expected Payoff

Decimal Output

EE 1 P1: (1) 0.000000 0.000000 0.000000 0.000000 1.000000 EP= 5.0 P2: (1) 1.000000 EP= 3.0 **(Indore)**

Rational Output

EE 1 P1: (1) 0 0 0 0 1 EP= 5 P2: (1) 1 EP= 3 **(Indore)**

Final result of best city through Game: Indore

[12] http://www.gametheoryexplorer.org/

CHAPTER. III: EFFICIENCY OF COMPLIANCE AND REGULATION

Item	2001	2011	2021	2026
Total Population (million)	1028.61	1192.50	1339.74	1399.83
Urban Population (million)	286.12	357.94	432.61	534.80
Urban (%)	27.82	30.02	32.29	38.21
Total AEGR (%)	1.48	1.32	1.23	1.16
Urban AEGR(%)	2.24	2.07	2.50	1.89

Source: Population Projections for India, 2001-26, Registrar General of India,2006
AEGR- Annual Exponential Growth Rate

Table 6 PROJECTED URBAN POPULATION

REGULATORY COMPLIANCE RELATED TO SUSTAINABLE URBANIZATION: Above table projected the growth of population of India and increasing trends of urban proportion of total population. To sustain these population and ensure better sustainability, affordability and better infrastructure India need structured policy, governance and regulation. As per the United Nations, 2016 Article 15(b), "The New Urban Agenda recognizes "the leading role of national Governments, as appropriate, in the definition and implementation of inclusive and effective urban policies and legislation for sustainable urban development."[13] The trio of **policy, governance and regulation** will help to improve the environmental and living standard of mega cities and its sustainability.

[14]Rapid urbanization in Asia-Pacific means the urban population has grown faster than the cities' capacity, often leading to unsafe, low-quality, and/or informal employment (Hildebrand, Kanaley, & Roberts, 2013). Cities may increase inequality, as urban dwellers experience higher wages and living standards, while urban poor and rural dwellers do not (Hildebrand et al., 2013). Reflecting this line of thought, both China and India have policies aimed at slowing down rural-urban migration, as they perceive unplanned urbanisation as potentially negative (Kundu, 2009).

Recently Delhi government launched vision for making Delhi as global city by 2047, but it is very important to understand that before making it global it is essential to make it sustainable. It is not only for Delhi, all of our studied cities lack the environmental sustainability variables such as NDVI report on densely forest cover, variation of precipitation in 100 mm from the 40 years average, and Wet Bulb temperature index.

Indian cities are widely diverse from each other because of geographical locations, physical topography (such as elevations and natural drainage system), Temperature zone, and different urban agglomeration rate and industrialization process. So, due to these diverse background it is impossible to draw one policy for all cities on same parameters.

[13] United Nations 2016 Article 15 (b)

[14] http://www.gsdrc.org/docs/open/hdq1082.pdf

Twelfth schedule (Article 243 W) clause 8 of the Constitution of India, it is mandatory for all Municipal Corporations to protect the environment & promotion of ecological aspects. Thus as a regulatory and controlling authority for the development of the cities, the Municipal Corporations have to play major role in this scenario. Under **74th constitution amendment act in 1993** mentioned the role and responsibilities of Urban local bodies (ULB), this was the first initiative of decentralization to formulate the better policy and governance at grassroot level according to the cities, But unfortunately after 27 years of constitution status to ULB. It still doesn't perform at its utmost potential. It is better to reform before it's too late.

Role of decentralization in sustainable urban planning: Decentralization is the basic structure of Indian constitution enshrined under federalism where ULBs has responsibilities in planning and financial distribution at local level. These ULBs at grassroot level helps to draw the problem and solution according to their geographical and topographical conditions. This can be called as Bottom to up approach for governance and planning for sustainable urbanization.

[15]Strong local governments are better able to manage cities (Hildebrand et al., 2013). Administrative decentralisation must be accompanied by financial decentralisation. Gupte (2013) notes that, in most countries, responsibilities are more decentralised than revenues or fundraising capacity. Local governments also need the capacity to monitor and oversee private sector investment, as this is a major driver of growth (Gupte, 2013). Many countries in Asia have implemented strong decentralisation to good effect (Kundu, 2009). Decentralised governance has allowed some cities to invest in the capital market, secure high credit ratings and use this to invest in infrastructure as well as attract private investment (Kundu, 2009). Further independence may result in more appropriate local decisions (Kundu, 2009).

[16]Ministry of housing and urban affairs in 2020 released the municipality performance index, (MPI) Which is a framework to assess and analyse the performance of Indian Municipalities based on their defined set of functions. Municipal responsibilities range from provisioning basic pubic services to more complex domains such as urban planning. This assesses the performance of 114 cities across 5 pillars, 20 categories and 99 indicators.

5 Pillar and their sub categories of Performance:

Services: Education, Health, Water and waste water, SWM and sanitation, Registration and permits, Infrastructure.

Finance: Revenue management, expenditure management, fiscal responsibility, fiscal decentralization.

Planning: Plan preparation, plan implementation, plan enforcement.

Technology: Digital governance, Digital access, Digital literacy.

Governance: Transparency and accountability, human resource, participation and effectiveness.

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[15] http://www.gsdrc.org/docs/open/hdq1082.pdf

[16] https://amplifi.mohua.gov.in/mpi-landing

In all mega cities some cities like Indore and Pune which is ranked in top of ease of living and municipality performance index, these local authorities perform in much better sense in compare to other cities of the study.

Compliance of ULB (urban local bodies) which are effective and better for other cities to learn from them:

Lesson from Chandigarh development Administration and ULBs

Bottom to Up approach of planning: Chandigarh adopted the feature of bottom to up approach of planning and implementation where each zone of the city has its special planning and implementation according to their own features.

Zoning plan: Chandigarh divided into multiple sectors and zone and each zone has their map and features of planning, citizens in that zone abide to follow the rule of that zone.

Layout for zones is given on the Pune development authority in GIS mapping format to understand it better and easy for citizens.

Master Plan: Chandigarh as whole has one compendium where all the legal and governance framework are mentioned for planned and prepared future urban expansion and mitigate the problem of unsustainability and environmental concern.

