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Analytical Study on Impact of Urban Heat Island and its Potential Health Risk on Urban Dwellers of Major Cities of India

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Abstract: ***Urban built up area recording higher air temperature then its immediate rural-urban fringe (RUF) is known as Urban Heat Island (UHI). It is one of the major urban hazard facing many urban areas around the world. It is attributed to unplanned land use and land cover (LULC) changes perpetrated in the industrializing urban area which is dominated by low albedo heat-absorptive surfaces (such as dark pavement, walls, roofs, roads), heat-generating activities (such as automobile engines, power plants and generators) and the absence of vegetation, water bodies (which provides evaporative cooling). This paper seeks to understand the impact of UHI on the health of the Urban dwellers using the Heat Index and also identifies mitigation measures to check UHI in emerging urban areas.***

Keywords: Urban Sprawl, Heat Index, Land Use and Land Cover (LULC), Urban Heat Island, Surface Urban Heat Island Intensity (SUHII), Urban Agglomeration, Rural-Urban fringe.

1. Introduction

Urban areas are engines of economic development and growth-centers of world economy. These large settlements generate huge tax income for the governments around the world and garner revenue, business and employment opportunities for large populace. Urban areas are characterized by high population density to support secondary and tertiary activities as a result they attract migrants from its hinterland, today more than 55% of the world, 35% of Indian population live in urban settlements (World Bank,2020). Urban areas are truly the modern wonders of the Human Civilization. Economic opportunities coupled with better living standards in Urban areas triggered rural to urban migration, which in turn led to uncontrolled urban sprawl. Many urban agglomerations (UAs) around the world have grown haphazardly without a sustainable plan and have turned into built-up concrete jungle encroaching natural landscape around it such as lakes, forests, arable land and wetlands. Today's urban areas have become cancers of the modern economy with numerous health hazards to its inhabitants. Urban Heat Island (UHI) is the overall built-up region that is substantially warmer than its suburban and rural surroundings. The differences of the land surface temperature (LST) between urban and surrounding non-urban areas is known as surface urban heat island intensity (SUHII).

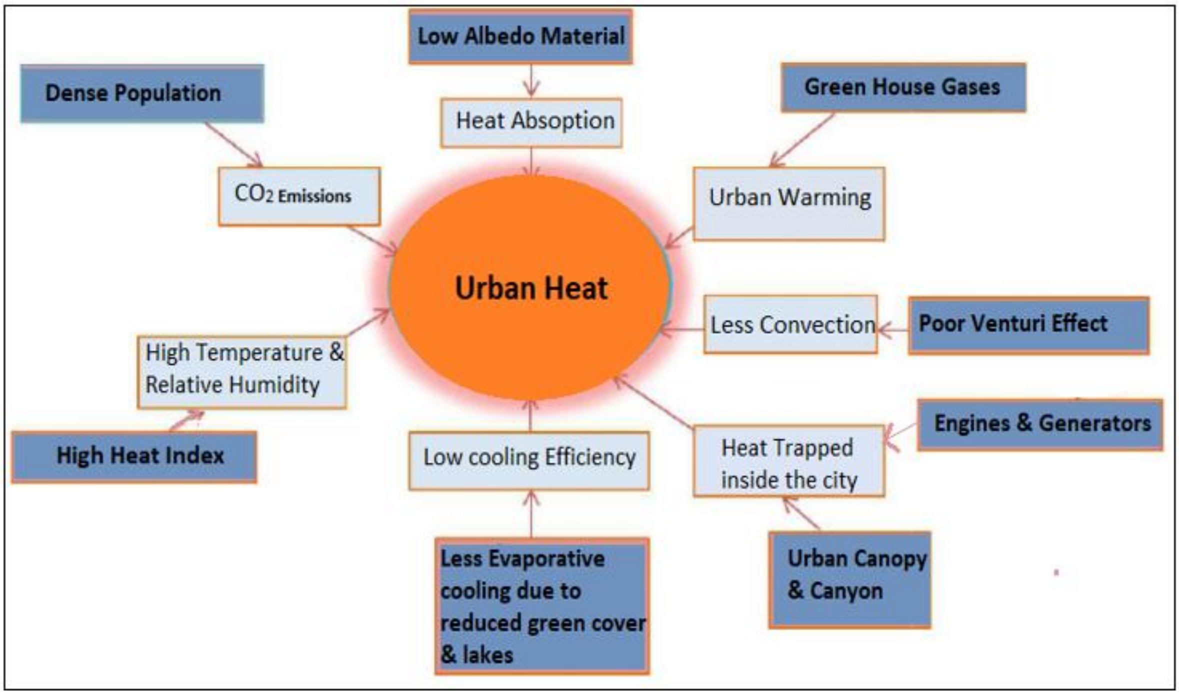
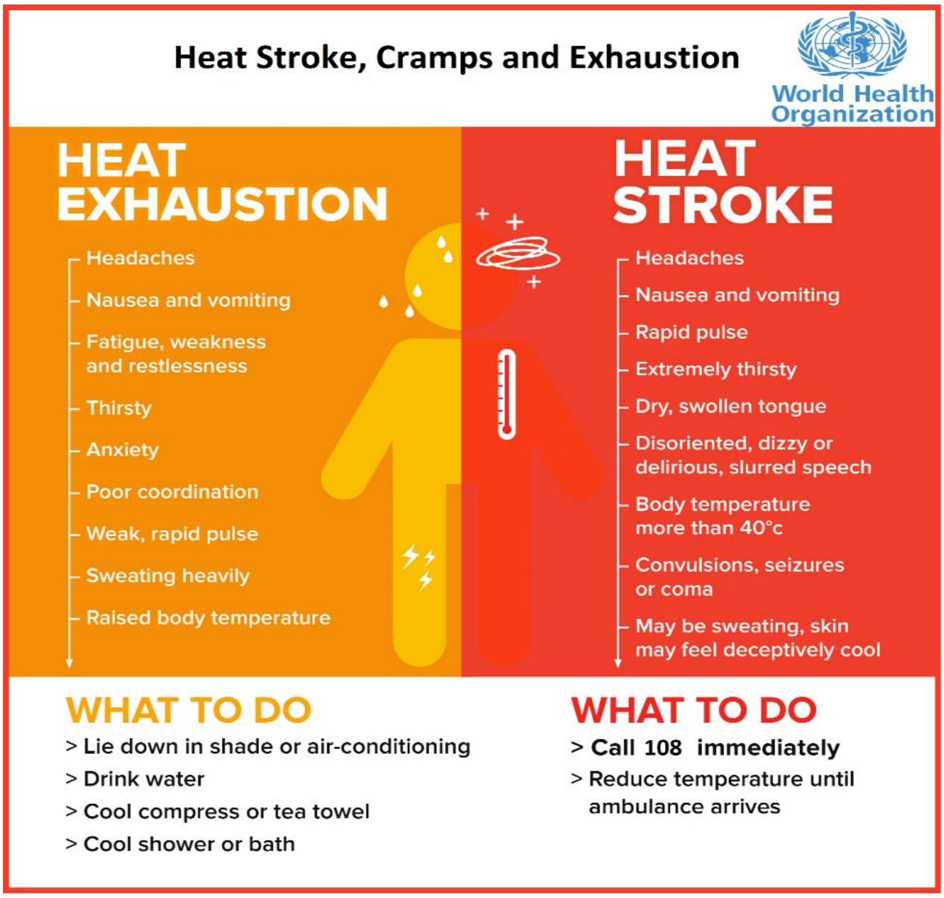


Figure 1: Formation of Urban Heat Island.

Urban Heat Island (UHI) is considered as one of the major problems in the 21st century posed to human beings as a result of urbanization and industrialization. In many tropical and subtropical countries, Urban heat is responsible to heat waves in summer months. In India, Pre-monsoon surface day-time and night time temperatures are very high as a result heat wave takes a toll on urban population. As per IMD, Heat Wave is considered when maximum temperature of a station reaches at least 40°C for Plains and at least 30°C for Hilly regions. UHI is an outcome of many factors such as Heat Index, which is calculated taking in account surface air temperature and relative humidity; Heat index helps us to understand the impact of UHI effect on human health. The health impacts of Heat Waves typically involve dehydration, heat cramps, heat exhaustion and/or heat stroke. The signs and symptoms are as follows:

- Heat Cramps: Ederna (swelling) and Syncope (Fainting) generally accompanied by fever below 39°C i.e.102°F.
- Heat Exhaustion: Fatigue, weakness, dizziness, headache, nausea, vomiting, muscle cramps and sweating.
- Heat Stoke: Body temperatures of 40°C i.e. 104°F or more along with delirium, seizures or coma. This is a potentially fatal condition.



Heat Stroke, Cramps and Exhaustion

World Health Organization

HEAT EXHAUSTION

- Headaches
- Nausea and vomiting
- Fatigue, weakness and restlessness
- Thirsty
- Anxiety
- Poor coordination
- Weak, rapid pulse
- Sweating heavily
- Raised body temperature

HEAT STROKE

- Headaches
- Nausea and vomiting
- Rapid pulse
- Extremely thirsty
- Dry, swollen tongue
- Disoriented, dizzy or delirious, slurred speech
- Body temperature more than 40°c
- Convulsions, seizures or coma
- May be sweating, skin may feel deceptively cool

WHAT TO DO

> Lie down in shade or air-conditioning
> Drink water
> Cool compress or tea towel
> Cool shower or bath

WHAT TO DO

> Call 108 immediately
> Reduce temperature until ambulance arrives

Figure 2: Effect of Heat stroke, cramp and exhaustion.

2. Need for the Study

Despite various research on urban heat island (UHI), its effect has increased exponentially over the last few decades; a systematic review of factors contributing to UHI effect has scarcely been reported in the literature. All research papers till date have concentrated only on causes of Urban Heat Island and none have linked its impact on human health and identified the mitigation measures. My research aims to highlight the link between UHI and Heat waves in Urban areas using Heat Index (HI) and corresponding health risks involved.

3. Review of Literature

Sarath Raj et al. (2019) highlighted the impact of anthropogenic activities on urban areas. According to him Urban heat island (UHI) phenomena is among the major consequences of the alteration of land cover due to human activities. The relatively warmer temperatures in urban areas compared to suburban areas (i.e. UHI) has potential health hazards, such as mortality due to high temperatures and heat waves.

Pawar AS et al. (2015) in his paper highlighted how all aspects of the environment including biosphere, hydrosphere and atmosphere are affected by urbanization. Replacement of natural surfaces with extensive impervious built mass, reduces bio-habitat, increases run-off and absorbs more insolation [6]. Re-radiation of absorbed insolation acts as a secondary source of energy, increasing energy gain of atmosphere, while depleted bio-habitat and increased run-off deplete atmospheric humidity. These are few factors which combine together to cause urban heat island (UHI) effect which increases thermal discomfort. Other causes of UHI are increased pollution from automobiles and industries causing anthropogenic heat gain as well as hindrance to radiation energy loss to sky.

Shastri et al. (2017) highlighted the main reason for UHI i.e., Reduction of evaporative cooling is considered to be the dominant factor contributing to UHI. Urban regions in India are presumed to be affected more by climate extremes, such as heat waves and precipitation extremes than non-urban areas, which are strongly related to the urban heat island development. Article attributed the seasonal variation of day-time SUHII to the differences in Evapo-Transpiration (ET) between the urban and nearby non-urban region.

