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The discomfort levels in Gujarat-A comparison of different thermal stress indices

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ABSTRACT

The characterization of discomfort of any location is essentially required to understand the efficiency of human activities. In the present study, four different thermal stress indices (Heat Index of Rothfusz (US_HI), simple Heat Index (S_HI), Discomfort index of Thom (EU_DI) and Discomfort index of South Africa (SA_DI) weather service) have been used to characterize the Gujarat state under different comfort level using daily climatic data of 12 stations spread across the state. Results revealed that all the thermal indices showed similar pattern of variation during the year, except the Heat Index of Rothfusz (US_HI) which is more or less constant during winter season when its values are less than 80. On an average, about 225 to 275 days have been characterized as the discomfort period of varying stress condition in different parts of the state. The peak period of discomfort index was found to be during May and June. Arnej and Viramagan are the two stations having highest level of discomfort at danger level. A comparison of all the four indices revealed that the two indices viz. US_HI and SA_DI are more or less similar in characterization; however, these indices are unable to detect and/or characterize the lower levels of discomfort. The Simple model (S_HI) could not differentiate the most discomfort period/location as characterized by the other three thermal indices. The thermal indices EU_DI seems to be very sensitive for discomfort as all 365 days at Surat has been characterized as discomfort to be experienced by the people.

Key words: Temperature humidity index (THI), apparent temperature (AT), discomfort index (DI), heat index (HI), distress index, wind chill, thermal comfort index

It is a well known fact that the human discomfort felt during hot weather depends on many factors that includes temperature and humidity. During summer season the human body makes use of perspiration to maintain its temperature within proper physiological limits. The sweat evaporates taking away heat so as to have a cooling effect on the skin. High humidity level in the surrounding environment obstructs this process limiting the evaporation. The human body so can't eliminate the excessive heat receiving a sensation of higher temperature and thus discomfort is felt. Besides temperature and humidity, other atmospheric factors influencing comfort levels are; vapour pressure, radiation, and wind speed. In addition, the human body dimension, skin type, clothing and its activity also determine the comfort levels (Bishnoi, 2010).Different bioclimatic indices have been proposed by different scientists to integrate the effect of environment on the human thermal comfort. These indices are categorized into two groups viz. "warm season indices", and "cold season indices" (Bishnoi, 2010). Most of the indices are empirical in nature which is based on objective and subjective strain response data obtained on individuals and group of individuals exposed to various levels and combinations of environmental and metabolic heat stress factors. The summer season indices are Apparent Temperature (AT) of Steadman (1979), Heat Index (HI) of Rothfusz (1990) and Discomfort Index (DI) of Thom (1959) and Giles *et al.* (1990). These indices are also referred as Temperature Humidity Index (THI) (Schoen, 2005). The winter season indices include Wind Chill Index of Siple and Passel (1945) and Steadman (1971). Most of these models use two or more weather variables which include air temperature (T), wet bulb temperature (Tw), dew point temperature (Td), wind speed (u) and relative humidity (RH) as input parameters. There have also been attempts to improve the existing indices using some mathematical and functional relationship (Schoen, 2005; Mohan *et al* 2014)for making them more adoptable.Oleson *et al.* (2015) have used five heat stress indices viz Heat Index (HI; Rothfusz, 1990), Apparent Temperature (AT; Steadman, 1994), Simplified Wet Bulb Globe Temperature (SWBGT; Willett and Sherwood, 2012),

Table 1: Locations of different agrometeorological stations and period of data used

S.No	Station	Period of data used	Altitude (m)	Latitude (^{O}N)	Longitude (^{O}E)
South Gujarat					
1	Bharuch	1993-2013	17	21° 43'	73° 01'
2	Surat	1993-2012	11	21° 12'	72° 49'
3	Navsari	1993-2013	14	20° 57'	72° 55'
Central Gujarat					
4	Anand	1993-2013	40	22° 32'	72° 59'
5	Arnej	1993-2013	14	22° 35'	72° 17'
6	Godhra	1993-2013	122	22° 46'	73° 37'
North Gujarat					
7	SK Nagar	1994-2013	155	24° 21'	72° 20'
8	Khedbrahma	1993-2008	203	24° 02'	73° 03'
9	Viramgam	1999-2012	24	23° 08'	72° 02'
Saurashtra					
10	Amreli	1993-2013	118	21° 36'	71° 13'
11	Junagadh	1993-2013	89	21° 31'	70° 27'
12	Targadhia	1993-2013	136	22° 18'	70° 48'

Humidex (Masterson and Richardson, 1979), and Discomfort Index (DI; Epstein and Moran, 2006) in community land model version 4(CLM4) and community land model (CLMU) for climate change studies. The trend and variability of discomfort index have been reported in Iran by Mokhtari *et al.* (2016) and Ghaedi (2018) and in Greece by Paliatsos and Nastos (1999).

