Spatio-Temporal Analysis Of Urbanization In Surat Region

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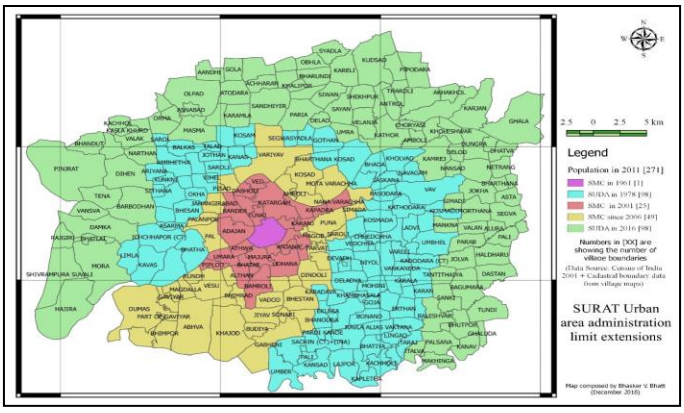
Abstract: Surat city has emerged as an earmarked urban space drifting with the development of built-up areas. The momentum was observed in the decadal census of the year 2001 while the city registered a decadal growth rate of higher than 88%. Globally, the city is ranking among the top hundred considering various lists, and yet the pace is not slowed down. The emerging buildings are occupied in different purposes viz. residential, commercial, institutional and industrial as well. Along with buildings, connectivity through more extensive and planned roads and other infrastructure are also made available to citizens migrating in and settling in the city. The current research work is aiming to understand and analyse the developmental trend spatially (NDVI based) on an annual temporal scale for the duration since the year 1995 till 2019. Satellite images of Land SAT missions of 4-5, 7 and 8 are used for processing and extracting information of the past situations. Area delineation for the analysis was made considering the administrative boundary of the Surat Urban Development Authority (1357 km2). Not only the direction of development is identified, but also, the area being converted in the built-up spaces is worked out. The findings are suggesting the growth (planned though) in the North-east and South-West directions. These are towards the inland and away from the Arabian Sea in the West. The developed spaces are consuming agricultural pastures in the fringe. The annual rainfall has significantly allowed for agrarian activities around the year, adding prosperity among citizens. Authors attempted to discuss the results of an analysis for minimum and maximum temperatures and rainfall pattern for a duration of two decades. Also, the developing areas are identified to be vulnerable to inland flooding and sea-surge as projected through global IPCC Models. The paper discusses the details with possible remedial measures through the mechanism of modifications in the existing planned land-use (development plan).

Index Terms: Climate change, Development, Image processing, Land SAT, Urbanization.

1. INTRODUCTION

The urban expansion involves the land-use shift from natural vegetation or flora state to the inevitable development of built forms. In the western part of India, Surat urban agglomeration recorded a population of 14.98 Lakh and 28.11 Lakh in the years 1991 and 2001 respectively (Rokad & Bhatt, 2014a). It increased to 45.91 Lakh by the year 2011, reporting a growth rate of 87.59 and 63.30 percent in the past two decades respectively (Surat Municipal Corporation, 2015). The city reached on the ninth position amongst million-plus cities in India (City Mayors, 2011). City Mayors Statistics (the year 2007) listed Surat as the fourth fastest-growing cities on the globe with 4.99% average annual growth for the duration of 2006 to 2020 (PTI, 2018). Also, it is projecting for Surat to be 41st largest urban areas on the globe housing a population of about 7.72 million (Rokad & Bhatt, 2014b). Fig. 1 below shows the extent of regulatory limits as extended over years for Surat Municipal Corporation (SMC) and Surat Urban Development Authority (SUDA). The image shows the facilitation granted by the state government for urban expansion by extensions of civic administration over a period of half a century.