B. Chun et al. (2014) considers the urban heat island (UHI) as a mounting problem in built-up areas, leading to increased temperatures, air pollution, and energy consumption. This paper explores the urban determinants of the UHI, using two-dimensional (2-D) and three-dimensional (3-D) urban information as input to spatial statistical models. The research involves: (a) estimating land surface temperatures, using satellite images, (b) developing a 3-D city model with LiDAR data, (c) conducting spatial regression analyses. The results show that solar radiations, open spaces, vegetation, building roof-top areas, and water strongly impact surface temperatures, and that spatial regressions are necessary to capture neighbouring effects. The best regression is obtained with the general spatial model (GSM), which is then used to simulate the temperature effects of different greening scenarios (green roofs, greened parking and vacant lots, vegetation densification) in the center of Columbus. The results demonstrate the potential of such models to mitigate the UHI through design and land-use policies.

M. Mohan et al. (2011) identified that deterioration of the living environment, increase in the cooling energy requirements, elevation in the ground level ozone and even an increase in the mortality rates are some of the few ill effects of urban heat islands. The mass scale deforestation, the reduction in the green cover, the increase in the built-up land, the use of materials like concrete, asphalt, tar, etc. have significantly altered the energy balance of the urban area often causing the temperature to reach relatively higher value than its surroundings. It is also believed that air pollutants, in particular aerosols, can absorb and re- radiate long wave radiation and inhibit the corresponding radiative surface cooling producing a pseudo-green house effect that may contribute towards the urban heat island effect.

Oleson et al. (2011) mentions in his paper that due to UHI effect present-day annual mean urban air temperatures are up to 4 °C warmer than surrounding rural areas. Averaged over all urban areas resolved in the model, the heat island is 1.1 °C, which is 46% of the simulated mid-century warming over global land due to greenhouse gases. Heat islands are generally largest at night as evidenced by a larger urban warming in minimum than maximum temperature, resulting in a smaller diurnal temperature range compared to rural areas. Spatial and seasonal variability in the heat island is caused by urban to rural contrasts in energy balance and the different responses of these surfaces to the seasonal cycle of climate. The larger storage capacity of urban areas buffers the increase in long-wave radiation such that urban night-time temperatures warm less than rural. Space heating and air conditioning processes add about 0.01 W m^{-2} of heat distributed globally, which results in a small increase in the heat island. The significant differences between urban and rural surfaces demonstrated here imply that climate models need to account for urban surfaces to more realistically evaluate the impact of climate change on people in the environment where they live.

Deilami et al. (2018) provides a systematic and overarching review of different spatial and temporal factors affecting the UHI effect. UHI is a phenomenon when urban areas experience a higher temperature than their surrounding non-urban areas and is considered as a critical factor contributing to global warming, heat related mortalities, and unpredictable climatic changes. Therefore, there is a pressing need to identify the spatial-temporal factors that contribute to (or mitigate) the UHI effect in order to develop a thorough understanding of their causal mechanism so that these are addressed through urban planning policies.

Theeuwes et al. (2012) measured the impact of green vegetation and water surfaces in the urban areas on UHI effect. They found that each 10% vegetative cover can reduce the temperature by 0.6K and commented that trees can reduce the effect substantially.

Akkari (2009) assessed the impact of urban heat island effect in the Enugu city of Nigeria and suggested adaptive measures to keep UHI effect under control in the city. Their study concluded that the use of high dense green vegetation roofing materials and lightening of pavement materials can reduce the effect in Enugu urban.

Yamamota (2006) suggested several mitigation measures for UHI effect and also gave description about some mitigation projects in Japan and other counties including the wind paths in Freiburg in Germany. He recommended some key mitigation measures like energy saving buildings and traffic systems, restoring green areas in urban areas and improvement airflow.

4. Aim

The main aim of the study is to assess the impact of Urban heat island on health of the urban dwellers.

Objectives:

1) To understand the concept of Urban heat island.
2) To analyze its impact on health of urban dwellers.
3) To Identify the link between the Relative Humidity and Heat Index.
4) To suggest mitigation strategies to prevent the effect of Urban Heat Island.

5. Methodology

Study is based on secondary descriptive data collected from various sources and statistically analysed using Multiple regression analysis and Pearson's Correlation coefficient analysis.

1) Analyse the temperature and relative humidity of Mega Cities during Pre-monsoonal summer season (March-April-May) for the years 2005,2010,2015 and 2020.
    a) New Delhi
    b) Chennai

  c) Hyderabad
  d) Mumbai
2) Land Use Land Cover (LULC) map for above cities are also considered for understanding the extent of Urban Sprawl.
3) Calculate the Heat index through multiple regression analysis carried out by Lans P. Rothfus.
4) Calculate the correlation between Relative Humidity and Heat Index.
5) Analyse Heat wave death statistics from 2010-2020.
6) Choropleth of Heat wave map of India for the year 2015 is plotted.

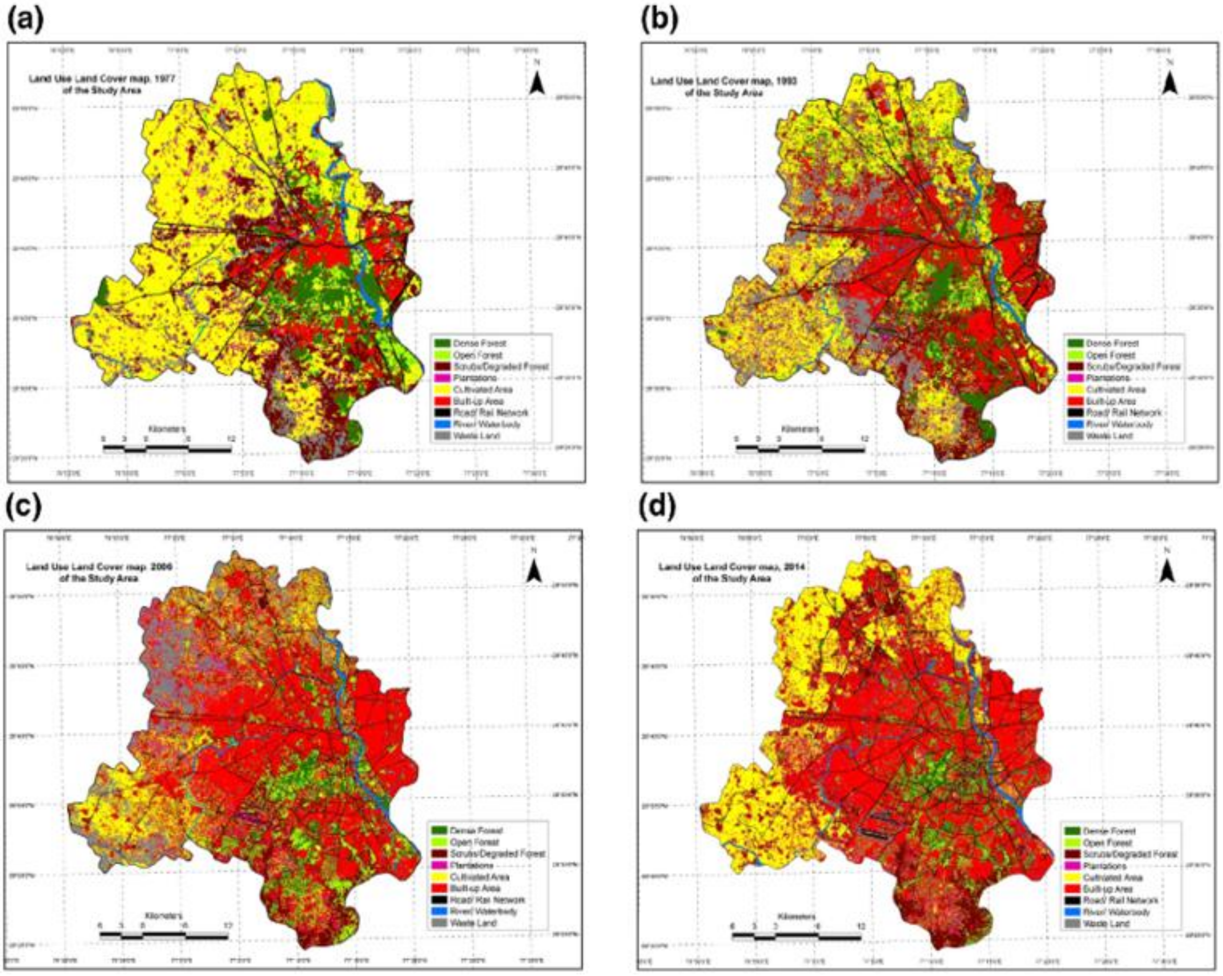
6. Study Area

Republic of India
States: 28 states
UTs: 8
Total Geographical Area: 3.28 million km2 or 328 million hectares
Population: 1.2billion (Census 2011)
Heat wave affected states: 22 states.

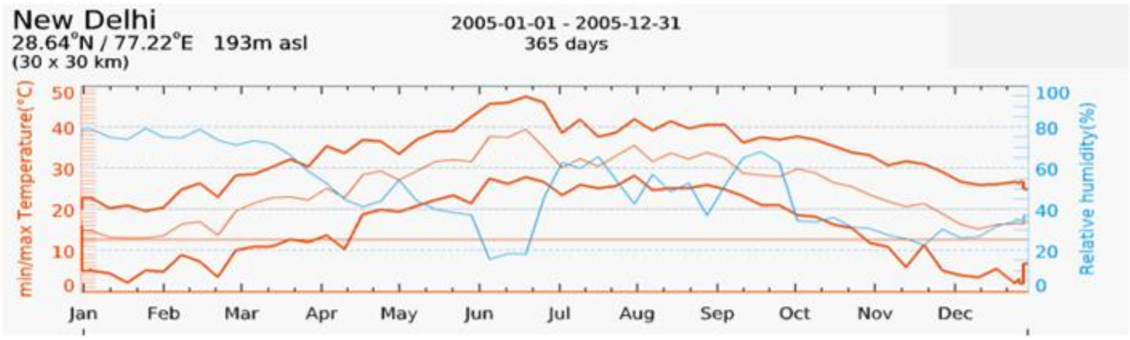
Figure 3: Map of India

7. Results & Discussion

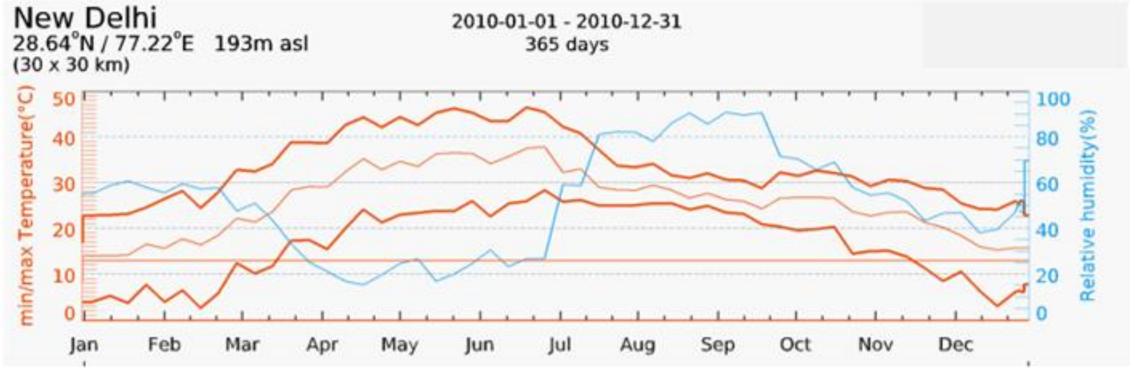
1) Temperature and relative humidity of Mega Cities during Pre-monsoonal summer season (March-April-May-June) for the year 2005,2010,2015 and 2020 is shown below:
  a) New Delhi National Capital Territory of Delhi, India, 28.64°N 77.22°E, 212m asl Land Use and Land Cover (LULC MAP showing Urban Sprawl (US)