Sustainable Habitat and other concept of Chandigarh administration:

1. Chandigarh adopted city and reginal level concept for sustainable habitat:

CITY CONCEPTS

• Sensitive site selection. • The natural gradient of the site facilitating storm water drainage, availability of water, scenic beauty, backdrop of the hills • Concept of Sun, Space and Verdure. • Self sufficient neighborhoods offering serene family life. • Size of the sector based on walkability to enable easy access to daily needs. • Each dwelling unit having abundance of sunlight, air, ventilation and greenery. • Solar Passive Architecture. • Longitudinal green belts - green lungs connecting communities and nature. • City forests . • The hierarchical and equitable distribution of social infrastructure, efficient circulation system-V7s aimed at enabling men and machine to seamlessly connect within the city and outside without conflict. • The mandatory space for the pedestrian in the road sections. • The use of natural materials for building construction. • The orientation of buildings for comfortable indoor living and to reduce heat gain.

Regional concepts

• The concept of the periphery with the expanse of green belt surrounding the city to enable- • Nourish the city . • Improve the microclimate . • Ensure regulated development around the city. • Maintain Man Cosmos relationship. • Enable scope for future expansion.

2. Chandigarh adopted tax exemption and incentivize to green building, which has certain features and parameters for sustainable habitat and better environment for urban built-ups.
3. Integrated urban planning approach: An integrated planning approach is proposed to be adopted encompassing various facets of the city's development in terms of the following:-
    - Sensitive site selection and Eco-sensitive Planning, - Chandigarh to be declared Solar City, - Environmental friendly management of city level services- - Concepts of REDUCE, RECYCLE AND REUSE of water, solid waste,

sewerage, - Creating Self Sustaining Neighborhood units in terms of Power, Water and Sewage Disposal, - City's Green -- High percentage of land dedicated to open spaces, city greens and water bodies, - Increasing the Green Cover by Mandatory Plantation, - Comprehensive Mobility Plan for Chandigarh and the Region. - Efficient Transportation System, - Eco-friendly transport system within sites, - Promote Bicycle as a Mode of Transportation in the City, - Construction of Green Buildings/Campuses, - All future developments in & around the City sensitive to its environs.

[17]**Town planning scheme via Expression of interest (EOI) in Pune:** Town Planning scheme through Expression of Interest is one of the first initiative in India. MOU is executed between 2000-Watt Smart City Association of Swiss Government and Maharashtra State Government.
Through this project, Pune metropolitan region development authority (PMRDA) intends to adopt elements of carbon neutrality and energy efficiency in its approach towards planning and development of Pune Metropolitan Region.

- Model Land Development of 1 sq.km, with a Carbon Neutral Neighborhood for over 10,000 inhabitants to be developed first, as a proof of concept.
- A vital urban mix of Residential Buildings and Offices, Shops, Restaurants and Public Facilities promoting a Green City.
- Concept proposes to offer its residents a maximum of quality and minimum resources consumption through:
    - High Density
    - Minimized Embedded Energy
    - Zero Carbon Operation
    - Mixed use, Including Habitation, Offices Shops, Restaurants, Senior Living
    - School, Day Care facilities
    - Excellent Mobility

[17] http://www.pmrda.gov.in/getProjectById

CHAPTER. IV: SUSTAINABLE URBANIZATION IS A SUSTAINABLE CHOICE

[18]In 1987, the United Nations Brundtland Commission defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." Today, there are almost 140 developing countries in the world seeking ways of meeting their development needs, but with the increasing threat of climate change, concrete efforts must be made to ensure development today does not negatively affect future generations.

Framework for sustainability at broad level:

1. Environmental wellbeing

2. Human and social wellbeing

3. Economical and developmental well being

As discussed in above climatic parameters and urbanization pattern of 40 years. There are multiple challenges and problems associated with these developments and solution to these challenges are one that is sustainable and planned cities. Urban flood, heat dome and heat stress are the major challenges these days in Indian cities.

System dynamics modelling- CLD (causal Loop diagram): It is an analysis system which works on the relation between different variables and degree of impact on each other. it helps in identifying and understanding the

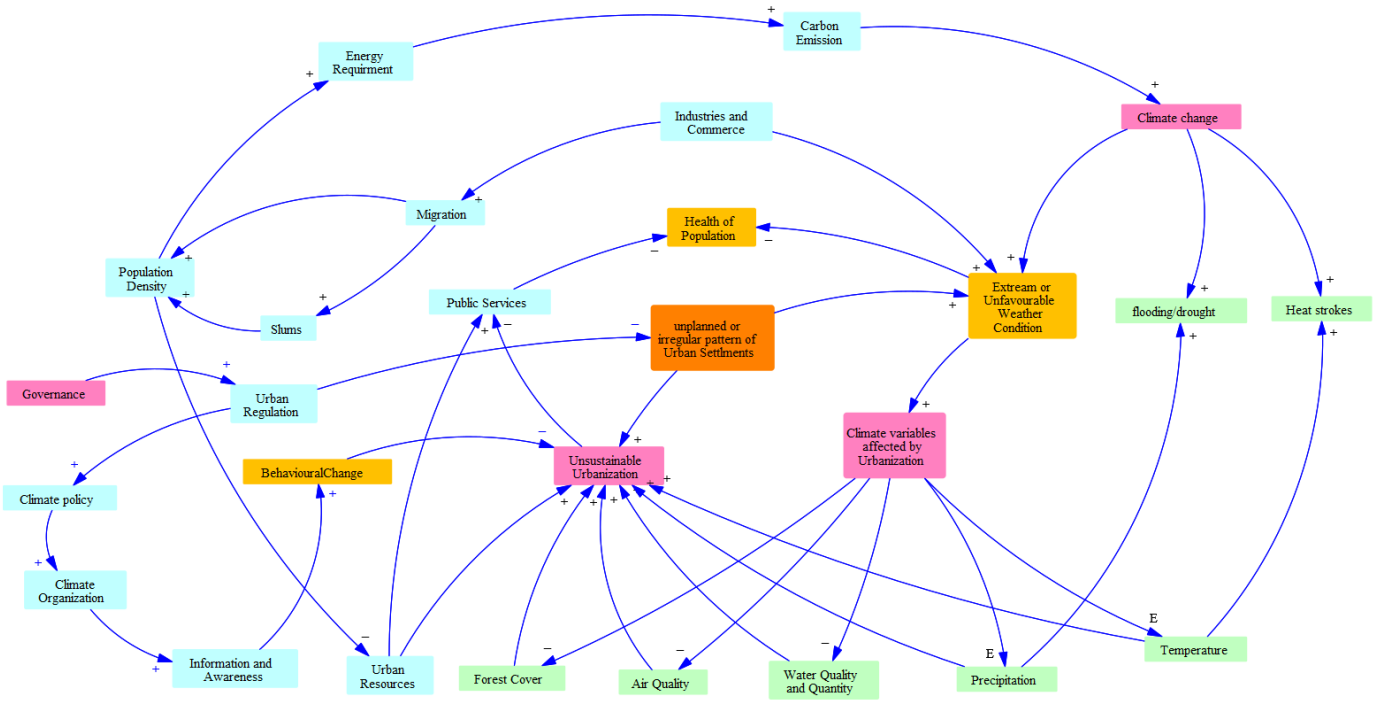

Figure 29 CLD: SUSTAINABILITY

[18] https://www.un.org/en/academic-impact/sustainability

factors responsible for the existence of the problem behaviors. For the purpose of this study a causal analysis of the factors responsible for unsustainability of urbanization has been conducted with the help of above findings, literature review and comprehensive data analysis.