Source: Authors

Figure 1: *Administrative limit extension for SMC and SUDA*

The SMC is consistently and efficiently puttingefforts to serve the citizens through the provision of infrastructure and services towards compliance to the Constitute of India and Amendment acts. The SMC has been recognised through bagging several national and international awards of appreciation- 78 awards since the year 1997 (Surat-Municipal-Corporation, 2019). The Gujarat State Government established SUDA in the year 1978 under the provisions of the Gujarat TP and UD Act, 1976 (Surat Urban Development Authority, 2015). The authority was declared with an area of administration as 722 km2 that remained until the extension in the year 2016 (SUDA, 2014). The primary function of the authority is to prepare a development plan of the area under administration and prepare for town planning schemes in the areas of fringe to Surat city (Government of Gujarat, 1976). Besides, the formulation of development control norms, i.e. building byelaws was also among the responsibility assigned to SUDA. However, the criteria are defined by the Government of Gujarat and implemented-monitored by SUDA after implementation of the CGDCR act (Urban Development and Urban Housing Development Department, 2019) since about a year now. There is an overlay from government departments and state as well national level lateral organizations to tackle

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with activities about various sectors which seek for a unified and integrated approach for sensible development of cities. Facilitation from all the organisations towards progressive development probably will enablefor people to get attracted while in search of economic growth that will results in a substantial rise in the population of the city.

2. LITERATURE REVIEW

Sharma R. et al. (during the year 2012) at TERI University conducted a detailed study on Spatio-temporal footprints of urbanisation in Surat for the year 1990-2009 (R. Sharma, Ghosh, & Joshi, 2013). The study claimed for a derived increase of 42 km2 approximately per decade up to the year 2009. However, the paper does not discuss the aspects of demographics and its linkages with urbanisation as well as information on climatic variations. Following the rise in the population, the city limits also were extended (Surat Municipal Corporation, 2013). The land-use-land cover (LU-LC) and population density play a vital role in the generation of urban heat island effect in the habituated area (Rajashree & Meenal, 2016). The heat island results in an adverse effect on urban climate: increase in urban area results in a rise in various activities, transits of people and commodities showing inter and intra-space movements resulting in the emission of greenhouse gases (Kalnay & Cai, 2003) by the deployment of vehicles on transit axis. Surat was situated on the banks of Tapi River initially. However, the extent of urbanisation has made the city to have banks of two perennial rivers with inclusion of Mindhola river at the Southern administrative boundary (Bhatt, Kumar, & Sharma, 2020). Both the rivers carry a large quantum of water during monsoon season and have an extensive system of natural drains. Developed land parcels without consideration of floods have resulted for areas of Surat get flooded at times (UN Development Programme, 2006). For cities that are prone to flood, the urbanisation increases long-term risks (Zhu, Lund, Jenkins, Marques, & Ritzema, 2007). The urbanisation and change in local climate also affect the biodiversity (Clavero, Villero, & Brotons, 2011). Hence, the urbanisation may result in many adverse effects and needs to be appropriately managed to employ visionary planning and effective implementation thereof, to avoid the ill-effects to an extent possible. On a temporal-scale, the local climate change effects are taking place slowly, and citizens evolve with capacities to sustain natural climatic extremities (Tanja Wolf, 2013).

3. OBJECTIVES

A careful study of literature motivated the researchers to focus on understanding the growth directions of the urbanisation that is observed and local climatic variations. The goals set forth here include: (1) to understand the spatial population trend; (2) to make an to identify the directional growth of built-up within the study area; (3) to understand the atmospheric variation towards extreme occurrences. A methodology is thought of overlaying of the records available from diverse sources to generate a possible meaningful intervention if any. A further challenge can then be identified and addressed as an extension of the current research effort.