(a)
Land Use Land Cover map, 1977 of the Study Area
(b)
Land Use Land Cover map, 1993 of the Study Area
(c)
Land Use Land Cover map, 2006 of the Study Area
(d)
Land Use Land Cover map, 2014 of the Study Area
N
Kilometers
0 3 6 9 12
Dense Forest
Open Forest
Scrubs/Degraded Forest
Plantations
Cultivated Area
Built-up Area
Road/ Rail Network
River/ Waterbody
Waste Land

2005


New Delhi
28.64°N / 77.22°E 193m asl
(30 x 30 km)
2005-01-01 - 2005-12-31
365 days
min/max Temperature(°C)
50
40
30
20
10
0
Relative humidity(%)
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

2010


New Delhi
28.64°N / 77.22°E 193m asl
(30 x 30 km)
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365 days
min/max Temperature(°C)
50
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Relative humidity(%)
100
80
60
40
20
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Jan
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Oct
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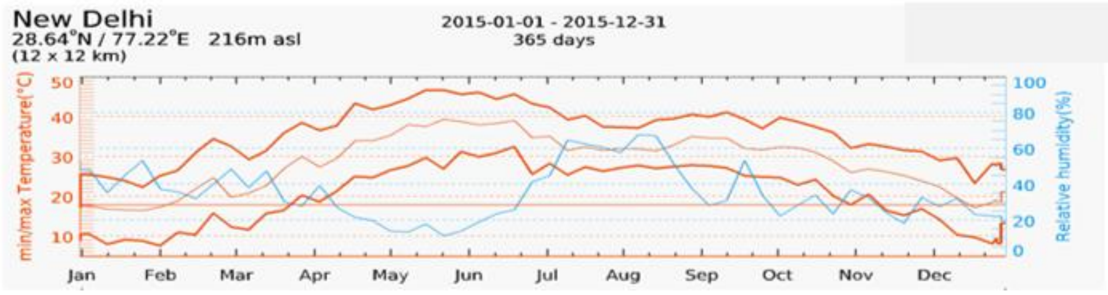
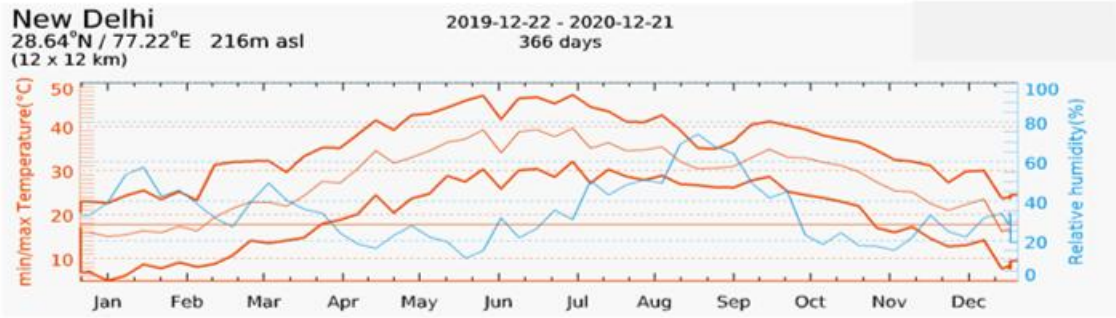
Dec

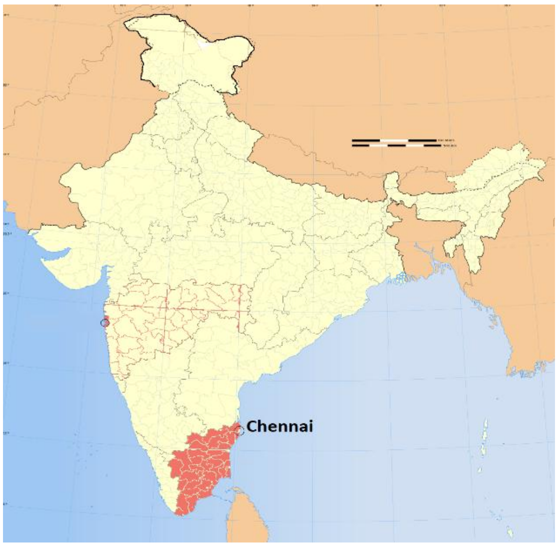
2015



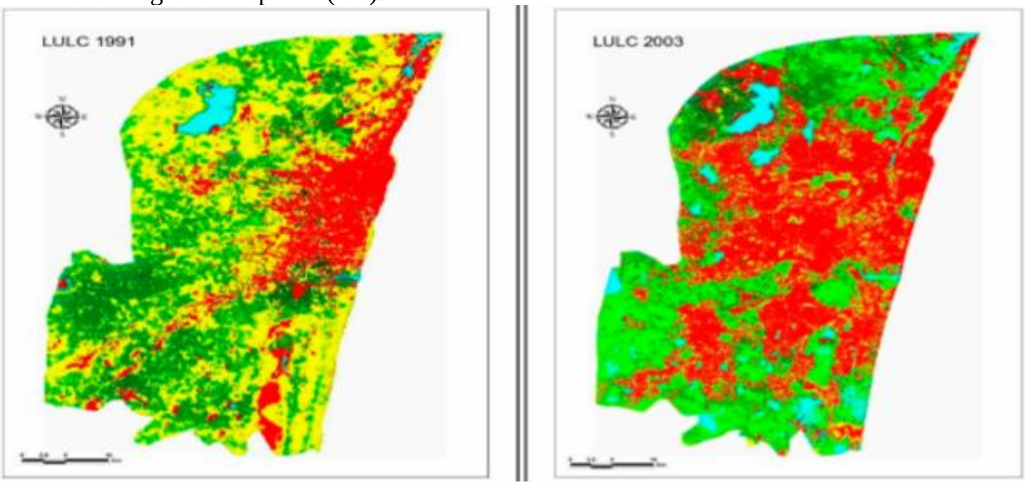
2020

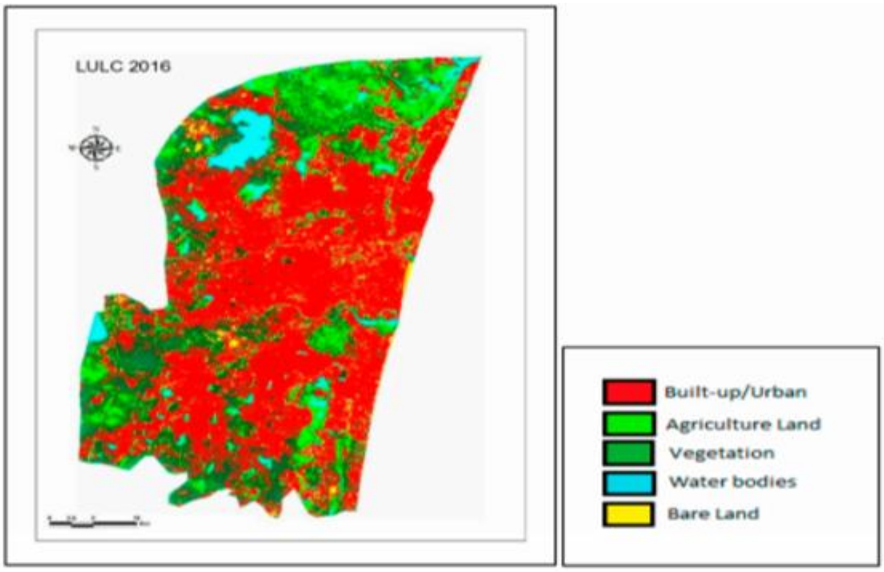


b) Chennai, Tamil Nadu, India 13.09°N 80.28°E, 14m asl



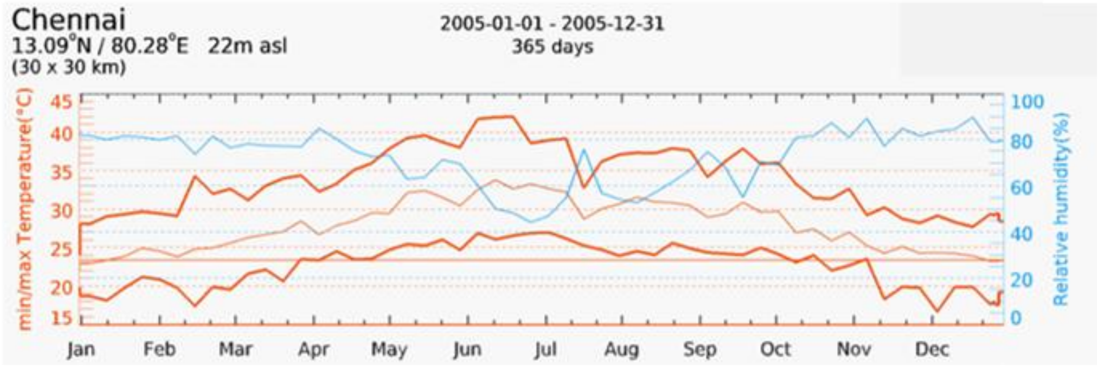
Chennai LULC MAP showing Urban Sprawl (US).