INFERENCES BETWEEN UNSUSTAINABLE URBANIZATION AND HUMAN HEALTH

Environment, human health, sustainable and efficient public services in Urban area is complex interconnection with high degree of impact. In our first chapter of study, we can see the change in anthropogenic activities impacted the climate, and further the climate impacted the human health and this vicious cycle goes on and on.

From above CLD we can see the health of urban population is negatively impacted by two variables first one is bad public services or utilities (overburden public services or utilities) and extreme or unfavorable weather conditions.

Overburden Public services/utilities: Public services in urban area is wide and complex interconnection, (for example transport services interrelated complex between environment, human settlement, and urban sprawl.) should be studies properly and before planning it is better to draw a proper correlation between them. Excess public density causes overburden to these utilities and further impacted the health of population. From the above CLD we can see the public services are inversely impacted by unsustainable urbanization pattern which is the core of this research.

Stressed public services or utilities like water, transport, Sewage, waste disposal system causes negative impact of health of urban habitants.

Extreme or Unfavorable weather conditions: Extreme or unfavorable weather conditions are those situations in which the extreme events like urban flooding and heat stress can be seen very frequently. In India the situations of extreme events in urban areas are very common. The reason behind these events is positively correlated by multiple variables as we can see in our CLD:

- **Industries and commerce induce the extreme weather conditions:** Industries in between the urban settlements induce the extreme or unfavorable weather conditions which means negatively impacted on weather conditions and create unfavorable conditions like urban heat dome and acid rain can be seen frequently.
- **Unplanned or Irregular pattern of Urban settlements:** Unplanned settlements also induce the extreme conditions like urban flooding and heat stress situation. Unplanned urbanization not only impact environment but multiple others issues are also there like service accessibility, traffic congestions, sewage and waste management hazards. In this research Delhi, Kolkata seems to be more unplanned. Which further shows the depletion of forest cover, increased Air pollution, water stress, unparallel sewage (sewage connected to river) and direct discharge of sewage in river in Delhi. These activities are not sustainable for any city.
- **Climate change:** climate change as big challenge to not only urbanization but for whole nation. Climate change leads to unpredictable monsoon pattern in India since last two decades which impacted the

whole nation either agriculture in rural India or flood and congestions in urban area.[19]The total economic losses due to crop, house and other property damages came to Rs 4.69 trillion.

> In November, 2019, the Union Minister of State for Jal Shakti, Ratan Lal Kataria told the Rajya Sabha that India suffered a loss of Rs 95,736 crore in 2018 floods. This was 2.6 times more than the financial loss due to floods in 2017. Climate change cannot be seen only in terms of environment but economy also.

- **Unsustainability and Behavior correlation:** human behavior is very unpredicatable and complex intermixing of different variable which lead the human behavior at the core of every environmental concern which can be converted of anthropogenic action. Here in this CLD we ca see the behavioural change leads to sustainable pattern which is affected by governance, information and awareness.
  Behaviour of individual is shaped through empathetic understanding and information symmetric in this case for attaining the sustainability behaviour needs to be change at first step.

Psychology of behaviour and generating pro-environment behaviour is not an easy task, where human intent to rational in decision making. Rationality to gain maximum benefit and rational choice theory behaviour of human is in the core of psychology. The in case of protecting environment and promoting sustainable development is not very easy. But in terms of Nudging the behaviour which can be one possible solution to change the behaviour.

1. Policy tools to influence individual behavior (House of Lords, 2011)

Regulation of the individual	Fiscal measures directed at the individual		Non-regulatory and non-fiscal measures with relation to the individual			
Eliminate and restrict choice	*Guide and enable choice*					
	Incentives and information			Nudging		
Laws and regulations	Fiscal incentives	Non-fiscal incentives	Provision of information	Simplification and framing of information	Changes to physical environment	Changes to the default policy	Use of social norms

Figure 30 NUDGE: HUMAN BEHAVIOUR

How to Nudge the human behaviour?

Nudging is not similar like incentivization it is different and more effective the incetive regulation. For example government can incentivize the gases over coal and wood fuel for domestic consumption which may change the behaviour of consumer to use gas but after a while when

[19] https://www.downtoearth.org.in/blog/climate-change/floods-cost-india-rs-4-7-lakh-crore-in-last-6-decades-72401

government would stop the incentive consumer again shift back to their original status and this method will not work in long run, environmental problem can be only solve through permanent change not by temporary change. This is why Nudging come into the picture, in the above discussed case using information, social norms and moral attachment can do more effective change, i.e. to promote clean fuel as discussed above Nudging used as releasing health concern information who used fossil fuel has damaged their lungs and life expectancy reduced (this will act as Nudge: information regulation), promoting by social structure i.e. like those who are using fossil fuel can join self help group and that self help group will help to promote them to using clean fuel.

INFERENCES BETWEEN GOVERNANCE, INFORMATION AND SUSTAINABILITY

In the above CLD we can see the relation between the governance, information and sustainability, where governance helps to make policy and impacted directly on urban regulation in terms of climate policy and information where information helps to change the behaviour of individual as we discussed in above section.

Variables which has colour ▭ are the factor of Governance:

- Energy Requirements
- Carbon emission
- Population density
- Migration
- Slum
- Urban regulation
- Industry and commerce
- Public services

These factors are direct corelated with the action of government, which has large proportion and effect on the other variables with very high degree of correlation either inversely or directly.

Major problems which are the main cause of unsustainability in Indian cities these days are urban deluges which cause urban flood and frequent extreme climatic events in the urban area.