4. RESEARCH METHODOLOGY

The study area under focus is the Surat region, as shown in Fig. 1 (covering an extent of 1357 km2 of the spatial region) as discussed in earlier sections. While the aim and objectives are to explore the spatial growth over duration, data in the form of satellite images were acquired from Earth Explorer portal of USGS. The images of Landsat Mission were obtained, and bands relative for construction of natural colour composition and false colour composition were stacked using QGIS. Further, the NDVI was extracted to understand the extent of vegetation (Earth Observing System, 2019). Population for decades of 2001 and 2011 were obtained from the Census of India for each of the villages under SUDA administration, as per the regulatory limits of 2016. The thematic population maps, density maps and satellite images were overlapped to understand the extent of population and growth in the built-up area. The extraction of NDVI revealed the scenario in terms of vegetation covers. Weather data for the duration of the year 1995 till the year 2015 were obtained from the IMD, Government of India for the Surat station.

5. DATA COLLECTION

The images from the USGS's Landsat TM 4-5, Landsat ETM Plus 7 and Landsat 8 OLI and TIRS satellites are downloaded that comprises several bands. Image composition from various satellites is shown in Table-1 below.

TABLE 1 *IMAGE BANDS FROM SATELLITES*

Landsat TM 4-5 (Wavelength in µm)	Landsat ETM 7 (Wavelength in µm)	Landsat 8 OLI and TIRS (Wavelength in µm)
Band 1 – Blue (0.45-0.52)	Band 1 - Blue (0.45-0.52)	Band 1 – Ultra Blue (0.435 - 0.451)
Band 2 - Green (0.52-0.60)	Band 2 – Green (0.52-0.60)	Band 2 - Blue (0.452 - 0.512)
Band 3 - Red (0.63-0.69)	Band 3 – Red (0.63-0.69)	Band 3 – Green (0.533 - 0.590)
Band 4 – NearInfrared (NIR)(0.76-0.90)	Band 4 – NearInfrared(NIR)(0.77-0.90)	Band 4 – Red (0.636 - 0.673)
Band 5 -Shortwave Infrared (SWIR) 1(1.55-1.75)	Band 5 -Shortwave Infrared (SWIR) 1(1.55-1.75)	Band 5 – Near Infrared (NIR) (0.851 - 0.879)
Band 6 - Thermal (10.40-12.50)	Band 6 - Thermal (10.40-12.50)	Band 6 – Shortwave Infrared (SWIR) 1 (1.566 - 1.651)
Band 7 – ShortwaveInfrared (SWIR) 2(2.08-2.35)	Band 7 -Shortwave Infrared(SWIR) 2(2.09-2.35)	Band 7 – Shortwave Infrared (SWIR) 2 (2.107 - 2.294)
-	Band 8 -Panchromatic (.52-.90)	Band 8 - Panchromatic (0.503 - 0.676)
-	-	Band 9 - Cirrus (1.363 - 1.384)
-	-	Band 10 - Thermal Infrared (TIRS) 1 (10.60 - 11.19)
-	-	Band 11 - Thermal Infrared (TIRS) 2 (11.50 - 12.51)

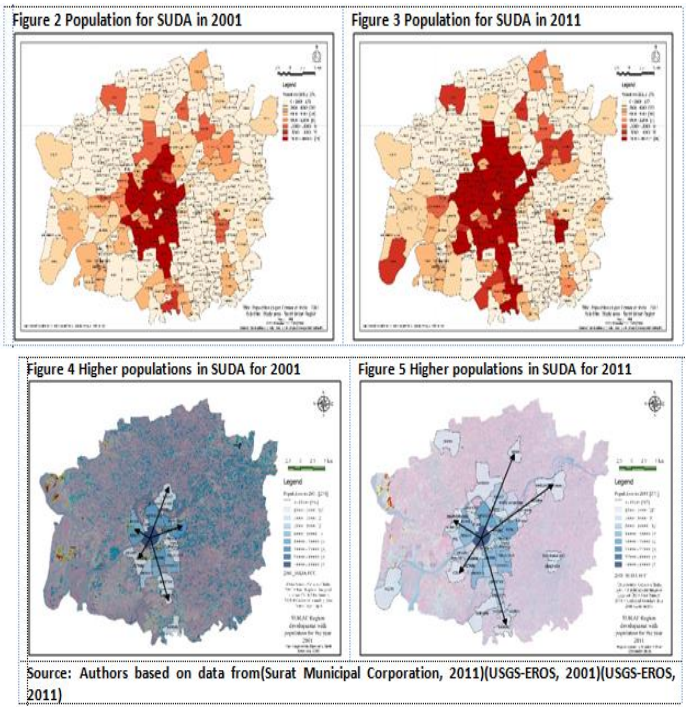
Source: "What are the band designations for the Landsat satellites of Landsat Mission (U.S. Department of the Interior | U.S. Geological Survey, 2014)