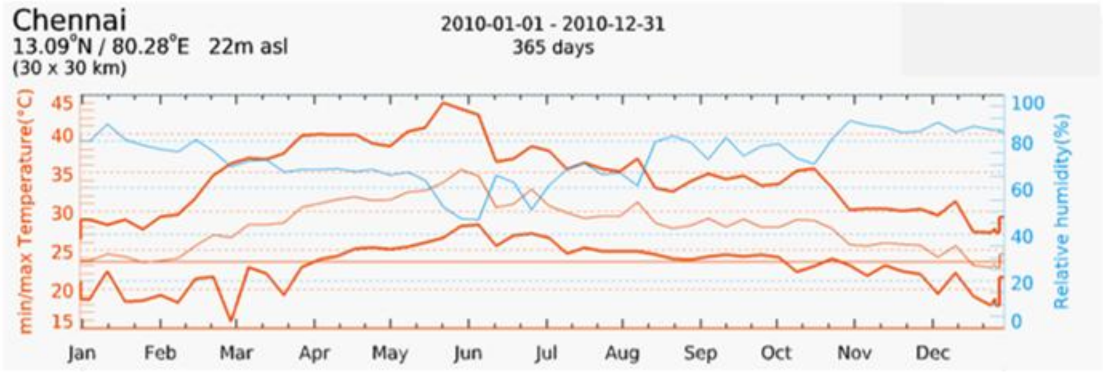


Source: earthdata.nasa.org

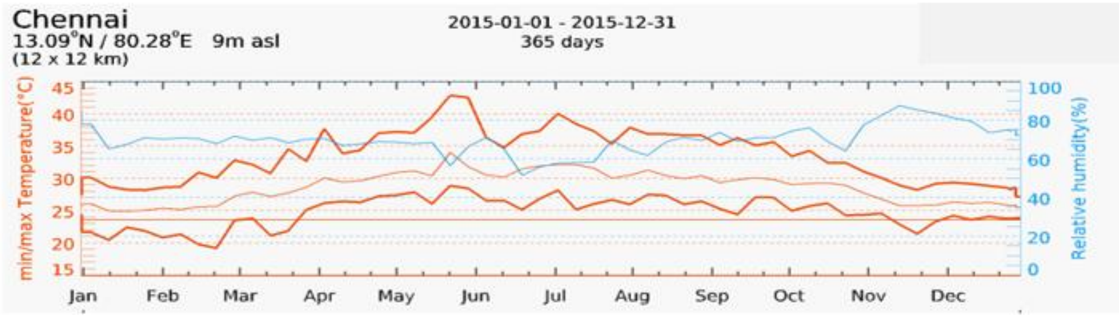
2005



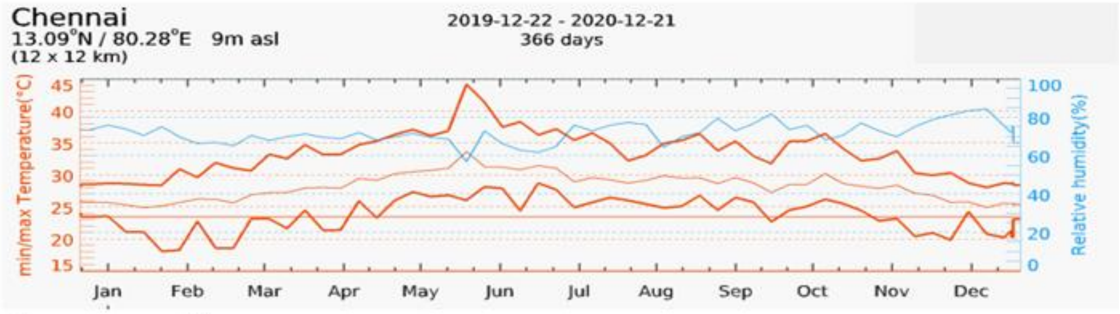
2010



2015



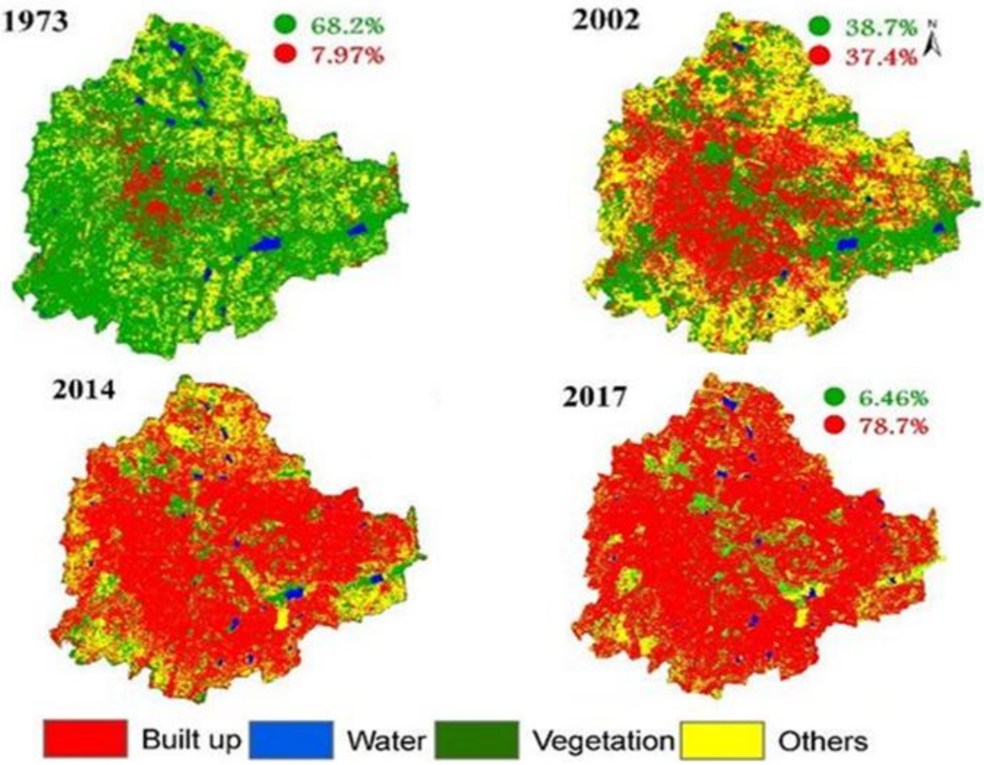
2020



Source: meteoblue.org

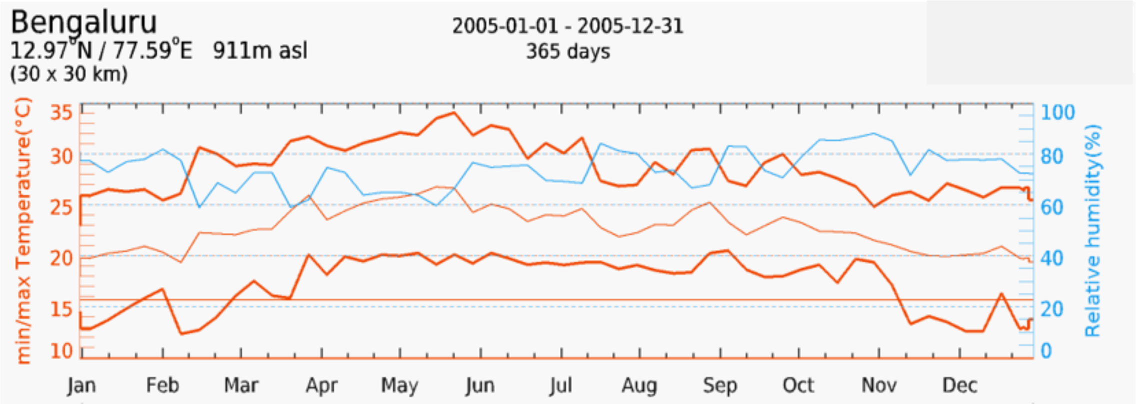
c) Bangalore Karnataka, India, 12.97°N 77.59°E, 920m asl

Bangalore LULC MAP showing Urban Sprawl (US)



Source: earthdata.nasa.org

2005



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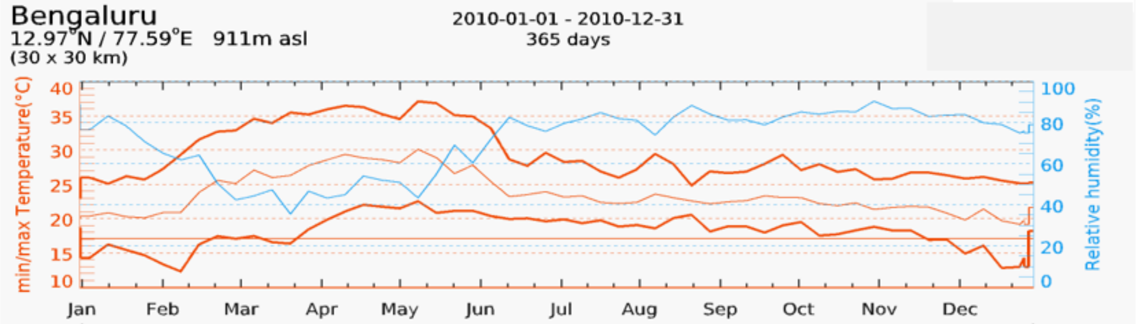
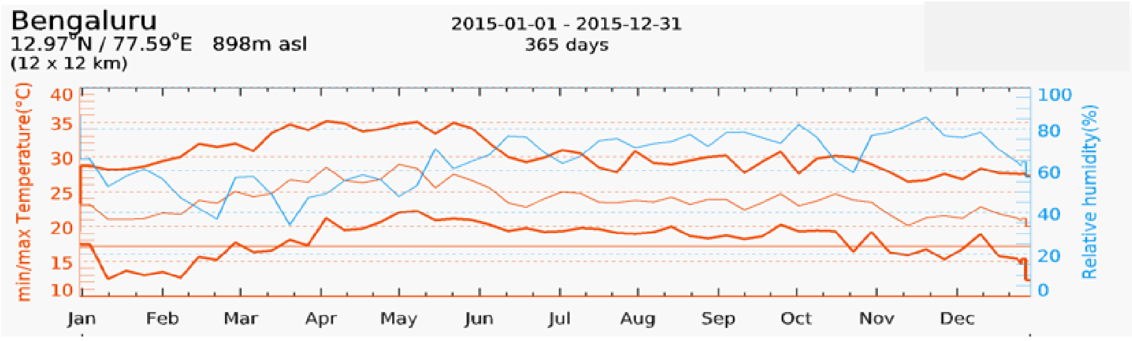
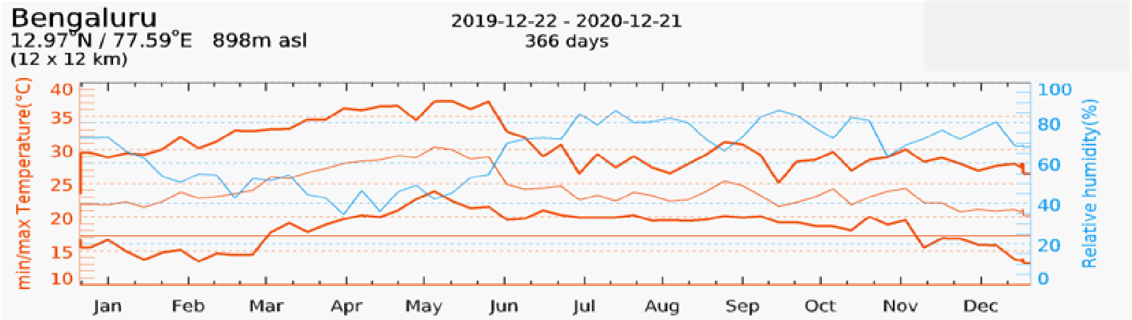


