Chapter 5
GIS Visualization of Climate Change and Prediction of Human Responses

P.K. Nag, Priya Dutta, Varsha Chorsiya, and Anjali Nag

Abstract Estimation of heat stress based on WBGT (wet bulb globe temperature) index is widely accepted as international standard. The purpose of the present study was to provide tolerance limit for people and interventions required to protect individuals from the dangerous consequences of heat. The meteorological data collected from Indian Meteorological Department of Ahmedabad (2001–2011) was used for estimating the WBGT. Multiple regression analysis was used to explore relationship between variables dry bulb temperature (T_{a}), wet bulb temperature (T_{wb}), and globe temperature (T_{g}) across the districts varied widely in two different seasons, i.e., summer and winter months. The linear regression analysis was applied for the purpose of future prediction, with respect to the WBGT index, and heat tolerance limit and visualized using GIS tool. The average tolerance time for 2001–2011 arrived at 82 ± 16 and 159 ± 36 min for the months of summer and winter, respectively. Thus, the WBGT and tolerance limit maps might prevail working population from heat stress fury.

Keywords WBGT • Tolerance time • Heat stress • GIS • Prediction

5.1 Introduction

Human being has a unique thermoregulatory mechanism to cope up against extreme climatic exposures and variations. But, frequent heat events indicate a risk to health in human. The strategies that minimize the physiological stress and strain depend

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on suitable adjustment to thermal, cardiovascular, and respiratory response characteristics that govern ones susceptibility limit to work in extreme hot climate. However, when the heat stress exceeds beyond the upper limit of acceptable strain, often called the limit of tolerance, heat strain may lead to heat casualty (Davies 1993). A state of dehydration may occur with the loss of body water as sweat, including loss of fluid through respiration, gastrointestinal tract as well as kidney (Gisolfi et al. 1995). This in turn disturbs the homeostasis of the body (Maughan et al. 1996), leading to decreased skin blood flow, elevated body core temperature (T_{cr}), decreased sweating rate, tolerance to work, and increased risks of heat injuries (Nag et al. 2013).

To understand past and future climate by using observations and theoretical models, GIS technology has been used in obtaining, storing, managing, analyzing and visualizing geographical, enviro-climatic, socioeconomic, and health data for effective decision making (Brooker and Utzinger 2007; Simoonga et al. 2008). Once the data are brought into the GIS database, the user can display large database by mapping with different tools and techniques. Researchers have also used GIS and remote sensing techniques in monitoring the groundwater quality relation to the land use/land cover (Srivastava et al. 2012). Research on satellite pictures has revealed that the glacier Siachen Glacier reduced to 5.9 km in its longitudinal extent from the time period of 1989–2009 (Searle 2013).

To develop a simple and authentic method to calculate increasing heat stress among population and working groups as a result of global warming. WBGT (wet bulb globe temperature) index is universally accepted and the method can be used to estimate daily weather station data. These estimates from weather station data can further be used to analyze past events and visualize the present scenario of climate change. But, when it comes to predicting change in the future, becomes a real challenge. Though the projections are exhaustive, extensive endeavor is needed to describe the impact of such dynamics on human health, in order to devise preventive and mitigating measures including warning alert for early preparedness. Therefore, to compute weather station data for future estimation is useful to prevent heat exposure at any places of the world with nearby authentic weather station data.

The Indian Meteorological Department (IMD) provides useful meteorological data from well-distributed weather stations across the country. These data include high resolution gridded daily rainfall data, temperature, and cloud. These data can be used for research work and projection. This chapter made a modest attempt to depict the climate change in the past 10 years (2001–2011) in 25 districts of Gujarat using the Indian meteorological data collected from 14 weather stations and to predict the probable future scenario of 2021 in light of biophysical variables of human. This study was also attempted to determine the tolerance limit of people and interventions required to protect individuals from the dangerous consequences of heat.

5.2 Method and Materials

The secondary data from the IMD from 2001 to 2011 were compiled and compared to the past and present environmental variables and further treated for regression analysis for expected future prediction. The data included minimum and maximum temperature (°C), dry bulb temperature (°C), dew point temperature (°C), relative humidity (%), bright hours of sunshine (hour and min), and wind direction (36 point of compass) of 14 weather stations across 25 districts of Gujarat. A single weather station could be shared by more than one district and vice versa. For calculation and predictions of heat stress and strain, these data were compiled, expressing into the WBGT index. The calculation was based on the average 10 days/season maximum temperature for each weather stations of Gujarat from 2001 to 2011 for summer (May and June) and winter (December and January). An entire day data was omitted if any hourly observations within that day were missing. The linear regression analysis was applied for the purpose of future prediction, with respect to the WBGT index, and heat tolerance limit and visualized using GIS tool.