Gujarat State having 1600 km of coastal boundary in the western part of India is characterized by arid, semi-arid and dry sub-humid climate. The trends of temperature and rainfall in different parts of Gujarat have been reported to vary significantly during last 30 years periods (Pandey and Patel, 2010; Lunagaria *et al.* 2012). Due to large spatial and temporal/seasonal variation in the climatic parameters across Gujarat; there would be obvious variation in discomfort index over the state. Although the discomfort level changes during day and night, the daily values of thermal indices based on average climatic condition would be useful for many purposes. There is need to quantify the period of the year during which discomfort level are high so that necessary precautionary measures could be taken to avoid the adverse effect on human performance due to exposure to different degree of heat stresses. No such work have been reported for Gujarat, hence, the present studyis attempted to quantify the discomfort index at 12 stations of Gujarat spread across the state using various approaches.

MATERIAL AND METHODS

The daily weather data of 12 stations of Gujarat (Table 1) spread across the state (Navsari, Surat and Bharuch of south Gujarat; Anand, Arnej and Godhra of Central Gujarat; SK Nagar, Khedbrahma and Viramgam of north Gujarat and Amreli, Junagadh and Targadhia (Rajkot) of Saurashtra) for 20 years period (1993-2013) were obtained from the Department of Agricultural Meteorology, Anand Agricultural University, Anand. The missing data/year were removed and daily means of available records were worked out which were used for calculating the different thermal comfort indices. Four models which are used in USA, Europe and South Africa have been selected to calculate daily heat indices and are compared.

Heat index of Rothfusz (1990) model

Rothfusz (1990) developed the multiple regression models using the data generated by Steadman (1979) during extensive biometeorological studies. The resulting equation is considered a Heat Index (HI) equation. Thus, here is an ersatz version of the Heat Index equation which is used by NOAA National weather Service (NWS) and is now denoted by US_HI.

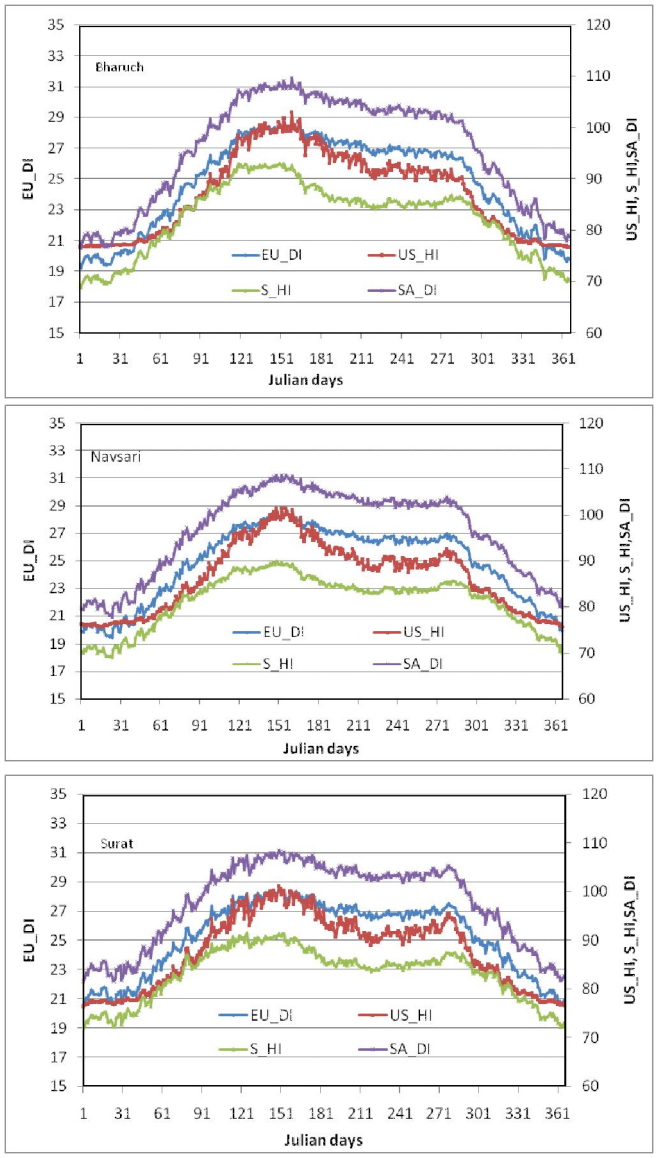

Fig.1: Daily variation of different thermal stress indices at three locations of south Gujarat