2015



2020



Source: meteoblue.org

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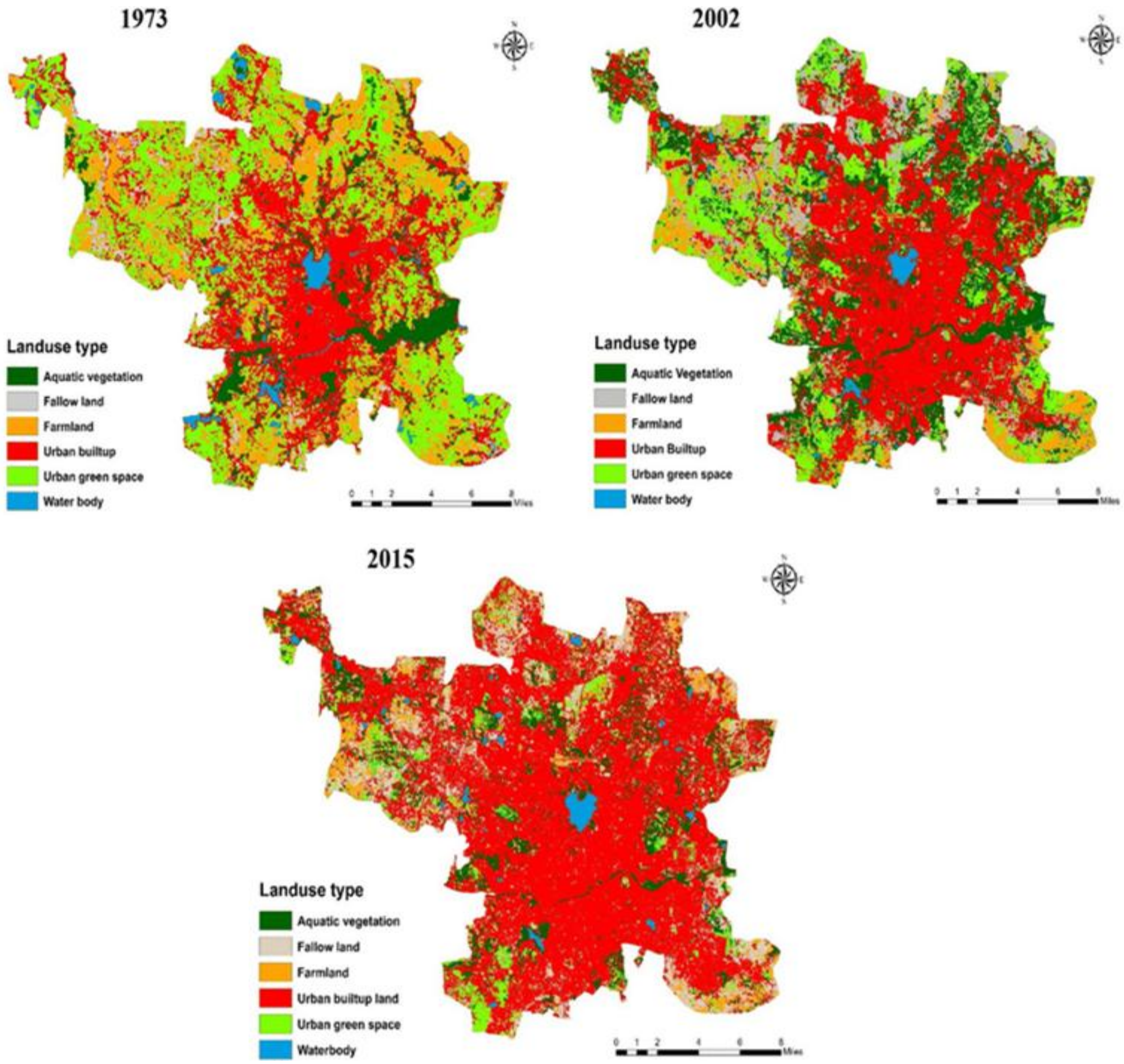
a. Hyderabad, Telangana, India, 17.38°N 78.46°E, 515m asl

Hyderabad LULC Map showing Urban Sprawl (US)



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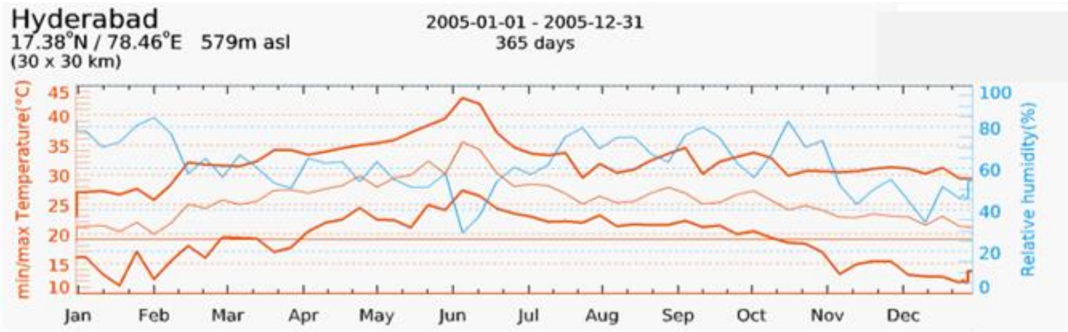
2005



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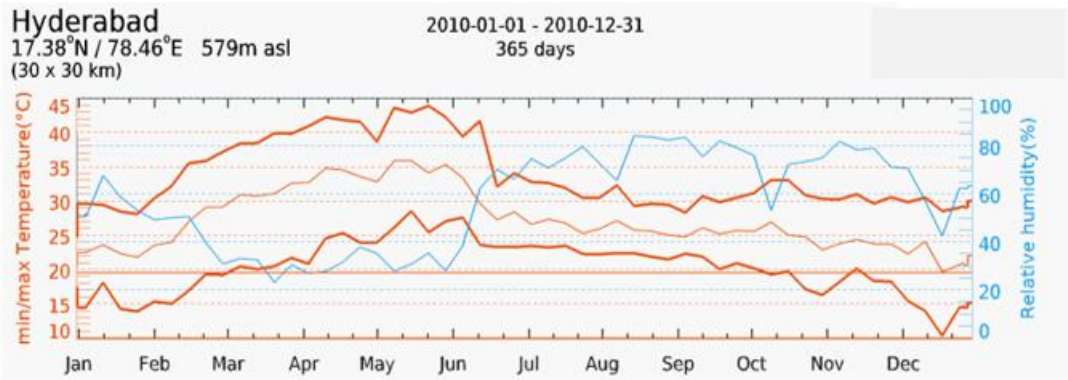
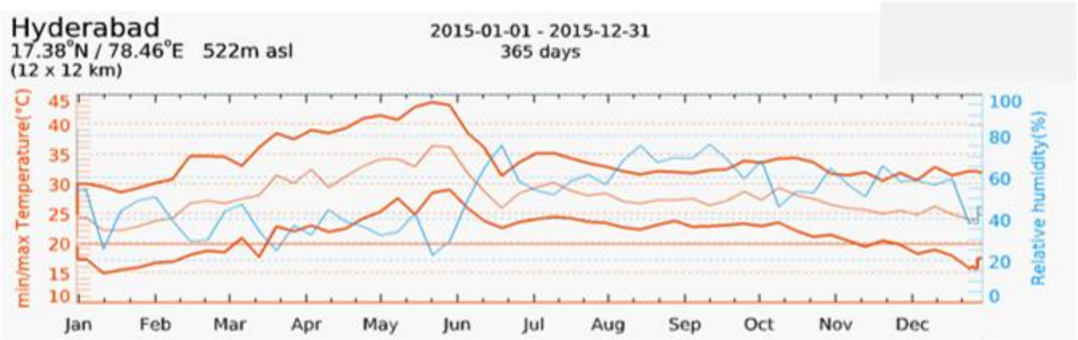
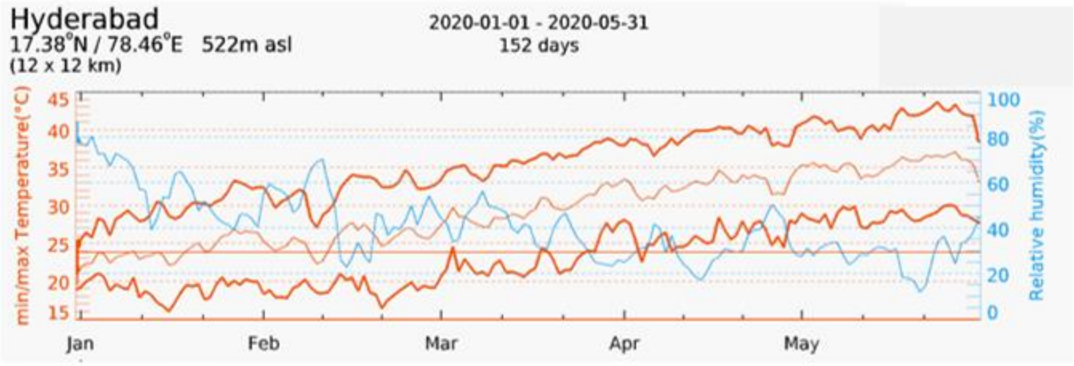


2015



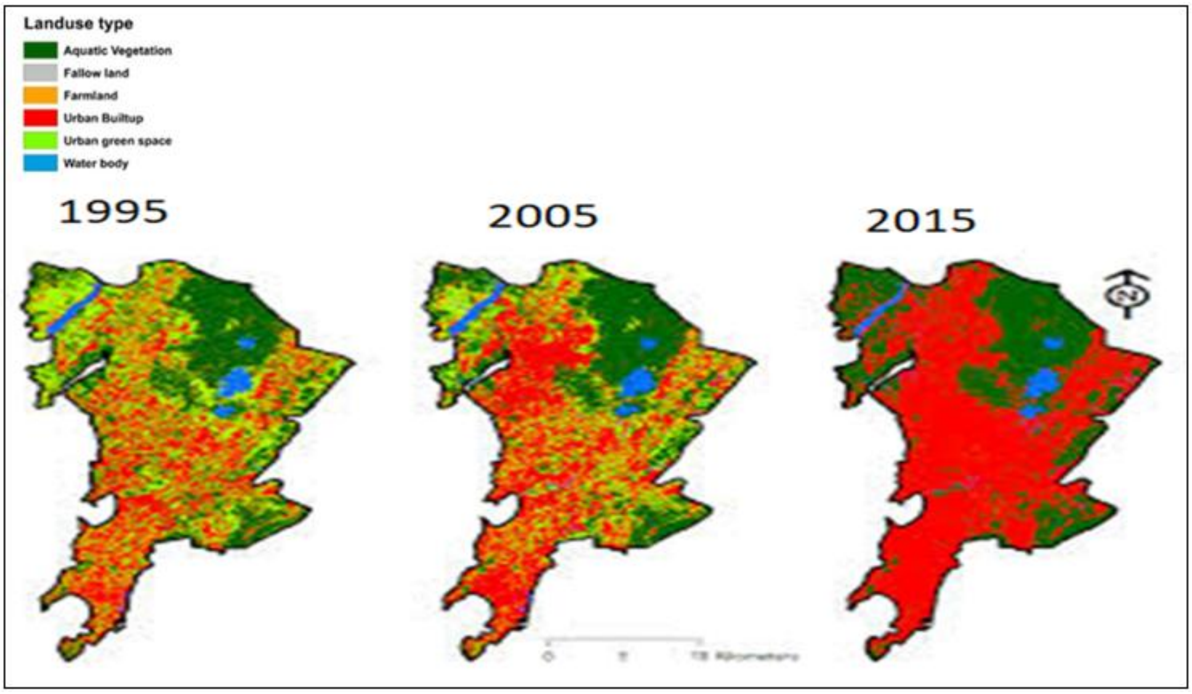
2020



Source: meteoblue.org

b. Mumbai, Maharashtra, India, 19.07°N 72.88°E, 8m asl

Mumbai LULC Map showing Urban Sprawl (US)