URBAN FLOOD

[20]Urbanization leads to developed catchments, which increases flood peaks from 1.8 to 8 times and flood volumes by up to 6 times, urban flooding differs greatly from rural flooding. As a result of the faster flow times, flooding occurs extremely quickly (in a matter of minutes). Urban regions are densely inhabited, and people who live in flood-prone areas suffer as a result of flooding, which can result in death. It is not only the occurrence of flooding that causes human pain, but also the secondary effect of infection, which results in loss of livelihood and, in extreme circumstances, death.

[20] https://ndma.gov.in/Natural-Hazards/Urban-Floods

Urban areas are also centers of economic activities with vital infrastructure which needs to be protected 24x7. In most of the cities, damage to vital infrastructure has a bearing not only for the state and the country but it could even have global implications. Major cities in India have witnessed loss of life and property, disruption in transport and power and incidence of epidemics. Therefore, management of urban flooding has to be accorded top priority.

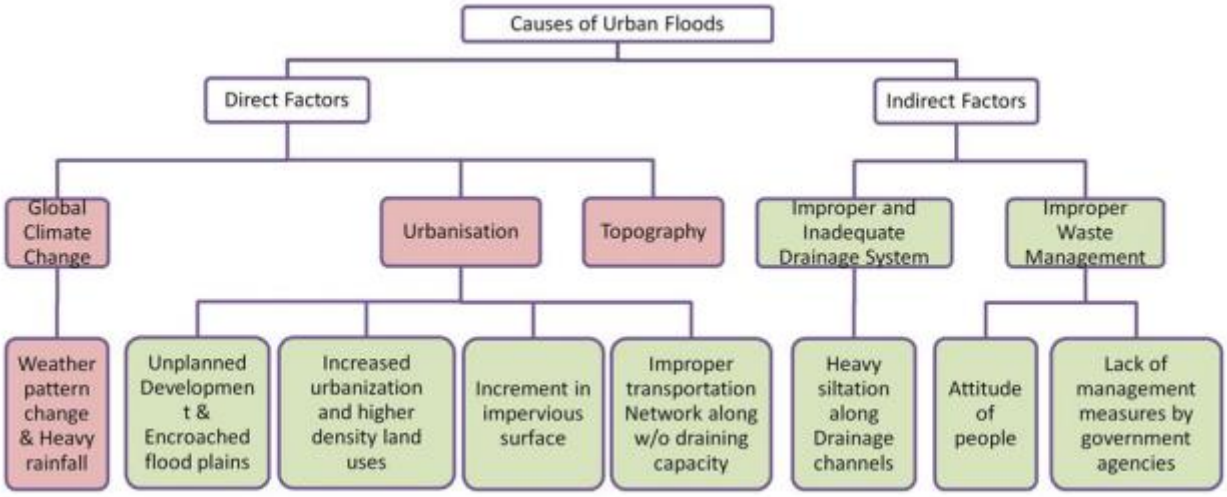

Figure 31 CAUSE DIAGRAM FOR URBAN FLOOD

HEAT STRESS

As per the government record 6167 people died due to heat stroke in India in between 8 years and 2015 was the deadliest one which has 34% contribution in total death by heat stroke.

In our study of temperature, we can see the rising trend of heat in urban spaces and Kolkata is the most vulnerable in heat stress (refer chnapter.1).

Air temperature, humidity and wind speed are the major environmental factor responsible for heat as we discussed in chapter.1. the situation in urban is very vulnerable because of heat trapped in long building due to less speed of winds and green cover. Humidity rises very quick in urban sphere while relative humidity is less in compare to outside of cities periphery due to concrete built-ups in the city, this means cities are hotter and rainwater in cities is unable to be absorbed into the ground and released into the air by evaporation and transpiration doesn't occur because cities have little vegetation.

RECOMMENDATIONS

Possible types of sustainable urbanization and consideration of climatic variables to plan urban structure:

Green field urbanization: Those urbanization which is proposed to planned from the scratch and total new planning and infrastructure involved known as green field urbanization. In India Amaravati the capital of Andhra Pradesh is green field project which is very large at scale. what are the climatic variables important to consider in green field planning?

- Land acquisition and efficient/smart use of land with advanced technology.
- Consideration of land use proportion to divide the uses of land into multiple sub category.
- Public services which are very essential key to make urban space sustainable must be keep in mind. Like water quality and quantity, sustainable transport etc.
- Crisis and disaster management for future.
- Decentralized planning from zonal to master plan for past, present and future.

Proposed pattern of Urbanization by author:

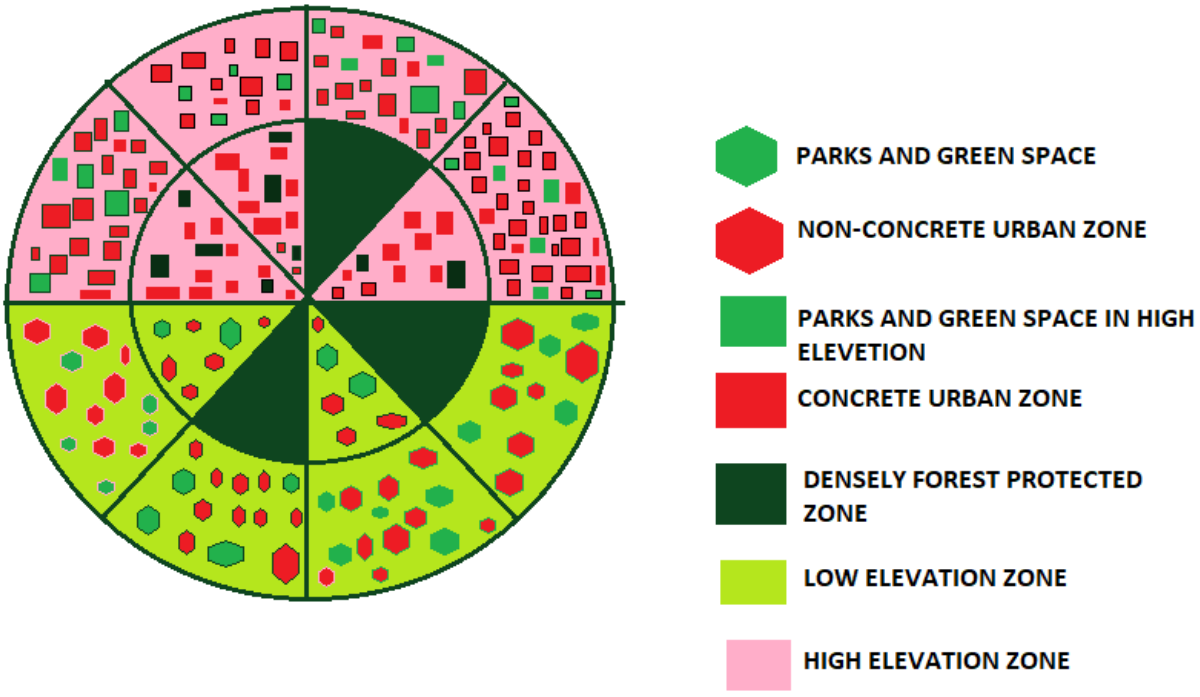

Figure 32 PROPOSED URBAN PATTERN

Under the proposed pattern of urbanization, we are planning to tackle the problem of urban deluge, carbon emission balancing and heat stress. Here in the above proposed figure, we can see the division on area under

