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Temperature and Humidity Variability for Surat (coastal) city, India

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ABSTRACT

Climate czars have brought up an ascent in mean surface temperature of 2ºC above pre-industrial levels will put the Earth in unsafe, uncharted region. Heat is less regarded as highly appreciable hazard for Indian Cities. Surat (coastal) city is highly vulnerable to climate change due to its ecological background and geographical location This paper reports summer (March to May) variability analysis of temperature and humidity for Surat city from 1985 – 2014 in general and 2010-2014 in particular. Data of Temperature and humidity for Surat city for the period of 2010-2014 (summer) were analyzed through SPSS version (16.0). Descriptive statistics and statistical difference using one-way analysis of variance (ANOVA) followed by the Tukey's multiple comparisons test were performed. Significance was set at $P < 0.05$. There were more frequent maximum temperature spikes identified in the last decade (2005-2014) as compared to previous two decades (1985-1994 and 1995-2004). Humidity increased from 54.9% to 60.4%. Maximum summer temperature increased to 1.6ºC from 2011 to 2014. There were 37 hot days with the maximum temperature ≥40°C. Of 425, 384 are heat risk days having HI more than 41ºC. Year 2010 had significantly higher mean summer temperature ($F = 4.545$, p 0.001) and HI ($F = 18.243$, $p<0.0001$) than the summer mean temperature and HI for the year 2011-2014 respectively. This analysis of temperature and humidity indicates that dangerous periods of extreme heat with more frequent maximum temperature spikes and rising humidity are likely to occur more frequently and suggesting the need for measures to reduce population vulnerability including health. This analysis will also useful in developing climate change adaptation strategy for Surat.

Keywords: Climate, Humidity, Heat Index, Heat Wave, Surat

1. Introduction

Variations in temperature and sultriness are everywhere due to global warming which can apply vigorous pressures on population dynamics. Therefore, there is increasing resolve to

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constrain the public health impacts of exposure to sultry weather (Altizer 2006, Hajat 2010). Meteorological data for the last century suggests that the earth is warming but with significant variations at regional level (Kumar 2003). India faced the rise of the annual mean temperature, the annual mean maximum temperature and the annual mean minimum temperature by 0.42°C, 0.92°C and 0.09°C respectively over last century (Arora 2005). Indian Meteorological Department (IMD) defined heat wave as when either there is an excess of 5ºC over a normal daily historical maximum temperature (30 year average) of less than 40ºC; or an excess of 4ºC over a normal historical maximum temperature of more than 40ºC. However, the heat wave is acknowledged when the actual maximum temperature is above 45ºC without considering the normal historical maximum temperature (Azhar 2014, IMD 2014). Gujarat (An Indian State) has also witnessed an increasing trend in the mean annual temperature, annual mean maximum temperature and the annual mean minimum temperature by the rate of 1°C, 0.7°C and 1.2°C respectively during last 50 years (Rathore 2013).

Cities or urban areas experience larger amounts of hotness introduction than encompassing provincial ranges, because of the urban high temperature island impact whereby temperatures in urban regions are generally speaking 3.5ºC to 12ºC higher than those found outside city limit (Wong 2013). Urbanization can intensify heat exposures for inhabitants of urban center regions, particularly for creating nations where in-movement of country poor and unplanned improvement of urban administration frameworks will be unable to keep pace with interest. Then again, this on-going pattern additionally raises challenges for municipalities to actualize particular and focused on activities to alleviate the effects of climbing temperatures.

High temperature makes distress by debilitating the human body past its capacity to cool itself. Cooling is essentially fulfilled by the evaporation of sweat. How proficiently this methodology capacity is specifically identified with the measure of water vapor buzzing around. High moisture content lessens the evaporative cooling rate of sweat, making it troublesome for the body to keep up a consistent and safe inside temperature. Heat Index (HI) to be highly appreciated while measuring how hot it feels when both humidity and temperature are high. Hence HI qualities ought to be considered alongside temperature. HI is defined as a relationship between surrounding temperature and relative humidity versus clear temperature (Rieck 2014, Rajib 2011). As per the National Oceanic Atmospheric Administration (NOAA) (NOAA 2014), the HI is a measure of how hot it feels by addition of relative humidity to the real air temperature.