The daily records on daily minimum, maximum and average temperature, humidity, and rainfall were obtained for the year 1995 till the year 2015 from the Indian Meteorological Department (IMD), Government of India. Weather records for some of the days were found to be missing. The same was omitted from the analysis (0.9% of total records). The daily records were consolidated on a monthly as well as annual frequency in alignment with the calendar.

6. IMAGE PROCESSING AND RESULTS

The image processing and analysis thereof consists major three parts that include for (1) thematic mapping for population and density, (2) visualisation and understanding of extensions in built-up spaces; (3) developing and comparing changes in the vegetation cover index. The following sub-section discusses the above analysis. Figure 2 and Figure3 show population pockets according to the Census demographic constituencies in the study area, SUDA region for the decades of 2001 and 2011, respectively. It can be observed that the

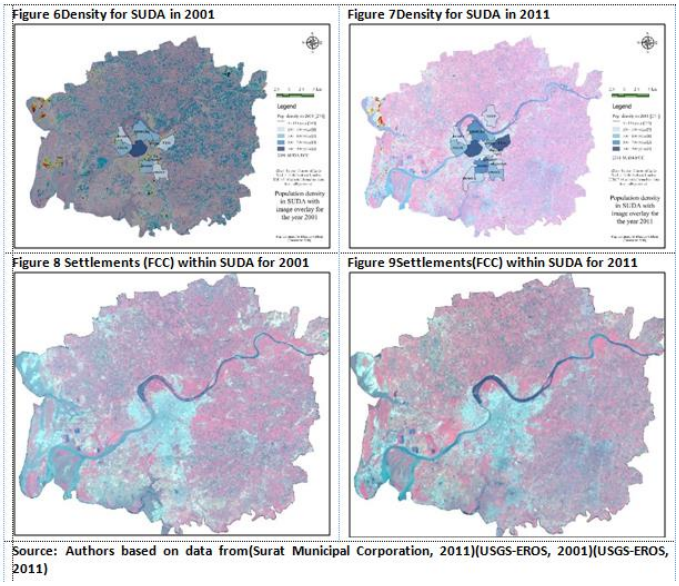
population is concentrated in the central part of the study area, that is, of course core Surat City. In the year 2001, there are pockets with a higher population in almost all the directions around Surat walled city. However, in the year 2011, the population increase is showing directional settlement of people, more towards the North-East and South-East compared to the West. The SMC administrative area extension in the year 2006 (Fig. 1) has also might have impacted for the human settlement rising in the South-West part of the city along with extensions in the North-West. In a way, it can be seen the Surat city is flourishing with the rise in population in all the directions around the walled area allowing to be at the centre.