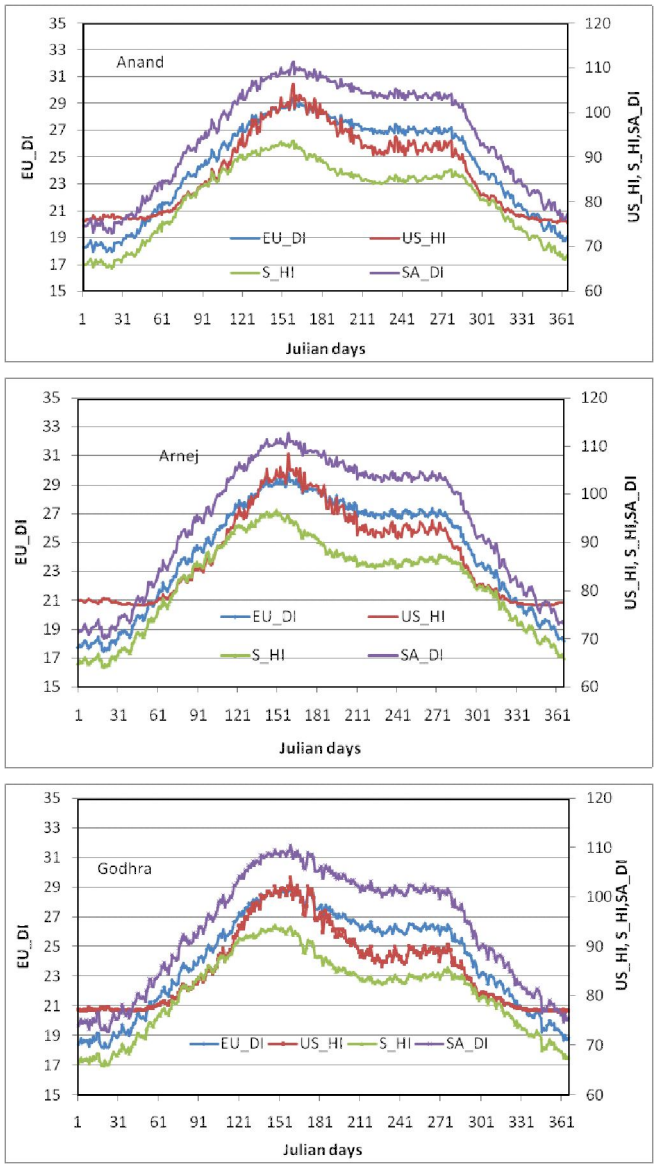

Fig.2: Daily variation of different thermal stress indices at three locations of central Gujarat

$$US\_HI = -42.379 + 2.04901523\,T + 10.14333127\,RH - 0.2247551\,T\times RH - 6.83783\times10^{-3}\,T^2 - 5.481717\times10^{-2}\,RH^2 + 1.2287\times10^{-3}\,T^2\times RH + 8.5282\times10^{-4}\,T\times RH^2 - 1.99\times10^{-6}\,T^2\times RH^2 \quad \ldots(1)$$

Where, T is air temperature in degrees Fahrenheit (F) and RH is relative humidity in percent. US_HI is the heat index in degrees F.

Although humidity and temperature are the only two parameters in this equation, the other variables like vapour pressure, wind speed, human dimension, clothing, skin properties etc are implied (Rothfusz, 1990).

If the RH is less than 13 percent and the temperature is between 80 and 112 degrees F, then the following adjustment is subtracted from HI:

Adjustment = [(13-RH)/4]*SQRT{[17-ABS(T-95.)]/17}

Where, ABS and SQRT are the absolute value and square root functions, respectively. On the other hand, if the RH is greater than 85 percent and the temperature is between 80 and 87 degrees F, then the following adjustment is added to HI:

Adjustment = [(RH-85)/10] * [(87-T)/5]

Charts of HI are prepared for different combinations of temperature and humidity and following categories of cautions are suggested for the public. We did not make any corrections in US-HI values as we never encountered low humidity with high temperatures.