Coastal cities of India behave differently from climate change perspective and Surat is one of them. Surat experience high relative humidity throughout the year so only temperature values will not provide the perfect scenario of how hot it feels in summer. Coupled with this the combination of heat and high humidity can cause an extreme heat event or heat wave. According to World Bank Sustainable Development Network, Surat is also one of the world's most climate change affected cities. More so, year 2010 is the warmest year Surat faced. Hence this paper reports summer (March to May) variability analysis of temperature and humidity for Surat from 1985 to 2014 in general and 2010-2014 in particular. Surat Municipal Corporation (SMC) is one of the very progressive Municipal Corporation with several award winning innovations and achievements also in the field of climate resilience. Urban health and Climate Resilience Centre (UHCRC) Governed by Surat Climate change Trust (SCCT) and both are developed under Asian Cities Climate Change Resilience Network (ACCCRN) - III initiatives are also symbolic of preparedness of SMC for Climate resilience. Also Surat city is proud of its inclusion in inaugural 33 cities under 100 Resilient

Cities of the Rockefeller Foundation. This analysis will be also helpful in developing climate change adaptation strategy for Surat.

2. Material and methods

2.1 Study area

Surat India's ninth most populated city having population of 4.5 million with an area of 326.515 sq.km. It lies between 21.112° North latitude and 2.814° East longitudes. The city has overall 82.91% literacy rate (Census 2011). **S**urat is the commercial capital of Gujarat State and rests on the bank of the Tapi River, which flows into the Arabian Sea. The city has witnessed exponential urbanization rates over the past several decades (Zahav 2014). According to the report on Surat City Resilience Strategy (SCRS 2011), from its current 4.5 million populations, Surat is projected to grow to around 6.4 million by 2021 and 8.5 million by 2031.

The seasons of Surat city is broadly divided into summer, winter and monsoon with fluctuation in temperature. Due to proximity to sea, it is predominately humid and hot and represents as sub-humid of tropical climate. Summer months (March, April, and May) are relatively hot with temperatures ranging from 37.78 to 44.44°C. The maximum humidity is around 80%. Winters are not very cold and the climate is pleasant during the monsoon (Chauhan 2008). City's mean rainfall is 60 inches. About 90% of the rainfall occurs from June to September (SMC 2014).

2.2 Temperature and Humidity Data and Analysis

The data on temperature and humidity were collected online from Tutiempo Network, S.L (Tutiempo 2014). Daily data including daily mean temperature (°C), daily maximum temperature (°C) for the period of 1985 to 2014 (only for summer months) is utilized for analysis. Daily mean temperature (°C), daily maximum temperature (°C) daily minimum temperature (°C) and daily mean humidity (%) for the period of 2010-2014 (only for summer months) is analyzed in detail for Surat city. Data were processed in Microsoft Excel and analyzed through SPSS version (16.0). One-way analysis of variance (ANOVA) followed by the Tukey's multiple comparisons test were used for statistical difference. Significance was set at $P < 0.05$.

Rothfusz Equation (Rothfusz 1990) for heat index is used because it fulfills the criteria of air temperature (>26ºC) and humidity (>39%). More so, this equation is also widely used for similar settings of Surat (Rajib 2011, Zahid 2010).

Heat Index equation:

$$HI = -42.379 + 2.04901523T + 10.14333127R - 0.22475541TR - 6.83783 \times 10^{-3}T^2$$
$$-5.481717\times10^{-2}R^2 + 1.22874\times10\text{-}3\ T^2R + 8.5282\times10^{-4}\ TR^2 - 1.99\times10^{-6}T^2R^2$$

Where,
T = ambient dry bulb temperature
R = relative humidity (%)

HI value per day was computed from per day maximum temperature and mean humidity data. The various categories of the heat index has been summarized as Extreme Danger: >130^{o}F or

>54ºC; Danger: 105 – 130ºF or 41-54ºC; Extreme Caution: 90-105ºF or 32-41ºC and Caution: 80-90ºF or 27-32ºC (Zahid 2010).