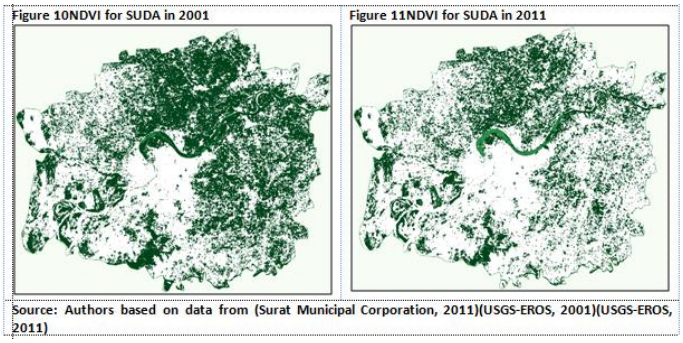


Further the visualisation of population density (Fig. 6 and Fig. 7) in various areas was performed. The images show the extent of developed land with built-up areas and population density as recorded in the past two census years. In contradiction to the rise in population, the concentration level and directional increase show a different trend. The denser populations are identified in the North and South part of Surat City for the year 2001 however, by the year 2011, the people began residing closely in the Eastern and Southern parts around Surat City. An inquiry on the built form has a scope for further investigation by a complete on-field survey. It depicts for the active development through urban planning tools where the density has not risen abruptly high. A land management tool, Town Planning Scheme following a Development zoning plan, is implemented for planned development of urban areas under the of The Gujarat TP and UD Act, 1976 (Surat Municipal Corporation, 2016). The satellite images as composed in False Color Composition (by stacking the order of Red-Green-Blue band images) shows the extent of built-up areas for the year 2001 and 2011 in models (Fig. 8 and Fig. 9) respectively. The images are in support of the population growth directions. Normalised Difference Vegetation Index (NDVI) was extracted using a mathematical formula applied on NIR and Red band images as suggested by NASA (USGS, n.d.). The expression is shown herewith.

NDVI=(NIR-RED)÷(NIR+RED)

The image pixels with no vegetation are showing a value near to 0.0 whereas the energy absorbed and reflected by the plant shows the pixel value in a range from least 0.0 to 0.9 highest vegetation (Earth Observatory NASA, 2000). The extracted NDVI images for the study area are shown in Fig. 10 and Fig. 11. For the year 2001, the analysis revealed that the vegetation index ranges between values of -0.101606 to +0.14902 that shows significantly sparse vegetation (and not dense, i.e. shrub sized crops) in the study region. While for the year 2011, it was found that the value ranges between -0.0327257 to +0.2285. It shows that the negative values have gone more negative, showing the increase in the presence of vacant lands. Also, a previous study mentioned that the urban agglomeration of Surat lacks designated green spaces (Patel & Bhatt, 2016).





The positive values have shown a rise, which shows a little densification in the vegetation cover compared to previous year state. It may be a result of improved water supply for agricultural use wherein the crops of sugarcane and cotton are ripped round the year in the region.

7. CLIMATE ANALYSIS & RESULTS

An analysis was performed to comprehend and recognize any pattern that might exist in the temperature profiling. Discussed herewith are the outputs obtained based on grouping of a data set of daily frequency as recorded by the Indian Meteorological Department, Government of India. The data set

was obtained for daily records for the duration of 1st January 1995 to 31st December 2015, in total daily records of 21 years for the Surat Station. The maximum daily temperature recorded in a month is higher than the overall daily average of maximum temperature for the study duration. Such incidences occurred in 218 months among 240 months (90% of months). The years of 1999 and 2009 (exactly after one decade) reported for as warmer months round the year. The Gujarat state average above 33 °C value is reported for 7 months. It means that for Gujarat State, the warmer months are 7 in a year, but in the case of Surat, it is almost 10 months for last 20 years. The study area of Surat region with 1357 km^2 area is constituting 0.69% in Gujarat State having geographical spread over 1,96,024 km^2. Hence, it can be intervened that the Surat region is having higher maximum temperatures than the Gujarat State. Except for June 1998, the maximum temperature of the state average has never been observed in the Surat region. However, the months of March, April and May have recorded higher maximum temperatures for 24 instances. In addition, the months of June, July and August are observed to have lower maximum temperature than the state average. Except for these three months, Surat has recorded higher maximum temperature for at least one day than the state average for the month. The year 1998 was consistently hot than the state average records among the study duration. The monthly average for the maximum temperature recorded round the month; it is observed that except for the summer months, the Surat has recorded higher maximum temperature than that of the state. On average, it can be stated that the Surat region has a relieve of about 4.6°C in the summers compared to other parts in the state. On the other hand, for rest of the months in the year, the average monthly maximum temperature is recorded to be higher than that of the state government average maximum temperature. The Fig. 12 below shows the differences observed in the monthly average records of maximum temperature in the state average to the Surat city. The trend (as in the Fig. 12) is a culmination of records and shows that the months in the middle of the year has higher monthly average values in the Gujarat State. Surat, however, is hotter in the rest of the months around the year where the average monthly maximum temperature in the Gujarat state is, comparatively lower.