US_HI of 80-90 is termed as Caution, 91-103 as

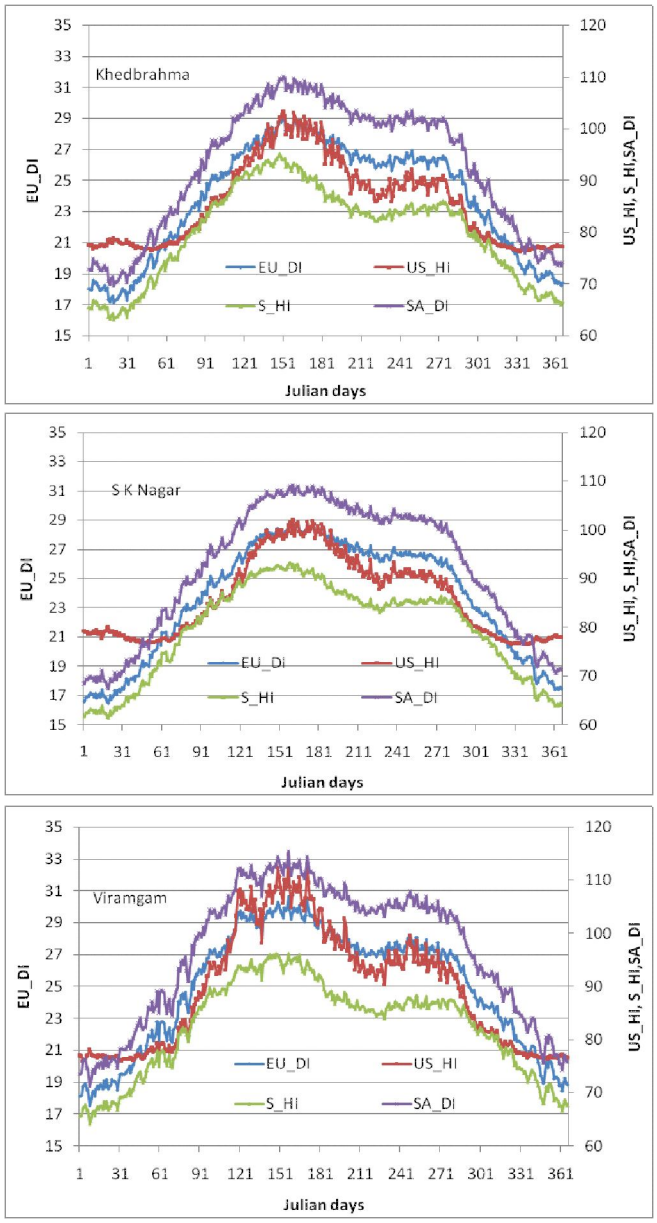

Fig.3: Daily variation of different thermal stress indices at three locations of north Gujarat

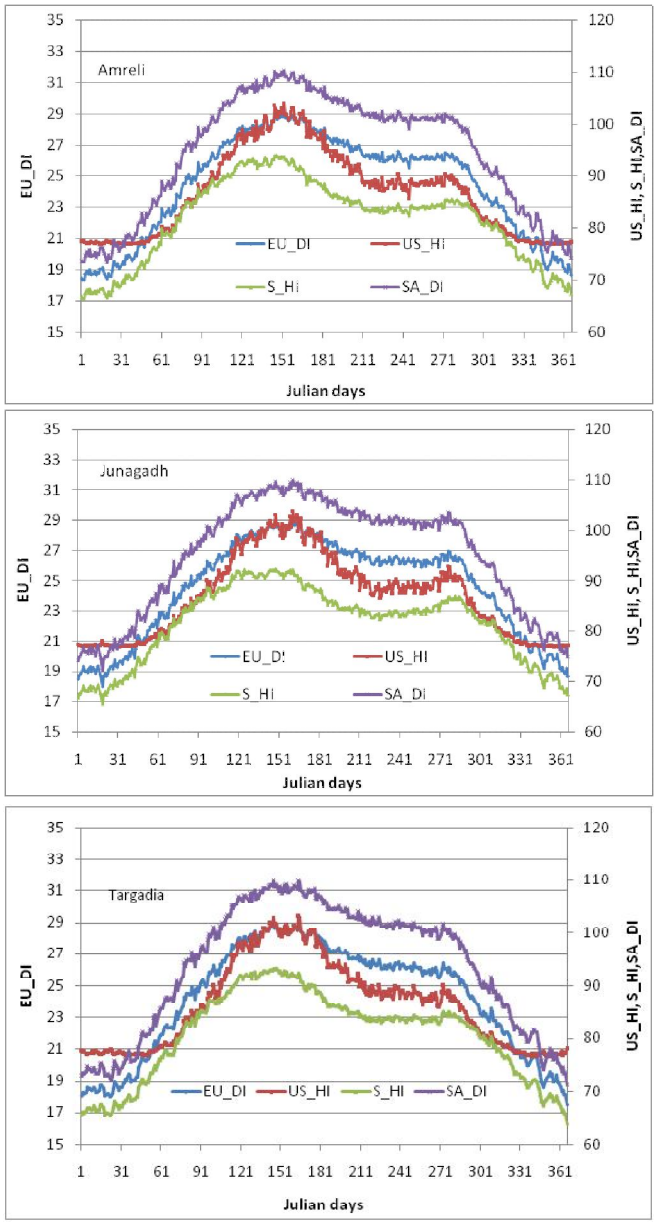

Fig.4: Daily variation of different thermal stress indices at three locations of Saurashtra