Heat Wave: A heat wave is a prolonged period of excessive heat most often in very humid conditions and may cause heat stroke or even death to humans in summer (Meehal 2004). According to the IMD (IMD 2014) a heat wave is declared if the maximum temperature is 40°C or above. Heat wave can be forecasted 48 hours in advance and can be declared for a single day (NRDC 2013). As per the definition, number of heat wave days was computed. Days with missing data for any of the climatic indicators were not included in the analysis.

3. Result and conclusion

The evaluation of temperature and humidity variability for the Surat (most vulnerable to climate change) ought to be the most urgent need of policy makers in the City and State, both in the environment and health sectors. This paper responds to this need by identifying the variability of temperature and humidity for last 30 years (1985-2014).

3.1 Summer (1985 – 2014)

3.1.1 Temperature

Analysis of temperature for summer season from 1985 to 2014 (2760 days) indicated that till 1990 there were two maximum temperature spikes in the year 1988 and 1990 respectively. After 1990 there was a spike at every fourth year till the year 2002 (spike in 1994, 1998 and 2002). The recorded maximum temperature was 44.44°C for the year 2004. However, 1988 showed maximum temperature 54ºC which may be a data error. There is a spike at every third year from 2004 onwards till 2010 (2007 and 2010) and followed by a steady increase (Figure -1).

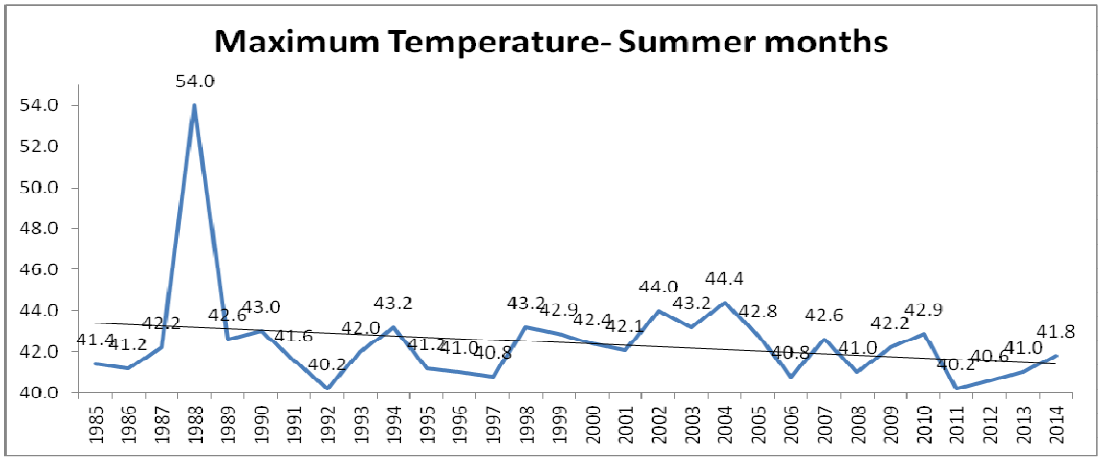

Figure 1: Summer Temperature (1985-2014)

3.1.2 Humidity

The mean humidity for summer months has shown increasing trend from 54.9% to 60.4% over the last 30 years (Figure 2).