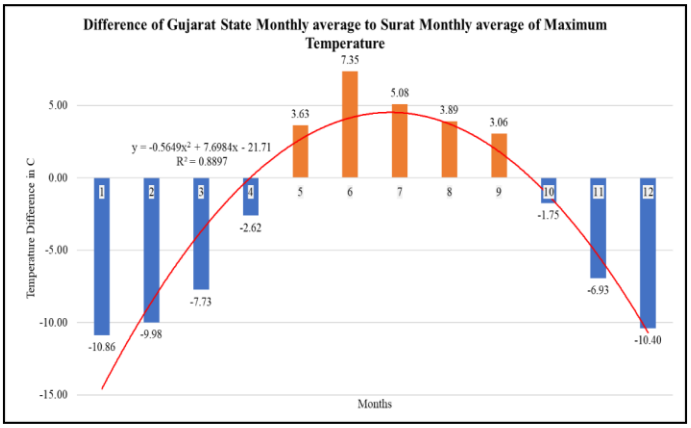


Figure 12: *Maximum temperature temporal track in Surat (Source: Authors)*

The table below shows the values of maximum and minimum of monthly average records for maximum temperature in Surat region.

Maximum Temperature Monthly Average for Surat (Years 1995-2015)					
Years	**Max.**	**Min.**	**Years**	**Max.**	**Min.**
1995	27.77	29.46	**2006**	29.56	30.53
1996	29.46	28.86	**2007**	30.53	29.46
1997	28.86	29.62	**2008**	29.46	30.56
1998	29.62	31.00	**2009**	30.56	29.23
1999	31.00	30.39	**2010**	29.23	29.83
2000	30.39	30.19	**2011**	29.83	28.25
2001	30.19	29.43	**2012**	28.25	29.65
2002	29.43	30.43	**2013**	29.65	28.86
2003	30.43	29.13	**2014**	28.86	29.02
2004	29.13	28.60	**2015**	29.02	19.20
2005	28.60	29.56			

(Table source: Author) (Base-data source: IMD, Government of India, 2016)

The average value of daily minimum temperature is 24.00 °C as recorded for the duration of the year 1995 to 2015. In the year 2003, the minimum temperature in Surat did not surpass the average minimum temperature for even once. Over two decades of study duration, the minimum temperature in Surat region has never exceeded the highest average minimum temperature recorded in the state as 26.90 °C which happens to be in the month of July in the Gujarat state. Controversial to the higher temperature trends, the minimum temperature in a day is averaging higher than that of the Gujarat state average low temperatures. Except for the month of July, round the year, minimum temperatures in Surat region is recorded higher than the state average. The behaviour is visualized in the diagram shown below. It shows that during a year, Surat region stays comparatively warmer at nights.