two part where first part is high elevation and second is low elevated area and plan for low elevation is different from high elevation this will solve the problem of urban deluge where high elevation doesn't have capacity to hold rain water and movement of water towards low elevation which further in form of non-concrete zone that allows to absorb the water and make it sponge city.

3/8 pattern: it is pattern of green zone carbon emission balancing; this proportion will change according to population density and number of industries and their locations. This means under 8 proportion of core grid part of city 3 part must be green and protected which not only helps to do the carbon sequestering but also make it sponge city and balance heat dome of the city.

Brown field urbanization: Those urbanization which is planned for expansion or improvement on the existing urban pattern which is still there. These types of urban planning is more in Developed nation while in Developing nations in the initial phase of urbanization and space available to them. But in case of India brown field urbanization project is for the mega and old cities which are already existed from several decades and updating to these is still big challenge in India.

Example: AMRUT, Smart city plan and development of Urban through different central and states schemes are also more focused on brown field urban development.

Recommendation at glance:

- **Need of regular Impact Assessment:** Assessment of urban policy and planning is very important to know the progress of action taken by authorities, in India the impact assessment is lacks even in 21st century.
- Green field urban development with proper proposed plan and GIS mapping with the help of modern technology.
- Brown field urban development focused to regulate and carefully develop urban periphery and regulate the plan accordingly.
- Nudging and information symmetry for the human behavior regulation to more citizen centric urban development.
- Public utilities and services must be part of sustainable and green planning.
- Illegal and unlawful urban pattern such as slums are part of urban planning so planning these spaces is very important. Most Indian cities not planning for slums and not considering them part of urban planning this cause the vulnerable to population living into this space.

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ANNEXURE

ANNEXURE-I : RAINFALL DATA ANALYSIS (Raw Data: IMD Gridded Data of India for all coordinates and rainfall stations from 1980 to 2021)