Source: earthdata.nasa.org

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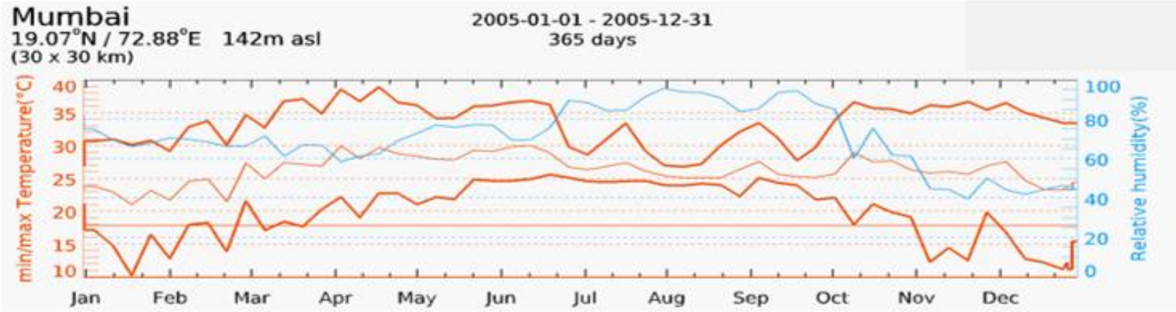

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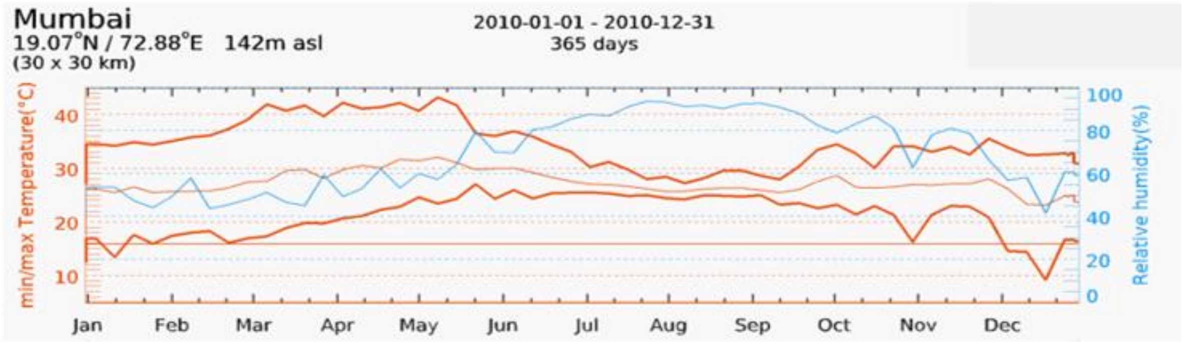

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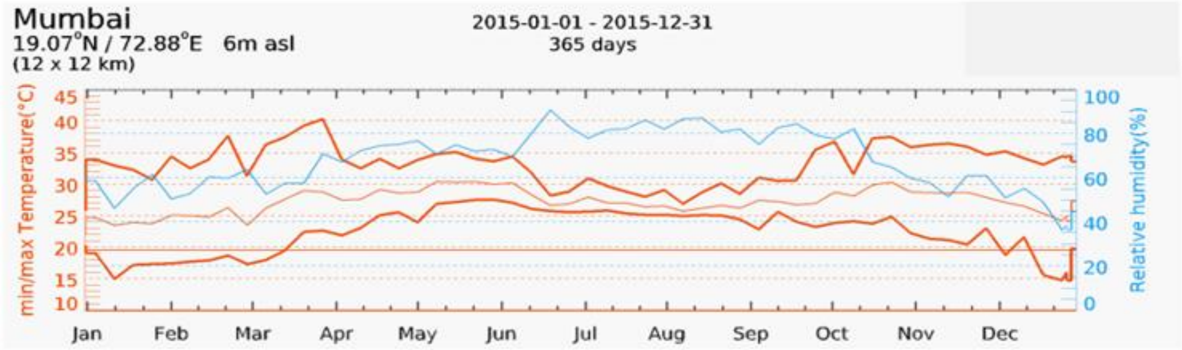

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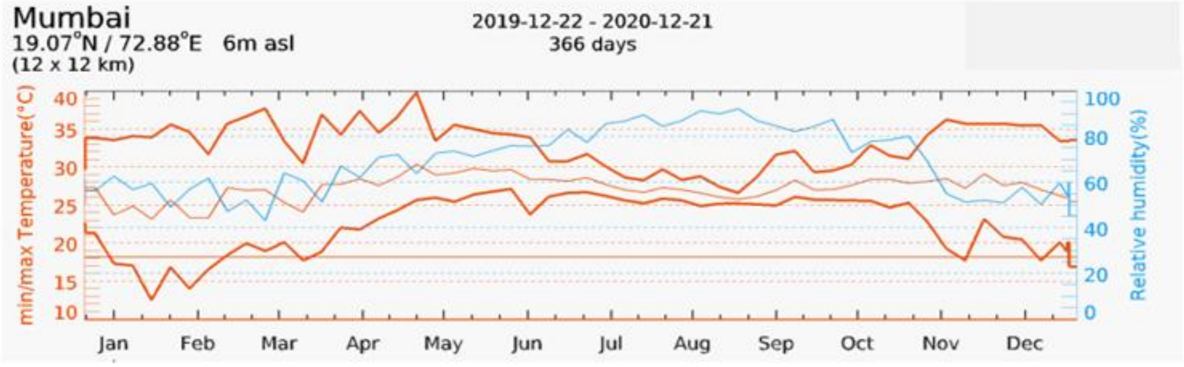


Source: meteoblue.org

1) Heat Index

The Heat Index is a measure of how hot it really feels when relative humidity is factored in with the actual air temperature.

The human body normally cools itself by perspiration, or sweating. Heat is removed from the body by evaporation of that sweat. However, high relative humidity reduces the evaporation rate. This results in a lower rate of heat removal from the body, hence the sensation of being overheated.

The computation of the heat index is a refinement of a result obtained by multiple regression analysis carried out by Lans P. Rothfus.

The regression equation of Rothfusz is

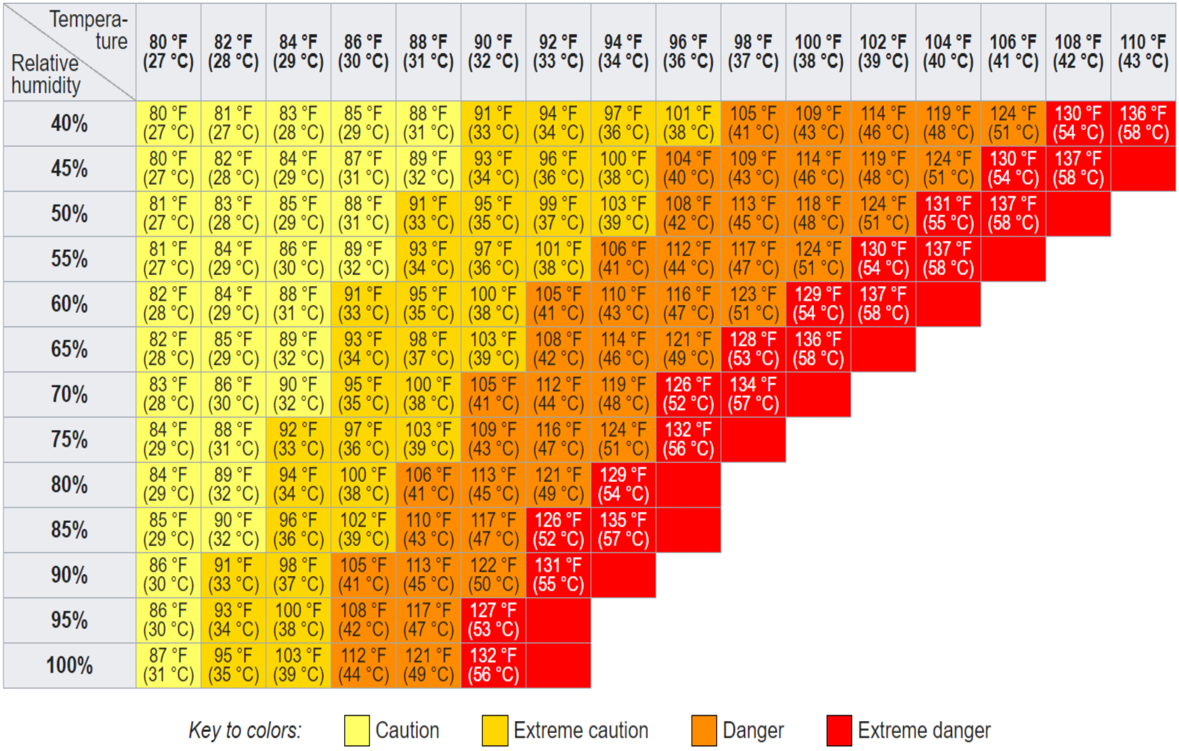
$$HI = -42.379 + 2.04901523*T + 10.14333127*RH - .22475541*T*RH - .00683783*T*T - .05481717*RH*RH + .00122874*T*T*RH + .00085282*T*RH*RH - .00000199*T*T*RH*RH$$

Where, T is temperature in degrees F and RH is relative humidity in percent. HI is the heat index expressed as an apparent temperature in degrees F.

This combined effect is called the " Heat Index." The higher the air temperature and/or the higher the relative humidity, the higher is the heat index and the hotter it feels to our bodies.

Celsius	Notes
26–32 °C	Caution: fatigue is possible with prolonged exposure and activity. Continuing activity could result in heat cramps.
32–41 °C	Extreme caution: heat cramps and heat exhaustion are possible. Continuing activity could result in heat stroke.
41–54 °C	Danger: heat cramps and heat exhaustion are likely; heat stroke is probable with continued activity.
over 54 °C	Extreme danger: heat stroke is imminent.