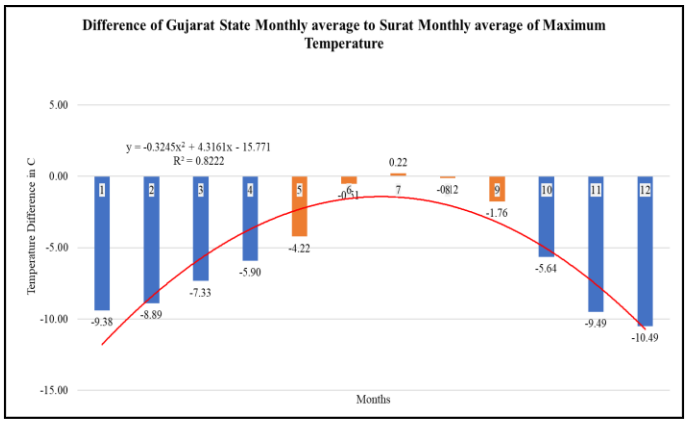


Figure 13: *Lower maximum temperature trend in Surat (Source: Authors)*

The chart below shows a trend of the number of hot days (above an average of 33 °C) in each year of the study duration. The average of hot days having a temperature higher than 33 °C is 308 days per annum. The year 1999 recorded the maximum number of hot days, as high as 335 days in the year. The year 2005, on the other hand, recorded lowest number of hot days, i.e. 281. The number of hot days is following the trend in the sixth order of polynomial fitting with a regression value to the extent of 60%. The trend is expressed by the equation:

$y = 0.0003x^{\wedge 6} - 0.0184x^{\wedge 5} + 0.4487x^{\wedge 4} - 5.1164x^{\wedge 3} + 27.205x^{\wedge 2} - 58.749x + 352.61$

Having the value of $R^2 = 0.6086$

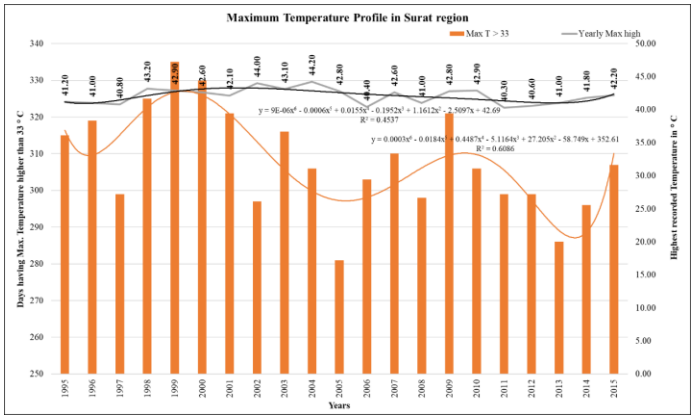


Figure 14 *Temperature profile for Surat (Source: Authors)*

While extrapolation of the equation shows a declining trend which probably indicates the reduction in the number of hot days. In the same chart, a line shows with highest recorded temperatures in a year. These highest recorded maximum temperatures have attained the value of 44.2 °C in the year 2004 and lower as 40.3 °C in the year 2011. The average maximum temperature is 42.07 °C in Surat. A trend is examined with the best-fitting level attained at about 45% of the regression value and is expressed as an equation:

$y = 9E\text{-}06x^{\wedge 6} - 0.0006x^{\wedge 5} + 0.0155x^{\wedge 4} - 0.1952x^{\wedge 3} + 1.1612x^{\wedge 2} - 2.5097x + 42.69$

Having a value of $R^2 = 0.4537$

The extrapolation of the equation shows a rising trend. Considering both the trends, it can be interpreted that the heat in Surat is becoming intense and rising with temperature and the duration of hot days are reducing. The climate is shifting to extreme heat for shorter durations resulting in heat-wave effects. The graph below shows the box plot of twenty years value of the daily minimum and maximum temperature records for Surat. The maximum temperature has an overall range from lower of 25 °C to a higher of 41.2 °C as recorded in the duration. Most of the maximum temperature has an average of daily records as 33.00 °C with a deviation from 31 °C to 35.1 °C in the duration. For the minimum temperature in the study, region ranges from a higher of 30.2 °C to a lower of 7.6 °C. The average minimum temperature in a day is recorded as 22.25 °C with values accumulating around 26.3 °C and 18.2 °C.