City	Bangalore (77.5,13)					PUNE (73.75,18.5)					Kolkata (88.5,22.5)					Indor (75.75,22.75)					delhi (77,28.75)						Jaisalmer (71,27)					India	
Year	min	max	av	sum	davs	min	max	av	sum	davs	min	max	av	sum	davs	min	max	av	sum	davs	min	max	av	sum	ND	davs	min	max	av	sum	davs		Av	N.D
1980	0.11815	112.316	6.2359	767.015	123	0.13582	63.7173	6.27293	727.65971	116	0.13617	97.8583	11.1281	1658.09	149	0.13269	62.3476	9.41754	1045.34748	111	0.12488	65.999	7.27461	603.793	0.002090403	83	0.10521	24.2994	5.07346	162.351	32	1980	1183.53	0.00409
1981	0.10786	50.5944	7.03159	780.506	111	0.133	60.1699	6.09019	669.92126	110	0.10955	116.502	11.772	1848.2	157	0.13666	207.638	11.96	1076.39597	90	0.1212	66.207	5.188	513.612	0.001747227	99	0.13988	84.9715	8.68849	243.278	28	1981	1142.31	0.00435
1982	0.10541	73.96	8.50569	774.018	91	0.1089	48.6302	5.07015	501.94492	99	0.10717	58.259	8.58381	1090.14	127	0.14353	78.7363	8.73811	716.524765	82	0.15756	40.0314	6.71345	738.48	0.001788681	110	0.13988	41.5113	5.27262	189.814	36	1982	1093.96	0.00361
1983	0.1328	48.4408	7.01639	792.852	113	0.10823	91.8098	7.1934	712.14631	99	0.10717	66.6538	9.94361	1620.81	163	0.10261	75.6775	9.79101	1008.47428	103	0.11466	71.1809	7.22269	743.937	0.001758504	103	0.13988	34.0123	8.89502	284.641	32	1983	1305.88	0.00103
1984	0.12649	77.0612	6.9577	765.347	110	0.14093	93.835	8.50228	892.73976	105	0.11464	206.823	13.311	2076.51	156	0.10324	121.416	11.3416	861.964981	76	0.10683	67.6957	7.35953	471.01	0.001483167	64	0.31954	26.4726	7.37111	140.051	19	1984	1150.96	0.00436
1985	0.10046	38.2384	5.49403	609.837	111	0.11135	74.969	6.44262	579.83613	90	0.11685	70.3703	10.4104	1519.92	146	0.11324	147.417	13.7759	895.433437	65	0.1262	40.0622	4.57341	320.139	0.000551869	70	0.13988	33.4674	7.1342	92.7446	13	1985	1138.69	0.00433
1986	0.10136	105.272	9.05697	1014.38	112	0.13582	57.2052	6.10436	537.18373	88	0.10852	216.548	13.5619	2197.03	162	0.13715	107.674	12.9852	934.9373	72	0.10388	43.6905	5.61349	376.104	0.000857776	67	0.19853	22.2442	5.89991	70.7989	12	1986	1119.22	0.00412
1987	0.12935	49.6499	6.6138	753.973	114	0.11831	135.64	6.58953	632.59476	96	0.11897	105.885	11.2435	1697.76	151	0.15072	119.78	10.3514	745.303371	72	0.14734	87.3345	5.92101	361.181	0.000769171	61	0.10521	24.6658	3.63517	43.622	12	1987	1097.62	0.00369
1988	0.13395	107.434	9.71787	1049.53	108	0.1331	68.8358	9.69133	998.20741	103	0.10436	167.329	13.3095	2036.36	153	0.13269	96.6481	10.9316	1027.56607	94	0.10365	77.5622	9.79284	851.977	0.001057656	87	0.15977	83.6174	9.91788	218.193	22	1988	1307.22	0.001
1989	0.11815	60.4847	8.28266	803.418	97	0.10557	86.9115	7.09317	680.94434	96	0.10717	51.7721	10.6626	1524.76	143	0.11585	44.5776	8.97901	763.216123	85	0.10339	35.4723	4.82405	284.619	0.000398591	59	0.13988	39.6089	6.41451	153.948	24	1989	1120.17	0.00413
1990	0.10353	43.5149	4.3799	503.688	115	0.10364	63.9699	7.20709	872.05823	121	0.11897	68.0655	11.9079	2191.05	184	0.13269	116.044	9.75455	1131.52736	116	0.16376	55.941	8.98453	898.453	0.000768658	100	0.13988	36.1121	3.60797	129.887	36	1990	1361.7	0.0003
1991	0.12649	110.731	10.1189	1285.1	127	0.10598	111.898	8.06439	854.8256	106	0.10717	82.0971	9.83303	1602.78	163	0.1256	85.7181	9.76405	732.304064	75	0.12488	50.7824	9.24423	573.142	0.00201765	62	0.25895	37.5304	7.36079	103.051	14	1991	1135.48	0.00431
1992	0.11663	57.5481	6.55032	759.837	116	0.11087	47.6568	7.10562	646.61183	91	0.11464	177.875	12.8946	1869.72	145	0.12916	60.5655	9.3309	541.19221	58	0.10614	28.6654	4.81847	356.567	0.000742731	74	0.32979	48.5277	6.1862	222.703	36	1992	1091.42	0.00354
1993	0.11086	59.0932	5.00206	620.255	124	0.12947	48.1168	6.04156	743.11245	123	0.11685	103.996	12.011	1945.78	162	0.13308	103.993	11.4549	1019.48457	89	0.23242	137.215	13.2933	903.944	0.00073726	68	0.12999	165.121	17.4205	348.411	20	1993	1192.83	0.00392
1994	0.10075	26.9041	3.57279	418.017	117	0.12947	62.0301	7.93678	920.66685	116	0.11464	57.7139	9.69885	1532.42	158	0.10048	128.304	13.7847	1364.68524	99	0.11687	83.5873	9.11703	829.65	0.001206704	91	0.13988	22.7599	5.95494	238.198	40	1994	1256.97	0.00221
1995	0.1041	13.622	2.83235	337.05	119	0.12947	46.798	5.60809	577.63334	103	0.11649	126.319	13.7226	2181.89	159	0.12389	144.934	12.1172	981.492422	81	0.10846	85.1568	12.0506	976.101	0.000394085	81	0.16249	64.048	11.0915	332.746	30	1995	1218.22	0.00331
1996	0.10156	26.1153	3.72923	451.237	121	0.12632	89.5289	10.6148	1093.3282	103	0.13428	124.579	13.253	1842.16	139	0.12954	198.513	16.5411	1273.66542	77	0.14985	73.837	9.09636	855.058	0.001037454	94	0.32638	41.9193	7.38277	199.335	27	1996	1178.81	0.00416
1997	0.11856	44.6044	3.54135	485.165	137	0.10131	73.132	9.54372	1030.722	108	0.10461	79.2112	10.0772	1803.81	179	0.108	237.289	11.6318	1163.18395	100	0.12048	54.2741	5.90935	720.941	0.001878589	122	0.17263	17.5106	4.17775	175.466	42	1997	1167.04	0.00429
1998	0.10513	188.488	11.4673	1307.27	114	0.11939	67.8105	7.46107	835.63947	112	0.11464	65.7181	10.9076	1941.55	178	0.13126	78.3329	9.15303	933.60935	102	0.10846	54.8592	7.21601	685.521	0.00202045	95	0.17263	55.6878	10.1921	305.763	30	1998	1208.36	0.00357
1999	0.11364	16.2661	3.15807	445.288	141	0.10754	50.9498	6.78455	732.73099	108	0.12881	149.787	15.4191	2251.19	146	0.13126	89.6773	10.9403	984.623239	90							0.13988	68.6606	13.579	339.474	25	1999	1164.52	0.00431
2000	0.109	17.56	3.55298	429.91	121	0.10548	44.2843	5.5827	513.60872	92	0.12145	81.8032	9.65599	1544.96	160	0.1256	52.9258	10.2198	633.629514	62	0.15061	48.3847	6.48796	583.916	0.002049061	90	0.25563	70.9062	14.8322	163.154	11	2000	1013.48	0.00142