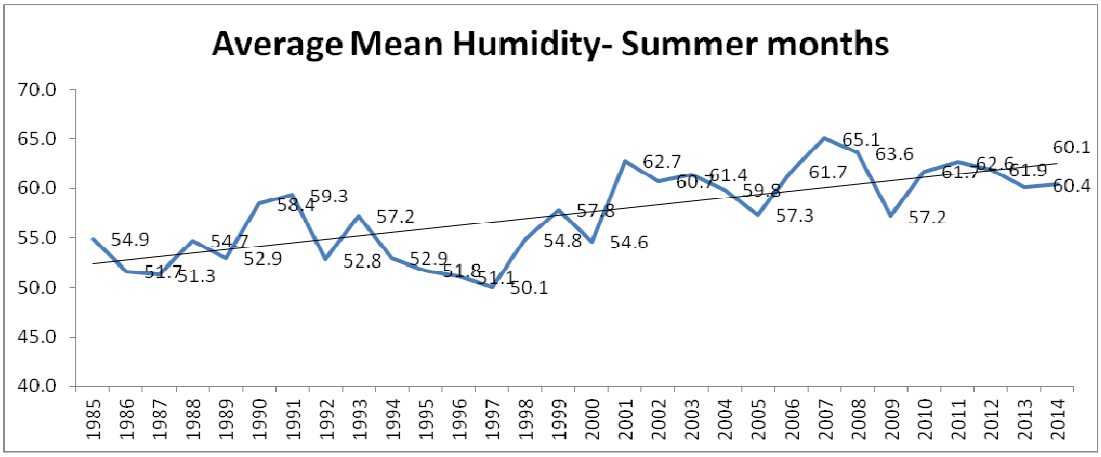

Figure 2: Summer Humidity (1985-2014)

3.1.3 Temperature and Humidity (2010-2014)

Analysis of the yearly data from 2010 to 2014 indicated that the annual mean temperature of the Surat city during 2010 was 27.6°C which increased to 27.9°C in 2014. The annual mean humidity has decreased by 4.5 percent from 2010 to 2014. The range of highest temperature was 40.2°C to 42.9°C and the lowest temperature was 9.3°C to 13.1°C. Maximum temperature has increased by 1.6°C from 2011 to 2014. Minimum of lowest temperature recorded in the year 2012 (9.3°C) and from 2010 to 2014 lowest temperature has increased by 2.6°C (Figure - 3).

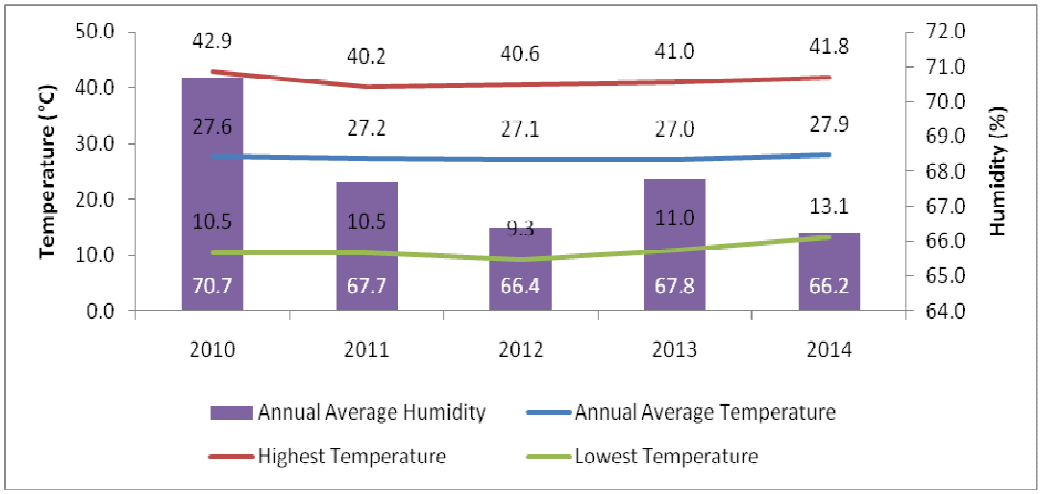

Figure 3: Temperature and Humidity (2010 – 2014)

3.2 Summer (2010-2014)

3.2.1 Temperature

Analysis of temperature for summer season from 2010-2014 (460 days) indicated that except 2010 (already high), the maximum temperature has shown increasing movement across the years. Mean and minimum temperatures were decline for two years followed by upsurge for two consecutive years (Figure - 4).