Extreme caution, 104-125 as Danger, and more that 125 as Extreme danger

Heat index simple model

The Rothfusz regression is not appropriate when conditions of temperature and humidity warrant a heat index value below about 80 degrees F. In those cases, a simpler formula is applied to calculate values consistent with Steadman's results. In practice, at first, the simple formula is calculated and then the result averaged with the temperature. If this AT value is 80 ^{0}F or higher, the full regression equation along with any adjustment equations as defined above is used. The Rothfusz regression is not logical for extreme temperature and relative humidity beyond the range of Steadman's data. This simple equation denoted by S_HI is given below.

$$S\_HI = 0.5 * (T + 61.0 + (T-68.0)*1.2 + RH*0.094) \ldots(2)$$

Where T is air temperature in degrees Fahrenheit (F) and RH is relative humidity in percent. S_HI is the heat index in degrees F. The criteria for stress classification are same as given earlier US_HI.

Discomfort index of Giles et al (1990) model

The discomfort index /distress index (DI) or thermal comfort index equation of Thom (1959) was used. This

Table 2: Duration of different intensities of heat index (US_HI) in Gujarat (Eq.1)

S.No	Station	80-90	91-103	104-125
South Gujarat				
1	Bharuch	01/3-16/4 (47) 05/10-12/11 (39)	17/4-04/10 (171)	
2	Surat	22/02-05/4 (43) 17/10-25/11 (40)	06/4-16/10 (194)	
3	Navsari	01/3-16/4 (47) 29/7-28/9 (62) 12/10-20/11 (40)	17/4-28/7 (103) 29/9-11/10 (13)	
Central Gujarat				
4	Anand	13/3-21/4 (40) 09/10-10/11 (33)	22/4-08/10 (170)	
5	Arnej	12/3-21/4 (41) 06/10-11/11 (37)	22/4-20/5 (29) 17/6-05/10 (111)	21/5-16/6 (27)
6	Godhra	15/3-25/4 (42) 27/7-05/11 (102)	26/4-24/7 (90)	
North Gujarat				
7	SK Nagar	16/3-27/4 (43) 09/8-23/8 (15) 24/9-30/10 (37)	28/4-08/8 (103) 24/8-23/9 (31)	
8	Khedbrahma	16/3-20/4 (36) 27/7-28/10 (94)	21/4-26/7 (97)	
9	Viramgam	14/3-04/4 (22) 12/10-19/11 (29)	05/4-27-4 (23) 01/7-11/10 (103)	28/4-30/6 (64)
Saurashtra				
10	Amreli	08/3-12/4 (36) 28/7-11/11 (107)	13/4-27/7 (106)	
11	Junagadh	03/3-14/4 (43) 02/8-27/9 (57) 14/10-13/11 (31)	15/4-01/8 (109) 28/9-13/10 (16)	
12	Targadhia	12/3-15/4 (35) 30/7-07/11 (101)	16/4-29/7 (105)	

The values in brackets are number of days.

equation was revised by Giles *et al*. (1990) for estimating DI in degree Celsius and is denoted by EU_DI.

$$EU\_DI = T-0.55*(1-0.01RH)*(T-14.5) \quad \ldots\ldots\ldots(3)$$

Where, T is mean air temperature in degrees Celsius (^{0}C) and RH is the relative humidity in percent. Discomfort increases as DI increases. Following are distress type indicated based on DI (Giles *et al.* 1990). This model has been used in most of the European countries (http://www.airlab.edu.gr, Paliatsos and Nastos 1999)

DI (^{0}C)	Discomfort conditions
DI<21	No discomfort
21<DI<24	Less than 50% of the total population feels discomfort
24<DI<27	More than 50% of the total population feels discomfort
27<DI<29	Most of the population suffers discomfort
29<DI<32	The discomfort is very strong and dangerous
DI>32	State of medical emergency

Table 3: Duration of different intensities of heat index (S_HI) in Gujarat (Eq.2)