2001	0.1103	29.2508	3.99942	447.935	112	0.10106	37.6805	5.63909	575.18744	102	0.10532	66.3481	9.3339	1549.43	166	0.12908	473.289	16.7982	1444.64316	86	0.1027	87.9647	5.45402	610.85	0.002099691	112	0.13988	68.6606	13.579	339.474	25	2001	1067.73	0.0029
2002	0.1077	23.2498	3.24956	295.71	91	0.11849	74.6351	5.6428	428.85272	76	0.11464	106.709	12.3085	1895.52	154	0.11736	80.6385	9.74601	682.220534	70	0.17136	75.0605	6.67285	600.557	0.002085186	90	0.1865	10.4104	4.02375	48.285	12	2002	936.51	0.00028
2003	0.13188	57.4947	7.13973	713.973	100	0.10791	56.7856	4.86079	466.63552	96	0.14959	193.587	11.8378	1965.08	166	0.10048	100.371	13.2589	1180.04387	89	0.15501	98.6529	8.87032	1002.35	0.000302663	113	0.12781	62.3077	5.79286	185.371	32	2003	1168.46	0.00428
2004	0.11123	61.7748	7.55346	1072.59	142	0.10912	193.445	18.9591	2749.0759	145	0.13704	111.88	11.3393	1485.45	131	0.15072	94.2146	10.3922	852.16268	82	0.17501	59.5981	10.6969	577.633	0.002031485	54	0.17263	26.598	3.73918	63.5661	17	2004	1055.02	0.00253
2005	0.14811	85.3956	10.9086	1429.02	131	0.10755	268.871	25.1272	3266.538	130	0.15645	80.8792	12.1604	1532.21	126	0.10894	145.155	7.97467	653.92299	82	0.34033	62.4252	7.87491	527.619	0.001823595	67	0.43158	64.9612	9.10137	209.331	23	2005	1198.82	0.00379
2006	0.10051	35.7757	5.69385	586.466	103	0.1364	195.615	23.4716	3661.5701	156	0.13717	92.178	10.368	1399.68	135	0.10415	96.0238	9.4094	1016.21569	108	0.11873	67.0387	6.69775	428.656	0.001198344	64	0.16113	124.244	13.5519	487.868	36	2006	1180.78	0.00413
2007	0.1202	80.026	9.69309	1075.93	111	0.1364	137.898	19.8996	2567.0423	129	0.2	103	12.0699	1363.9	113	0.10239	48.6316	7.14759	457.44557	64	0.13516	35.7319	6.25942	456.938	0.001389436	73	0.13988	59.012	5.93852	201.91	34	2007	1188.48	0.004
2008	0.10021	107.792	8.98996	1060.82	118	0.16368	187.872	18.4053	2392.693	130	0.2	71.6	11.2788	1342.18	119	0.11104	56.0947	8.40619	680.901642	81	0.1128	44.8537	6.81393	606.44	0.002094224	89	0.13988	24.1713	5.72357	171.707	30	2008	1120.3	0.00413
2009	0.10425	48.9007	7.62273	777.518	102	0.10068	96.5965	10.7005	1016.5448	95	0.11951	86.6668	12.8835	1558.91	121	0.13126	211.741	14.7717	1093.1071	74	0.10669	78.6542	8.69269	625.874	0.002109786	72	0.10066	13.0002	3.76743	75.3486	20	2009	990.871	0.00095
2010	0.1029	71.6069	6.2034	942.917	152	0.10515	165.537	9.85458	1093.8583	111	0.11015	73.1227	9.94671	1253.29	126	0.13243	99.9112	9.60156	902.546331	94	0.10123	60.9965	10.2985	937.166	0.000562645	91	0.12379	92.5423	8.55801	359.436	42	2010	1230.24	0.00298
2011	0.10653	106.791	8.94476	1189.65	133	0.10912	104.967	17.8374	2265.3473	127	0.10602	69.1886	13.6954	1246.28	91	0.17835	133.74	12.4171	1105.11987	89	0.12345	49.7047	5.8603	539.148	0.001881186	92	0.17263	79.4306	8.75108	297.537	34	2011	1165.18	0.00431
2012	0.10745	84.8962	7.43118	676.238	91	0.10416	73.854	14.0259	1697.1303	121	0.10178	59.9405	5.75156	385.354	67	0.14705	129.865	15.7122	1037.00302	66	0.11584	27.6317	5.67766	397.436	0.000991662	70	0.39997	75.1961	9.90753	237.781	24	2012	1082.41	0.00331
2013	0.1029	80.8489	8.55299	1077.68	126	0.12351	70.6179	7.82326	797.9254	102	0.12632	64.6197	11.8467	1777	150	0.14192	223.627	15.2777	1573.60197	103	0.10901	77.3529	8.9153	775.631	0.001567101	87	0.14526	73.145	5.55232	210.988	38	2013	1235.51	0.00283
2014	0.11755	66.0313	7.99574	903.519	113	0.10783	83.3521	8.23904	823.90441	100	0.16644	128.831	13.4747	1495.69	111	0.14192	103.55	10.1759	844.600432	83	0.11566	38.2564	6.25653	469.24	0.001471483	75	0.15474	25.8688	5.52566	143.667	26	2014	1033.81	0.00194
2015	0.11082	75.6499	8.27774	1183.72	143	0.1129	95.9736	9.31272	838.14457	90	0.11053	146.499	12.0446	1638.06	136	0.15735	182.868	17.0628	1228.52368	72	0.12368	77.68	9.29626	808.775	0.001347892	87	0.29052	45.5541	12.5361	426.226	34	2015	1077.78	0.00318
2016	0.10675	68.9369	7.57342	817.929	108	0.12078	74.5626	7.66084	697.13625	91	0.14261	109.444	10.8858	1458.7	134	0.14093	100.735	10.8263	833.627576	77	0.13849	44.4709	8.24922	593.944	0.002072676	72	0.1672	80.608	8.41274	193.493	23	2016	1101.58	0.00378
2017	0.12804	132.956	11.7863	1426.14	121	0.13593	94.6761	8.81405	907.84714	103	0.14162	127.67	13.1977	1702.51	129	0.14093	58.9694	9.77265	762.266968	78	0.10129	53.6214	7.25867	566.176	0.00199415	78	0.14526	33.0054	8.61715	336.069	39	2017	1133.43	0.00429
2018	0.1012	40.1058	6.18786	742.543	120	0.15844	61.5149	4.9512	505.0229	102	0.10073	56.6283	9.10012	1237.62	136	0.10152	88.9145	11.6639	816.475376	70	0.24405	65.9089	9.65541	724.156	0.001862975	75	0.2508	57.3946	9.61349	192.27	20	2018	999.863	0.00113
2019	0.13378	82.2819	7.73927	1013.84	131	0.14073	78.6844	12.4628	1483.0722	119	0.11757	154.477	14.8122	1807.09	122	0.11339	90.2729	13.6718	1435.53476	105	0.11237	52.0067	6.5759	598.407	0.00208139	91	0.15474	33.6946	7.49411	337.235	45	2019	1271.55	0.00181
2020	0.1029	68.0529	9.01078	1126.35	125	0.1428	116.423	9.60099	1152.1186	120	0.10438	145.457	11.8931	1986.14	167	0.28185	139.232	12.2884	1155.11273	94	0.10966	85.2531	7.81762	695.768	0.001985493	89	0.12379	38.0734	6.00601	282.283	47	2020	1279.07	0.00162
sdv			2.38639	300.171	14.2268			5.12423	786.69331	16.1105			1.84098	354.453	23.5669			2.49547	250.304367	14.332			2.00093	189.051		16.3385			3.25273	104.322	9.91603	sdv	91.4313	
mean			7.00906	822.297	117.439			9.61681	1100.971	108.049			11.5497	1659.93	143.415			11.4473	965.600904	84.5366			7.61488	629.773	579	83.025			7.81752	215.45	27.925	mean	1150.38	
			av	sum	days			av	sum	days			av	sum	days			av	sum	days			av	sum	679	days			av	sum	days			