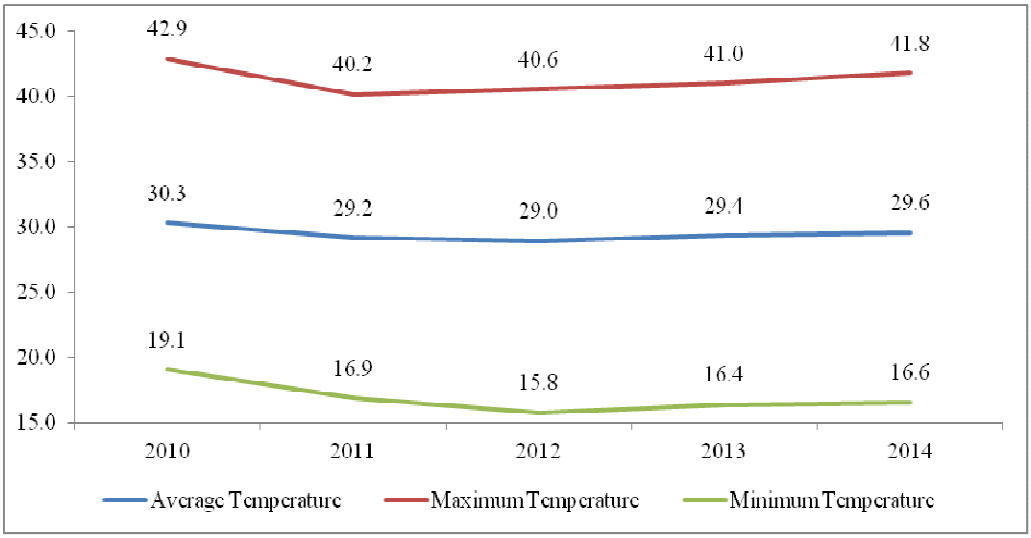

Figure 4: Summer Temperature (2010- 2014)

Analysis further revealed that the highest (42.9°C) and lowest (38°C) maximum temperatures were recorded in months of March 2010 and May 2011 respectively. A gradual decline in maximum temperature of March and increase in April-May for the year 2011-2014 is observed. Of 460 summer days, 37 days were having temperature of 40°C and above. Year 2010 was warmer in terms of high temperature with the maximum temperature of ≥40°C for 22 days as compared to 2011-2014. Graph also showing that after a pause for 2011 and 2012, 2013 and 2014 are showing upsurge in maximum temperature of ≥40°C (Figure 5).

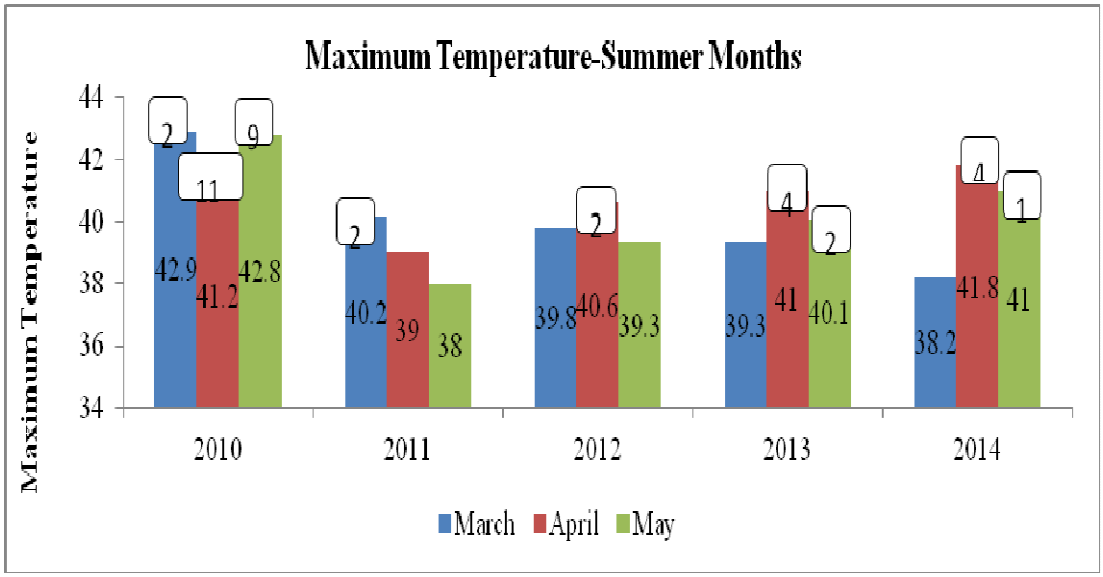

Figure 5: Number of days with maximum temperature ≥ 40°C

Note: Numbers in the ☐ shape indicate the number of days with temperature 40°C and above of respective months

For summer 2010, the mean temperature was 36.9 ± 3.2°C which is significantly higher than the summer mean temperature for the year 2011 to 2014 (F = 4.545, p 0.001) (Table 1).