S.No	Station	80-90	91-103	104-125
South Gujarat				
1	Bharuch	06/3-22/4 (48) 16/6-11/11 (149)	23/4-15/6 (54)	
2	Surat	26/2-27/4 (61) 02/6-20/11 (172)	28/4-01/6 (35)	
3	Navsari	12/3-16/11 (250)	-	
Central Gujarat				
4	Anand	16/3-03/5 (49) 17/6-06/11 (143)	04/5-16/6 (44)	
5	Arnej	13/3-21/4 (40) 30/6-09/11 (133)	22/4-29/6 (69)	
6	Godhra	16/3-26/4 (42) 24/6-30/10 (129)	27/4-23/6 (58)	
North Gujarat				
7	SK Nagar	17/3-06/5 (51) 03/7-23/10 (113)	07/5-02/7 (57)	
8	Khedbrahma	20/3-26/4 (38) 25/6-19/10 (117)	27/4-24/6 (59)	
9	Viramgam	15/3-20/4 (37) 02/7-08/11 (130)	21/4-01/7 (72)	
Saurashtra				
10	Amreli	09/3-23/4 (46) 15/6-08/11 (147)	24/4-14/6 (52)	
11	Junagadh	03/3-24/4 (53) 13/6-10/11 (151)	25/4-12/6 (49)	
12	Targadhia	12/3-25/4 (45) 16/6-05/11 (143)	26/4-15/6 (51)	

The values in brackets are number of days.

Discomfort index of South Africa weather service (http:// www.weathersa.co.za)

This index evaluates the impact of heat stress on the individual taking into account the combined effect of temperature and humidity. The formula used by the South Africa Weather Service to calculate discomfort index denoted by SA_DI is given below.

$$SA\_DI = (2 \times T) + (RH/100 \times T) + 24 \quad \ldots.(4)$$

Where: T is the dry-bulb or air temperature in degrees Celsius, RH is the relative humidity in percent.

This index gives the following degrees of discomfort:

90-100 - very uncomfortable

101-110 - extremely uncomfortable

111 and more - hazardous to health

The daily values of Heat index/Discomfort index were calculated for all the 12 stations of Gujarat using all the four equations mentioned above. These are graphically presented for comparison. The period of degree of heat indices/discomfort indices were identified for all the stations. For better comparison point of view all 12 stations have been grouped into four regions viz. South, Central, North and Saurashtra having three stations in each region.

RESULT AND DISCUSSION

Daily variation of thermal indices during the year

The daily values of heat indices/discomfort indices

Table 4: Duration of different intensities of discomfort index (EU_DI) in Gujarat (Eq.3)

S.No.	Station	21-24	25-27	28-29	30-32
South Gujarat					
1	Bharuch	11/2-18/3 (36) 26/10-11/12 (47)	19/3-26/4(39) 05/7-25/10 (113)	27/4-04/7 (69)	
2	Surat	01/01-15/3 (74) 11/11-31/12 (51)	16/3-24/4 (40) 29/6-10/11 (135)	25/4-28/6 (65)	
3	Navsari	11/02-17/3 (35) 06/11-27/12 (52)	18/3-09/5 (53) 29/6-05/11 (130)	10/5-28/6 (50)	
Central Gujarat					
4	Anand	03/3-03/4 (32) 23/10-09/12 (48)	04/4-06/5 (33) 20/7-22/10 (95)	07/5-19/7 (74)	
5	Arnej	02/3-04/4 (34) 22/10-30/11 (40)	05/4-29/4 (25) 20/7-21/10 (94)	30/4-19/7 (81)	
6	Godhra	21/2-05/4 (44) 19/10-29/11 (42)	06/4-03/5 (28) 26/6-18/10 (115)	04/5-25/6 (53)	
North Gujarat					
7	SK Nagar	27/2-04/4 (37) 17/10-19/11 (34)	05/4-11/5 (37) 20/7-16/10 (89)	12/5-19/7 (69)	
8	Khedbrahma	25/2-02/4 (37) 18/10-23/11 (37)	03/4-13/5 (41) 06/7-17/10 (104)	14/5-05/7 (53)	
9	Viramgam	12/2-24/3 (41) 23/10-08/12 (47)	25/3-19/4 (26) 28/7-22/10 (87)	20/4-19/5 (30) 15/6-27/7 (43)	20/5-14/6 (26)
Saurashtra					
10	Amreli	13/2-16/3 (32) 22/10-08/12 (48)	17/3-24/4 (39) 03/7-21/10 (111)	25/4-02/7 (69)	
11	Junagadh	14/2-20/3 (35) 26/10-01/12 (37)	21/3-26/4 (37) 09/7-25/10 (109)	27/4-08/7 (73)	
12	Targadhia	21/2-26/3 (34) 18/10-25/11 (39)	27/3-24/4 (29) 04/7-17/10 (106)	25/4-03/7 (70)	

The values in brackets are number of days.

computed using all the four equations as described in methodology are presented in Figs. 1 to 4. In all the figures, it may be noted that the values of HI as per equation 1 denoted by US_HI and simple equation 2 denoted by S_HI are in degree Fahrenheit (F), while discomfort index (DI) as per equation 3 denoted by EU_DI and discomfort index of South Africa Weather Service as per equation 4 denoted by SA_DI are in degree Celsius.