NOAA national weather service: heat index



Temperature / Relative humidity	80 °F (27 °C)	82 °F (28 °C)	84 °F (29 °C)	86 °F (30 °C)	88 °F (31 °C)	90 °F (32 °C)	92 °F (33 °C)	94 °F (34 °C)	96 °F (36 °C)	98 °F (37 °C)	100 °F (38 °C)	102 °F (39 °C)	104 °F (40 °C)	106 °F (41 °C)	108 °F (42 °C)	110 °F (43 °C)
40%	80 °F (27 °C)	81 °F (27 °C)	83 °F (28 °C)	85 °F (29 °C)	88 °F (31 °C)	91 °F (33 °C)	94 °F (34 °C)	97 °F (36 °C)	101 °F (38 °C)	105 °F (41 °C)	109 °F (43 °C)	114 °F (46 °C)	119 °F (48 °C)	124 °F (51 °C)	130 °F (54 °C)	136 °F (58 °C)
45%	80 °F (27 °C)	82 °F (28 °C)	84 °F (29 °C)	87 °F (31 °C)	89 °F (32 °C)	93 °F (34 °C)	96 °F (36 °C)	100 °F (38 °C)	104 °F (40 °C)	109 °F (43 °C)	114 °F (46 °C)	119 °F (48 °C)	124 °F (51 °C)	130 °F (54 °C)	137 °F (58 °C)	
50%	81 °F (27 °C)	83 °F (28 °C)	85 °F (29 °C)	88 °F (31 °C)	91 °F (33 °C)	95 °F (35 °C)	99 °F (37 °C)	103 °F (39 °C)	108 °F (42 °C)	113 °F (45 °C)	118 °F (48 °C)	124 °F (51 °C)	131 °F (55 °C)	137 °F (58 °C)		
55%	81 °F (27 °C)	84 °F (29 °C)	86 °F (30 °C)	89 °F (32 °C)	93 °F (34 °C)	97 °F (36 °C)	101 °F (38 °C)	106 °F (41 °C)	112 °F (44 °C)	117 °F (47 °C)	124 °F (51 °C)	130 °F (54 °C)	137 °F (58 °C)			
60%	82 °F (28 °C)	84 °F (29 °C)	88 °F (31 °C)	91 °F (33 °C)	95 °F (35 °C)	100 °F (38 °C)	105 °F (41 °C)	110 °F (43 °C)	116 °F (47 °C)	123 °F (51 °C)	129 °F (54 °C)	137 °F (58 °C)				
65%	82 °F (28 °C)	85 °F (29 °C)	89 °F (32 °C)	93 °F (34 °C)	98 °F (37 °C)	103 °F (39 °C)	108 °F (42 °C)	114 °F (46 °C)	121 °F (49 °C)	128 °F (53 °C)	136 °F (58 °C)					
70%	83 °F (28 °C)	86 °F (30 °C)	90 °F (32 °C)	95 °F (35 °C)	100 °F (38 °C)	105 °F (41 °C)	112 °F (44 °C)	119 °F (48 °C)	126 °F (52 °C)	134 °F (57 °C)						
75%	84 °F (29 °C)	88 °F (31 °C)	92 °F (33 °C)	97 °F (36 °C)	103 °F (39 °C)	109 °F (43 °C)	116 °F (47 °C)	124 °F (51 °C)	132 °F (56 °C)							
80%	84 °F (29 °C)	89 °F (32 °C)	94 °F (34 °C)	100 °F (38 °C)	106 °F (41 °C)	113 °F (45 °C)	121 °F (49 °C)	129 °F (54 °C)								
85%	85 °F (29 °C)	90 °F (32 °C)	96 °F (36 °C)	102 °F (39 °C)	110 °F (43 °C)	117 °F (47 °C)	126 °F (52 °C)	135 °F (57 °C)								
90%	86 °F (30 °C)	91 °F (33 °C)	98 °F (37 °C)	105 °F (41 °C)	113 °F (45 °C)	122 °F (50 °C)	131 °F (55 °C)									
95%	86 °F (30 °C)	93 °F (34 °C)	100 °F (38 °C)	108 °F (42 °C)	117 °F (47 °C)	127 °F (53 °C)										
100%	87 °F (31 °C)	95 °F (35 °C)	103 °F (39 °C)	112 °F (44 °C)	121 °F (49 °C)	132 °F (56 °C)										

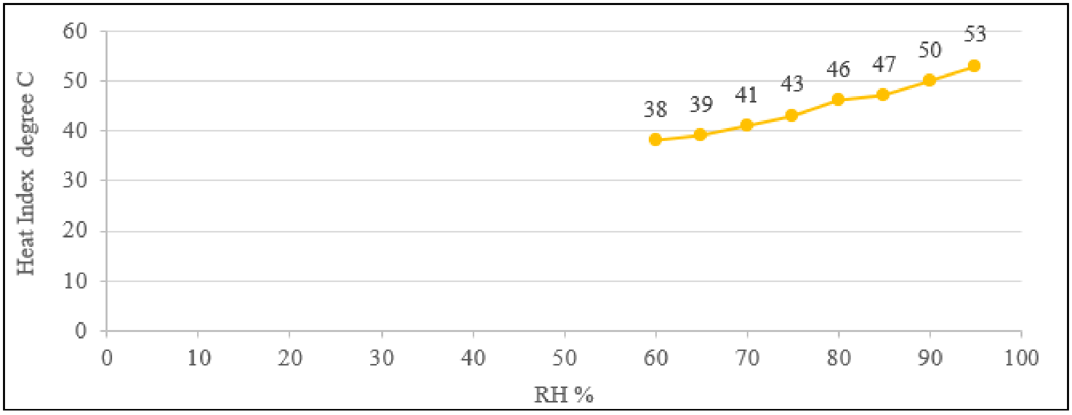
Key to colors: 🟨 Caution 🟨 Extreme caution 🟧 Danger 🟥 Extreme danger

1. **Correlation between Relative Humidity and Heat Index.**

Table 2: Correlation between Relative Humidity and Heat Index

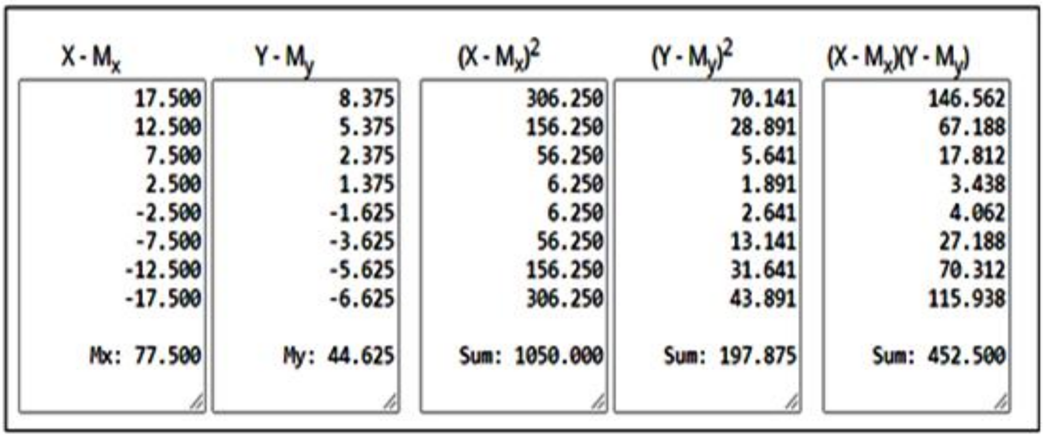
(X)Relative Humidity%	(Y) Heat Index (°c)
95	53
90	50
85	47
80	46
75	43
70	41
65	39
60	38

Correlation Graph

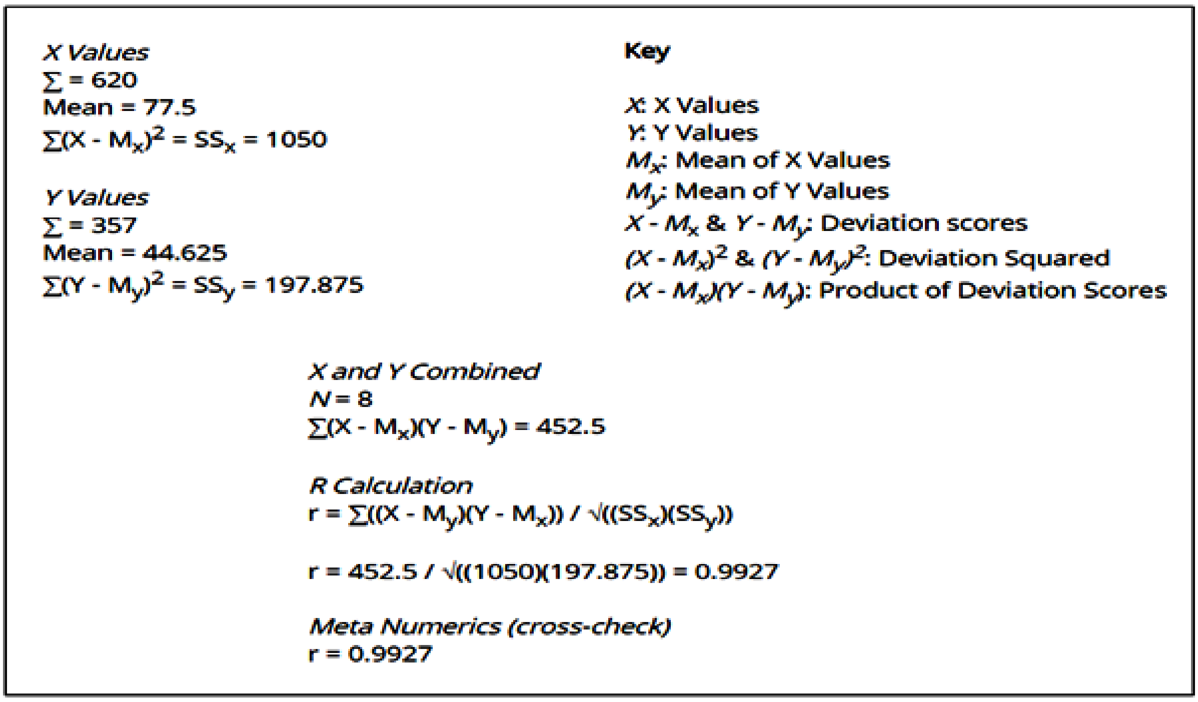


Source: www.who.org

Calculations



$X - M_x$	$Y - M_y$	$(X - M_x)^2$	$(Y - M_y)^2$	$(X - M_x)(Y - M_y)$
17.500	8.375	306.250	70.141	146.562
12.500	5.375	156.250	28.891	67.188
7.500	2.375	56.250	5.641	17.812
2.500	1.375	6.250	1.891	3.438
-2.500	-1.625	6.250	2.641	4.062
-7.500	-3.625	56.250	13.141	27.188
-12.500	-5.625	156.250	31.641	70.312
-17.500	-6.625	306.250	43.891	115.938
Mx: 77.500	My: 44.625	Sum: 1050.000	Sum: 197.875	Sum: 452.500



X Values
$\sum = 620$
Mean = 77.5
$\sum(X - M_x)^2 = SS_x = 1050$

Y Values
$\sum = 357$
Mean = 44.625
$\sum(Y - M_y)^2 = SS_y = 197.875$

Key

X: X Values
Y: Y Values
M_x: Mean of X Values
M_y: Mean of Y Values
$X - M_x$ & $Y - M_y$: Deviation scores
$(X - M_x)^2$ & $(Y - M_y)^2$: Deviation Squared
$(X - M_x)(Y - M_y)$: Product of Deviation Scores