Source: https://cdsp.imdpune.gov.in/home_gridded_data.php

ANNEXURE-II: Temperature data (Raw Data: Power data from NASA)

Year	Bangalore			Delhi			Indore			Kolkata			Pune		
	Max	Wet bulb Temp	RELATIVE HUMIDITY(RH)	Max	Wet bulb Temp	RH	Max	Wet bulb Temp	RH	Max	Wet bulb Temp	RH	Max	Wet bulb Temp	RH
1981	38.76	19.52	70.06	49.29	17.48	43.44	45.63	18.82	53.62	39.25	22.58	75.06	43.48	19.25	68
1982	38.71	19.34	67.56	44.58	18.19	50.19	43.15	19.75	54.12	42.24	22.59	70.06	40.26	19.74	69.38
1983	40.22	19.37	62.88	46.4	17.25	44.62	45.29	18.01	48	43.39	22.3	63.75	42.76	18.99	68.06
1984	38.8	19.61	67.75	49.03	16.41	36.62	44.94	17.44	43.38	44.05	21.75	67	41.76	18.99	64.62
1985	39.49	19.2	64.31	47.24	16.87	43.19	46.07	18.05	45.19	44.67	22.38	67.69	41.93	18.8	64.25
1986	39.34	19.76	67.25	48.26	16.64	36.62	44.88	17.84	43.88	44.56	22.38	68.88	41.35	19.02	63.31
1987	38.98	19.47	65.38	47.83	16.68	30.44	45.06	18.59	45.62	43.66	22.51	69.69	43.22	19.58	64.88
1988	39.39	19.69	68.31	48.37	17.57	43.94	45.69	18.62	48.44	44.06	22.5	68.5	41.79	19.45	67
1989	39.73	18.91	64.31	47.51	16.14	34.44	46.83	17.43	42.06	45.64	21.67	66.12	41.36	18.79	63.62
1990	39.65	19.58	63.5	47.04	18.19	46.75	43.72	19.17	54.56	42.16	22.69	73.56	42.58	19.43	69.31
1991	39.69	19.58	64.94	46.4	17.12	39.69	47.16	17.78	43.25	46.22	22.7	70	42.15	19.08	65.56
1992	39.84	18.93	65.94	47.39	17.17	39.25	45.37	17.88	44.69	45.11	22.17	68.75	41.48	18.7	61.75
1993	40.58	19.35	67.5	47.94	16.73	38.44	46.14	18.33	48.81	41.62	22.3	70.5	42.14	18.97	65.31
1994	39.16	19.58	67.38	48.4	17.19	41.25	47.17	18.23	50.88	44.01	22.27	69.88	40.62	19.2	68.62
1995	38.89	19.61	69.5	48.32	17.5	43.19	44.9	18.52	47.75	45.71	22.32	71.25	40.83	19.31	65.12
1996	39.38	19.27	69.25	47.26	17.31	45	44.4	18.53	49.88	45.51	22.3	69.44	40.34	19.28	66.94
1997	37.56	19.9	69.62	45.35	17.38	42.06	43.26	18.91	54.94	43.61	22.61	72.31	39.32	19.41	68.44
1998	40.22	20.31	71.62	49.01	18.08	48.25	46.45	19.33	53	43.9	23.08	75.25	43.12	19.85	69.56
1999	39.51	19.26	69.62	47.21	16.87	35.25	45.08	18.38	49.88	44.63	22.55	72.94	42.15	19.12	66.69
2000	38.8	19.52	69.12	46.5	16.76	37.44	45.22	17.21	41.56	42.4	22.55	74.38	41.65	18.84	63.56
2001	38.5	19.69	69.62	47.39	17.09	36.5	45.48	18.09	43.94	42.84	22.58	73.31	42.37	19.33	65.38
2002	40.22	19.69	65.75	47.76	17.61	38.25	46.9	18.4	44.75	46.81	22.88	74.06	43.07	19.42	62.06
2003	39.09	20	64.75	48.51	17.8	48.94	44.76	19.12	54.19	43.28	22.85	73.81	42.49	19.61	62.56
2004	39.96	19.4	69.94	46.42	18.22	43.62	44.69	18.98	50.31	44.62	22.73	74.19	41.27	19.3	65.75
2005	39.09	19.98	72.44	48.43	17.86	45.31	44.8	18.33	47.5	42.54	23.12	74.75	41.72	19.29	67.81
2006	38.78	19.78	70	46.32	18.48	43.5	45.41	19.45	53.5	42.75	22.92	73.94	41.07	19.73	69.38
2007	38.38	19.58	70.38	48.79	18.37	45.81	45.24	19.19	51	42.49	22.61	74.5	41.15	19.82	67.81
2008	39.02	19.58	72.75	44.92	18.09	50.12	44.57	18.33	46.69	41.26	22.8	76.88	41.98	19.32	66.38
2009	38.46	19.76	69.06	47.37	18.2	43.38	45.82	19.55	51.38	44.03	22.76	72.31	42.54	19.89	65.94
2010	39.01	20.29	71.31	48.72	18.58	50.19	46.25	20.07	55.38	45.28	23.14	72.88	41.92	20.49	71.62
2011	37.69	19.45	67.12	47.09	18.76	53.69	44.37	19.05	51.56	40.49	22.7	73.56	39.9	19.58	68.25
2012	38.34	19.6	62.56	47.84	17.17	43.25	43.93	18.35	49.12	43.86	22.44	72.38	40.37	19.14	64.44
2013	38.57	19.77	68.75	48.06	18.23	53.94	45.41	19.19	56.75	43.37	22.48	73.62	41.71	19.71	68.75
2014	38.25	19.74	64.94	48.22	17.66	42.62	45.55	19.48	52.19	44.65	22.55	72.25	41.02	19.83	66.06
2015	37.07	19.89	67.38	46.51	17.9	44.69	45.94	19.42	52.25	42.39	23.06	72.94	40.39	19.96	66.88
2016	40.37	19.69	62	47.12	17.62	39.81	47.76	18.92	50.94	44.48	23.44	73.5	41.51	19.41	65.75
2017	38.72	19.8	68.25	47.71	17.83	42.56	44.68	18.85	50.25	42.07	23.23	75.19	41.55	19.51	66.5
2018	38.49	19.72	64.88	46.55	18.03	47	45.83	18.44	45.75	40.98	22.61	73.38	41.3	19.46	64.12
2019	39.12	20.28	65.94	48.14	18.65	49.12	45.69	19.24	56.38	42.8	23.19	73.62	43.2	19.84	67.12
2020	38.69	20.37	70.88	47.42	18.51	48.94	44.25	19.87	59.06	41.07	22.95	77.62	41.15	20.59	73.5

Source: https://power.larc.nasa.gov/data-access-viewer/

Figure 33 UN SDG