In south Gujarat,which is characterized by dry sub humid climate, the US_HI values ranged between76 and 103^{0}F the higher values at Bharuch being the northern most part of the region (Fig.1) while simple HI (S_HI) values ranged between 69 and 93 ^{0}F. The discomfort index (EU_DI) values ranged between 19 and 29 ^{0}C at all the stations while values of SA_DI ranged between 78 and 110. In both the cases extremes were observed at Bharuch stations. The values of US_HI are always higher than that of S_HI by a maximum value 12 ^{0}F. During March and November both the values are more or less equal. The patterns of all the thermal indices during the year are more or less similar except US_HI which is more or less constant during winter season at all the stations.

In central Gujarat the US_HI values ranged between 76 and 108 ^{0}F the higher values at Arnej being in the Bhal zone of the region (Fig.2) while simple HI (S_HI) values ranged between 65 and 95 ^{0}F. The discomfort index (EU_DI)

Table 5: Duration of different intensities of discomfort index (SA_DI) in Gujarat (Eq.4)

Region	Station	90-100	101-110	>111
South Gujarat				
1	Bharuch	11/3-05/4 (26) 14/10-11/11 (29)	06/4-13/10 (191)	
2	Surat	23/2-04/4 (41) 21/10-24/11 (35)	05/4-20/10 (199)	
3	Navsari	05/3-11/4 (38) 17/10-20/11 (35)	12/4-16/10 (188)	
Central Gujarat				
4	Anand	16/3-21/4 (37) 15/10-10/11 (27)	22/4-14/10 (179)	
5	Arnej	16/3-18/4 (34) 09/10-06/11 (29)	19/4-28/5 (40) 17/6-08/10 (114)	29/5-16/6 (19)
6	Godhra	16/3-24/4 (40) 05/10-30/10 (26)	25/4-04/10 (163)	
North Gujarat				
7	SK Nagar	25/3-25/4 (32) 05/10-27/10 (23)	26/4-04/10 (162)	
8	Khedbrahma	20/3-20/4 (32) 05/10-28/10 (24)	21/4-04/10 (167)	
9	Viramgam	14/3-01/4 (19) 15/10-11/11 (28)	02/4-27/4 (26) 25/6-14/10 (112)	28/4-24/6 (58)
Saurashtra				
10	Amreli	12/3-10/4 (30) 08/10-10/11 (34)	11/5-07/10 (150)	
11	Junagadh	09/3-12/4 (35) 15/10-11/11 (28)	13/4-14/10 (185)	
12	Targadhia	12/3-13/4 (33) 13/9-5/11 (54)	14/4-12/9 (152)	

The values in brackets are number of days.

values ranged between 18 and 29 ^{0}C at all the stations while values of SA_DI ranged between 71 and 113. In both the cases of DI, the extremes values were observed at Arnej stations. The values of US_HI are always higher than that of S_HI by a maximum values 10-12 ^{0}F at different locations. During March and November both the values are more or less equal. The general patterns of all the thermal indices during the year in central Gujarat are similar to that observed in south Gujarat.

The general patterns of variation of all the thermal indices during the year in north Gujarat (Fig.3) are similar to that observed in other regions of Gujarat, with slight variation among the stations. The values of US_HI in north Gujarat ranged between 76 and 113^{0}F the extreme values being at Viramgamwhile simple HI (S_HI) values ranged between 62 and 96^{0}F. The discomfort index (EU_DI) values ranged between 17 and 31^{0}C at all the stations while values of SA_DI ranged between 68 and 115. A comparison of heat indices show that the values of US_HI are always higher than that of S_HI however, during March and November both the values are more or less equal. During winter season the US_HI values are more or less constant. This revealed that the Rothfusz regression model (US_HI) does not give reliable heat indices below 80^{0}F.

The thermal comfort indices at different stations of Saurashtra region (Fig.4) varied similar to that observed at

other stations of different regions of Gujarat. The values of US_HI at three stations of Saurashtra ranged between 77 and 104^{0}F. The simple HI (S_HI) values ranged between 64 and 94^{0}F. The discomfort index (EU_DI) values ranged between 17 and 29^{0}C at all the stations while values of SA_DI ranged between 71 and 110. As observed at other stations, the US_HI values are more or less constant at 77-78 during winter season although the temperature decreases during this period.