X and Y Combined
$N = 8$
$\sum(X - M_x)(Y - M_y) = 452.5$

R Calculation
$r = \sum((X - M_y)(Y - M_x)) / \sqrt{((SS_x)(SS_y))}$

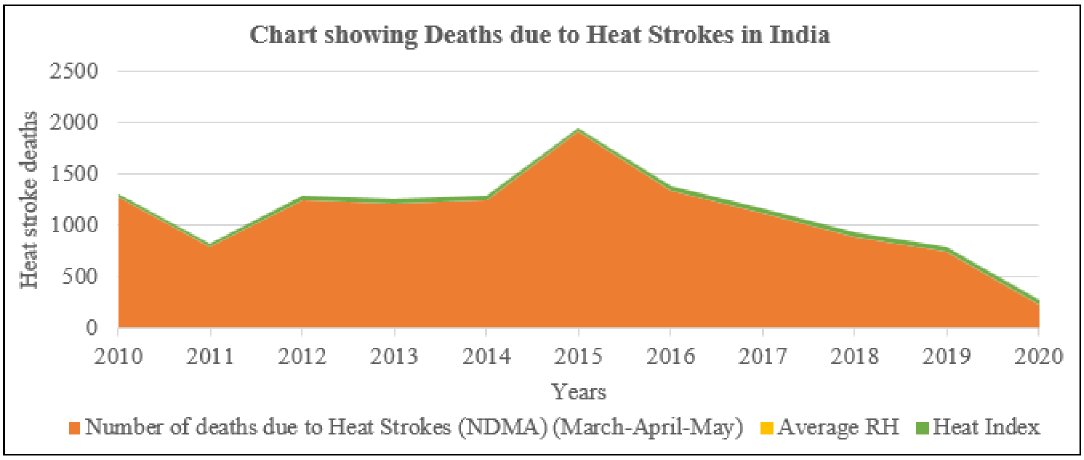
$r = 452.5 / \sqrt{((1050)(197.875))} = 0.9927$

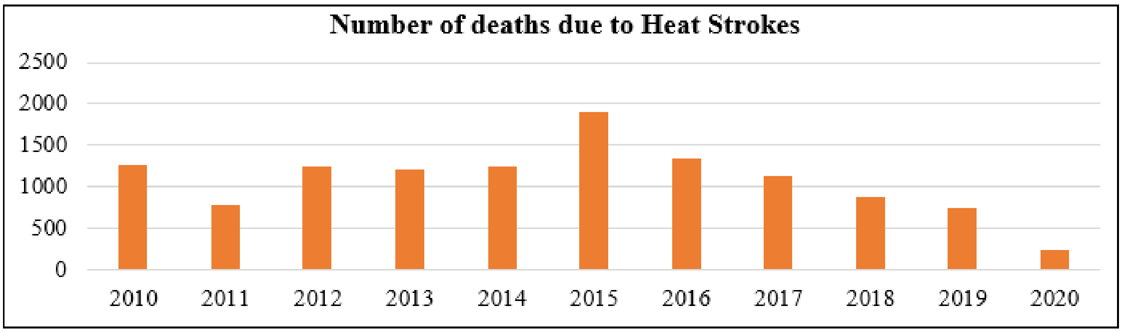
Meta Numerics (cross-check)
$r = 0.9927$

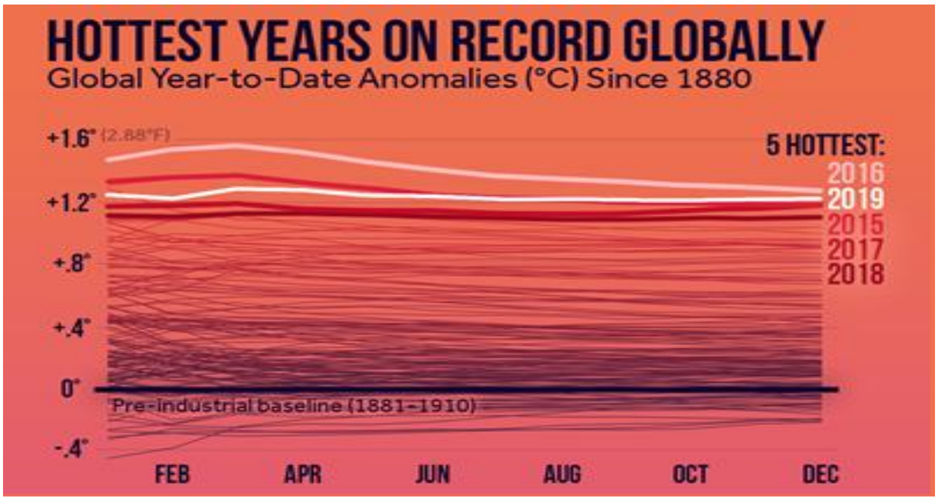
As per the above calculations, correlation coefficient observed is 0.9927, which indicates very high correlation between Relative Humidity and Heat Index.

d) Heat wave related death statistics

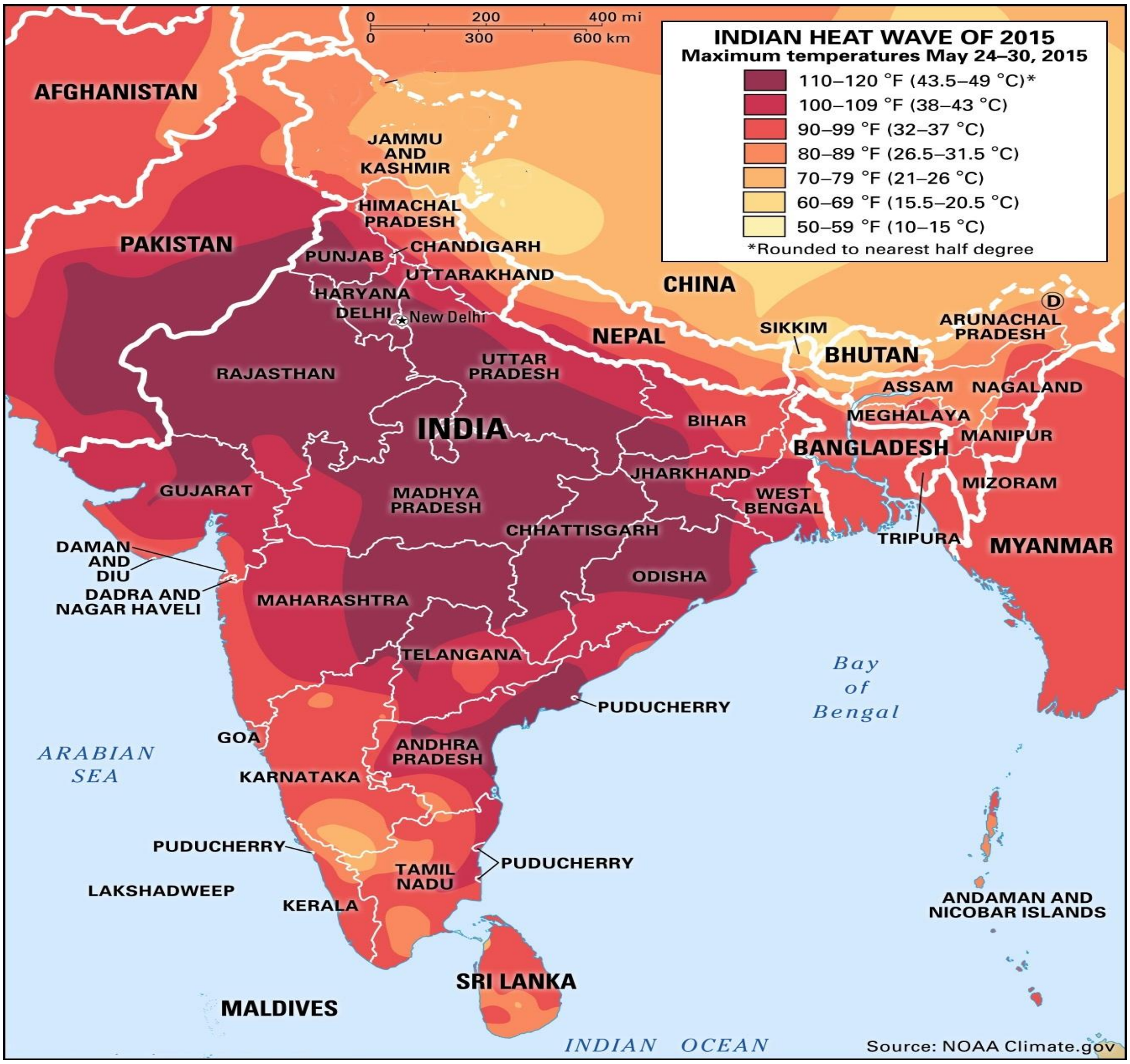
Year	Number of deaths due to Heat Strokes (NDMA) (March-April-May)	Temperature(°c) (March-April-May)			Average RH	Heat Index
2010	1274	28	34	36	32.3%	38
2011	793	29	33	36	33%	39
2012	1247	30	35	38	34%	40
2013	1216	31	38	37	33%	42
2014	1248	33	37	39	34%	44
2015	1908	32	38	39.5	37%	45
2016	1338	33	38	40	36%	46
2017	1127	32	35	37	33%	44
2018	890	33	36	38	34%	43
2019	746	34	35	37	32%	41
2020	240	30	34	36	33%	40







Source: earthdata.nasa.org



Source: NOAA Climate.gov

Mitigation Strategies

According to Sailor (2006) the urban heat island effect mitigation can be done in two ways. One is by increasing the albedo of the urban surface and the other is by increasing evapotranspiration. However, the major strategies to mitigate the UHI effect are described below:

a) High Albedo Roofing materials and Terrace Gardening (Green Roofs, Walls)
b) High Albedo Pavement such as White-Topping of Roads
c) Increasing the Green Cover in the Urban areas- Parks, Shade trees, Urban forests etc
d) Conservation of Water-bodies like Lakes and Wetlands.
e) Controlling Air Pollution.

8. Conclusion

The current study analyses the concept of Heat Index and explains how Urban heat Island influences heat index of the regions and its corresponding effect on the health of urban dwellers. Heat index is an efficient measure of the impact of UHI, it was calculated using multiple regression analysis method first developed by Lans P. Rothfus. It combines the values of air temperature and Relative Humidity to estimate the heat felt by an individual in the Urban area. Relative Humidity is very important weather element because it controls perspiration rate of an individual; higher the relative humidity, lower is the perspiration. Lower Perspiration in hot summers can result in heat cramps, exhaustion and heat strokes. Positive correlation was found between relative humidity and heat index by using Pearsons Correlation coefficient. Urban sprawl, urban canopy, low albedo surfaces, loss of evaporative surfaces like vegetation, waterbodies were found to be the main reasons for UHI, as a result necessary policy intervention, people’s participation is required for reducing the impact of UHI. Urban areas are the future of the modern economy and should be made more sustainable for the in a long run.

Finally, from a critical point of view, the following aspects are re-quired to be taken into account in future studies:

- The interrelations of urban morphology and UHI intensity result in very complex and multifaceted scenarios which require more in-depth and interdisciplinary studies towards mitigating the UHI effects in various urban settings under different climatic conditions.
- Future studies are recommended to be more focused on putting forward new solutions that are capable of being integrated with diverse urban contexts while being economically justifiable.

- Future studies are suggested to integrate multiple UHI mitigation strategies as a portfolio of solutions in order to optimize the effectiveness of combined strategies as well as their possible counter-interactions.

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