Table 1: Year wise summer mean temperature (2010-2014)

Year	Mean ± SD	95% Confidence Interval	F – Test	P – Value
2010	**36.9 ± 3.2**	**30.5 - 43.3**	**4.545**	**0.001**
2011	**35.5 ± 2.2**	**31.1 - 39.9**		
2012	**35.5 ± 2.6**	**30.3 - 40.7**		
2013	**35.5 ± 2.4**	**30.7 - 40.3**		
2014	**35.6 ± 2.5**	**30.6 - 40.6**		

3.2.1 Humidity

The maximum mean humidity for summer months was higher than 70% with negligible monthly variation except March month which is visibly fluctuating during all five years (Figure – 6).

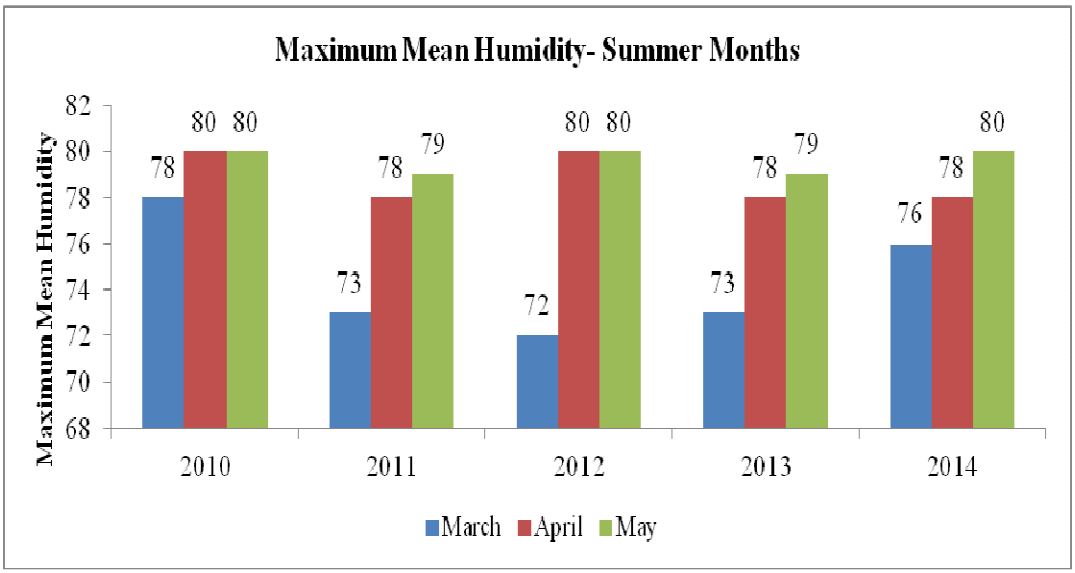

Figure 6: Summer humidity (2010-2014)

3.2.1.1 Heat (Hotness) Index: Heat Risk

Of 460 summer days, 36 days excluded from the analysis (humidity value ≤39%). Of 425 summer days, 85 days with HI value of >54°C (extreme danger level), 299 days with HI values between 41°C to 54°C (danger level) Table – 2.

Table 2: Heat index variability from 2010-2014

Heat Index Category	2010 Days (%)	2011 Days (%)	2012 Days (%)	2013 Days (%)	2014 Days (%)	Total Days (%)
Caution (27°C - 31°C)	0 (0)	0 (0)	1 (1.1)	0 (0)	1 (1.1)	2 (0.43)
Extreme Caution (32°C - 40°C)	4 (4.3)	4 (4.3)	11 (12)	7 (7.6)	12 (13.0)	38 (8.26)
Danger (41°C-54°C)	46 (50)	67 (72.8)	59 (64.1)	67 (72.8)	60 (65.2)	299 (65.0)
Extreme Danger (> 54°C)	34 (37)	12 (13)	15 (16.3)	9 (9.8)	15 (16.3)	85 (18.48)
Number of days with Humidity ≤ 39% hence not considered for analysis	8 (8.7)	9 (9.8)	6 (6.5)	9 (9.8)	4 (4.3)	36 (7.83)
Total	**92 (100)**	**92 (100)**	**92 (100)**	**92 (100)**	**92 (100)**	**460 (100)**

Maximum HI was 75ºC for the year 2010. Number of days with HI ≥41°C was almost similar from 2010 to 2014 which comprises significant proportion of summer days. Surat experienced extreme danger level heat index for 85 out of 425 days (Table 3).