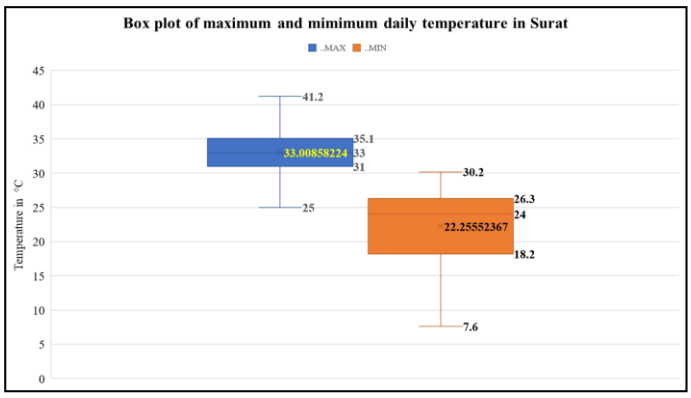


Figure 15 *Daily temperature variation ranges for Surat*

(Source: Authors)

The precipitation received in Surat is reflected in the Fig. 16. The average rainfall per annumin the region is 1317.30 mm for the study duration. The overall trend of precipitation is showing a rise in received water volume with increasing number of rainy days. The analysis also demonstrated that the extreme rainy days are also growing, not consistent, though. The infrastructure systems are probably not designed for and tend to fail. It may result in impounding of flooded areas.

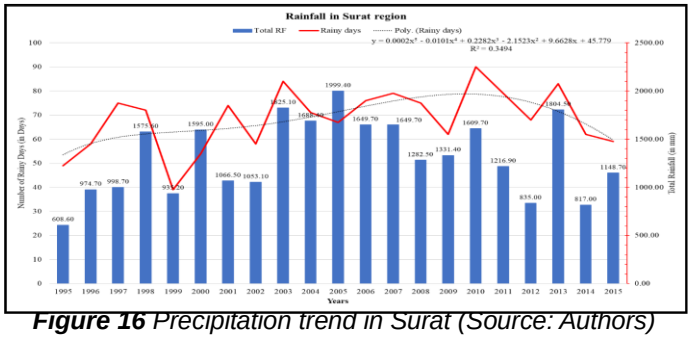


Figure 16 *Precipitation trend in Surat (Source: Authors)*

8. CONCLUDING REMARKS

Findings include for the population growth as identified in the northern and southern directions from the walled city. However, the increasing population is not resulting in a dense development. It is an indirect indicator of a planned expansion by means of implementation of town planning schemes which restricts for density by means of built-up control and regulations. The values of NDVI suggests for a sparse vegetation cover over the study region. There is a little increase in the benefits of vegetation cover during the study decade that is applicable for both vacant lands as well as vegetation type. Coverage of vegetation is decreased in the decade, and yet the dense vegetation is an indicator of improved irrigated areas having dense crops. Values from unsupervised classification followed by the reclassification of the images for the years of 2001 and 2011 suggests that there is an increase of 52.214 km^2 of built-up area in the decade. It shows that every year, about 5.2 km^2 of built-up is increasing in the study region of 1357 km^2. It may mean that the built-up land parcels (as an effect of reducing vegetation cover) are growing at a rate of 0.4 percent per annum in the study region of Urban Surat. A significant limitation of the study includes for (1) ground verification due to elapsed time and, (2) performing a secondary check on built-up area increase through analysis of granted building use permissions in the absence of location-specific records or on-field survey. Also, documents related to urban greens were not assessed. The extreme temperature rise, and fall are increasing along with similar events of precipitation. In addition, the temperature range is also extending for its lower and higher values. Heat waves are approaching for the region and may result in life losses. The pattern of rainfall also indicates the instantaneous flooding in the developed areas due to possible less capacities of storm water drainage infrastructure. There could be a hidden relationship developed among these parameters as explored. Future scope of research may include establishing a statistical correlation and modelling to predict the future occurrences may be attempted. Also, ongoing method of planned development can be reviewed for manifestations of natural hazards (floods in specific) along with spatial and local climatic trends. The event of hard paved surfaces and consistent

degradation of vegetation covers are possibly triggering the extreme behaviour of the local climate for which the developmental concerns were not thought of previously. Even though urban area of Surat is evolving as a living and working space for many people, is it to remain the same through ongoing development plan-zoning based practices in future as well? The practice in a combination of natural variation seems placing the term 'sustainability of livelihoods in Surat' in a suspicion in remaining effective-productive-livable for future generations of Surat.

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