Intensity of discomfort indices

Heat index of Rothfusz (1990) model (US_HI): The duration/ period of different categories of heat index (US_HI) at 12 stations of Gujarat are presented in Table 2. The heat stress period of Cautions (US_HI:80-90) starts during the first week of March at most of the stations. In southern parts of state it start little early by 1st March and late (16th March) in north Gujarat. Such conditions continue to be in April month having total duration ranging between 22 to 47 days at different locations. Similar discomfort levels (US_HI:80-90) are also experienced during late monsoon and post monsoon periods. At most of the stations such situations are experienced up to mid- November with total period ranging between 51 days (at Viramgam) to 149 days (at Navsari).

The higher intensity of heat index (US_HI:91-103) which is the period of ExtremeCaution, are experienced during April to October with slight variation over the locations. At most of the places the peak intensity of heat indices is experienced during May and June. At some of the locations where temperature falls considerably during monsoon season the heat index decreases. Among all the stations the Danger situation of heat index (US_HI:104-125) are observed only at two stations (Arnej and Viramgam) during May and June. Thus the central-north part of Gujarat region seems to be experiencing highest level of discomfort (Table 2). The total duration of discomfort in the state, taking all the three categories of heat index altogether ranges between 227 to 277 days in a year.

Heat index simple model(S_HI): The heat index calculated using simple formula (S_HI) shows that heat index period for Cautions (S_HI:80-90) during March and April and again during July to October (Table 3) with total period of discomfort caution ranging between 155 to 250 days. The higher number of days being south Gujarat region with maximum of 250 days in Navsari having all heat stress under this categories only as the this simple formula. The heat stress of Extreme Cautions (S_HI:91-103) period ranges between 35 to 72 days only mainly during April to June. The highest (72 day) being at Viramgam followed by 69 days at Arnej. Thus the total duration of heat stress across the Gujarat state is ranging between 214-251 days (Table 3). A comparison of the two heat indices (US_HI and S_HI) revealed that values of US_HI were higher that S_HI during most of discomfort periods. Under S-HI no station is categorized under Danger discomfort level.

Discomfort index of Giles et al. (1990) (EU_HI): Table 4 depicts the four categories of discomfort levels at different stations of Gujarat. According to this index the discomfort starts in the month of February at most of the places. Under the first category (EU_DI:21-24) when less than 50 percent of population feel discomfort, the duration is between 32 to 37 days at most of the places during February and March except at Surat where the discomfort is experienced from 1st January. Similar discomfort is also experienced during October and November for 34 to 51 days. The higher category (EU_DI:25-27) of discomfort when more than 50 percent of population feel discomfort, are experienced during mostly March and April with duration ranging between 25 to 53 days and again during July to October with duration ranging between 87 to 135 days (Table 4). During May and June most of population suffers discomfort as per EU_DI values between 28 and 27. Viramgam is the only station which experiences very dangerous level of discomfort for 26 days during May and June.

Discomfort index of South Africa weather service(SA_HI): There are three categories of discomfort of SA_DI. The very uncomfortable period (SA_DI:90-100) starts in mid March. Early (before 10 March) discomfort starts in southern part and late (after 20 March) in north Gujarat (Table 5). This situation is experienced for a period of 26 to 41 days in different parts of Gujarat. Similar discomfort level is also experienced during October and November months with duration ranging between 24 to 54 days. The extremely uncomfortable situations (SA_DI:101-110) are observed during April to mid October with total duration ranging between 138 to 199 days at different locations. At all the station the peak period of discomfort in during May and June, however, the higher level of discomfort i.e. (SA_DI:>111) hazardous to health is experienced at Arnej and Viramagam stations only (Table 5).

A comparison of all the four indices revealed that the two indices viz. US_HI and SA_DI are more or less similar in characterization; however, these indices are unable to detect and/or characterize the lower levels of discomfort. The Simple model (S_HI) could not differentiate the most

discomfort period/location as characterized by the other three thermal indices. The thermal indices EU_DI seems to be very sensitive for discomfort as all 365 days at Surat has been characterized as discomfort to be experienced by the people.

CONCLUSION

All the four indices used under the study are able to classify the different levels of discomfort at different locations of Gujarat. Results seem to be well supported with the climatic situations of the state. The central-north Gujarat comprising Bhal and surrounding regions seems to most uncomfortable during summer season. The information generated could be useful in providing the comfort levels during the periods of discomfort.

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