Table 3: Heat index with Maximum Temperature (Total 425 days for 2010-2014)

Year	Maximum Heat index (°C)	Number of days with the HI ≥ 41°C Days	HI (Extreme Danger >54ºC) Days	Maximum Temp. ≥ 40ºC Days	Maximum Temp. (≥ 40ºC) and HI (>54ºC) Days
2010	75	80	34	22	19
2011	64	79	12	2	0
2012	62	74	15	2	2
2013	65	76	9	6	5
2014	63	75	15	5	4

Table-4 depicted that year 2010 had significantly higher HI than the HI for the years 2011-2014 ($F = 18.243$, $p<0.0001$).

Table 4: Year wise mean heat index of Surat city

Year	Mean ± SD	95% Confidence interval	F – Test	P – Value
2010	52 ± 7.7	36.6 – 67.4		
2011	48 ± 5.9	36.2 – 59.8		
2012	48 ± 6.8	34.4 – 61.6		
2013	47 ± 6.1	34.8 – 59.2		
2014	48 ± 6.7	34.6 – 61.4	18.243	<0.0001

This paper aims to draw attention to temperature, humidity and heat risk index (relatively under-appreciated climate change determinants for coastal city of Surat), provides insight to understand climate change and directs for increasing resilience to extreme heat.

To the best of our knowledge, this is first paper of its kind for Surat (one of the twenty most climate change affected cities in the world) (Hallegatte 2013). Our findings of hot days and rise of Temperature are consistent with findings of the Intergovernmental Panel on Climate Change (IPCC), which shows that the mean surface temperature has expanded by around 0.6°c since the modern insurgency and is anticipated to climb further by 1.1ºC to 6.4ºC over the 21st century and hotness waves getting to be significantly more successive (Malik 2012). High temperature especially along with rising humidity is matter of concern in the context of Surat climatology as with most other coastal cities. There were more frequent maximum temperature spikes seen in the last decade (2005-2014) as compared to previous two decades (1985-1994 and 1995-2004). Humidity significantly increased from 54.9% to 60.4%. Maximum temperature has also shown increasing movement from 2011 to 2014. A gradual decline in maximum temperature for the month of March and increase in April-May for the year 2011-2014 is noted. Year 2010 was warmer in terms of high temperature with the maximum temperature of ≥40°C for 22 days as compared to rest of the study period. The maximum mean humidity for summer months is more than 70% for all five years. The hotness risk analysis from 2010-2014 portrays the significant augment of both temperature and relative humidity in recent past. This can well explained by the global warming which is responsible for the remarkable increment of most extreme and mean temperature amid summer. Proof from a few nations demonstrates that legitimate arranging and adjustment methods can minimize the unfavorable impact of high temperature and humidity (Malik 2012). Other than unfavorable climatic condition, natural contamination and conflict of precipitation brings about discernibly climbing humidity for Surat. Hotness and moisture content assume critical part in raised high temperature list component, which can prompt the uneasiness and wellbeing risk for Surat city populace.

Surat experienced 37 hot days and 384 days having HI more than 41ºC out of 425 days. These can influence the (a) work execution of the populace that thus may have affect on economy of Surat (City with high Industrial production) and (b) human wellbeing and may prompt hazardous hotness issue like muscles spasms and hotness stroke. Subsequently, there

is a dire need that Surat needs to arrange and execute intercessions to antagonistic climatic hotness influences.

Some limitations of our analysis need to be acknowledged.

1. The analysis is limited by the cut-off value for declaring heat wave for Surat. However, IMD guidelines were followed to declare heat wave but we believe that guidelines may be different for coastal city like Surat, where humidity cannot be ignored.
2. We can generalize the findings to other coastal cities like Surat but generalizibilty to all urban areas has limitation.

4. Conclusion

This paper concludes that example of climate change shows unsafe times of compelling high temperature with increase in humidity are liable to happen all the more as often as possible proposing the requirement for measures to diminish wellbeing weakness and to create environmental change adjustment technique for Surat city.

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