The WBGT index is compared with the experiments of climatic chamber that includes three environmental conditions based on the average of seasonal parameters. These three conditions form the climatic load in which the subject had to work for three 3 days, i.e., ambient temperature 39 °C, 42 °C, and 45 °C with relative humidity 65–70 %, 50–55 %, and 40–45 %, respectively. However, the total period of the study program for each subject lasted about 1 week because consecutive days of exposure to heat may influence the individual state of acclimatization. The ergometric workload and air velocity kept constant irrespective of the heat exposure and maintained at 75 W and 0.4 m/s, respectively. The subjects selected for the study were usually habituated to moderate physical work in the occupational field. Prior to starting the experiment, each subject was familiarized with the standard test procedure and consent was taken according to the Indian Council Medical Research (ICMR) ethical guidelines (2000) was taken. The safe exposure period achieved by predetermined end point criteria for T_{cr} (40 °C) or heart rate (95 % maximal heart rate), or physiological symptoms forced the subject to discontinue was taken as tolerance time in the present study (Nag et al. 2007; Montain et al. 1994).

5.3 Wet Bulb (T_{wb}) and Globe (T_g) Temperature as Physical Model to Predict WBGT

Estimation of the heat stress on human, based on the "WBGT (wet bulb globe temperature) index," is the accepted international standard that provides a simple method for the assessment and control of hot environments (ISO 7423 2003; ISO 7933 1989). The WBGT is calculated from dry bulb temperature (T_a), wet bulb temperature (T_{wb}), and globe temperature (T_g) using the following equation:

$$\text{WBGT outdoor} = 0.7T_{wb} + 0.2T_g + 0.1T_a \tag{5.1}$$

$$\text{WBGT indoor} = 0.7T_{wb} + 0.3T_g \tag{5.2}$$

The T_a, T_{wb}, relative humidity, and wind velocity were direct observation from meteorological data. Whereas the globe temperature (T_g) was determined from the experimental data of OHM thermal monitor (32.1, Italy), ambient temperature (T_a), and globe temperature (T_g) measurements, the following linear regression equation was derived:

$$T_g(°\text{C}) = 1.27T_a - 5.25 \quad (r = 0.912, p < 0.001, \text{df} : 2,993) \tag{5.3}$$

The prediction equation was obtained from T_a and T_g observations in the range from 27–40 °C to 28–45 °C, respectively.

The upper limit of acceptable strain, referred as tolerance time depends on the environment, work performed, and personal characteristics. Tolerance time can become a good biophysical indicator to predict heat load on a particular occupational group. It depends upon anthropometric dimensions of individuals, magnitude, and rate of climate variation to which a person is exposed to and their adaptive capacity. There is an obvious need to determine heat tolerance of an individual to avoid heat illness and disorders. Based on the relationships between the WBGT and tolerance time through simulated experimentation were utilized for calculation of tolerance time of people in different districts. Tolerance time shows moderate strong relation with the WBGT index.

$$\text{TT} = 235.13 - 4.9\text{WBGT} \quad (r = 0.596, p < 0.05, \text{df} = 30) \tag{5.4}$$

Table 5.1 illustrates the secondary data collected from 14 weather stations, covering 25 districts of Gujarat and the spread of T_a, T_{wb}, T_g, WBGT, and tolerance time across the districts varied widely in two different seasons. The mean and SD values presented in these tables were based on the compiled secondary data from the IMD sources (2001–2011). The direct observed values obtained from the IMD source were T_a, T_{wb} which is utilized for generating their respective predicted value of T_g, WBGT, and TT with the use of abovementioned equations. The obtained data were further treated for prediction as presented in Table 5.2. Since, the data required to make projection for the future prediction equations are derived, taking "year" as an independent variable for the WBGT and TT is finally used to predict the values for the year 2016 and 2021.

The regression coefficients as well as intercepts of the equations for the WBGT and heat tolerance time varied across the weather stations, due to variability in the meteorological data and also possible influence of the number of data points used in each equation. However, taking into account the degrees of freedom, all the regression equations and coefficient of determination (R^2) were found to be statistically highly significant.

In view of the fact that population characteristics such as age group, gender, bodily status, ethnic diversity, as well as pre-diagnosed health ailment have

Table 5.1 Descriptive statistics for T_a, T_{wb}, T_g, WBGT, and tolerance time

District name	Weather station	T_a (°C)	T_{wb} (°C)	T_g (°C)	WBGT (°C)	Tolerance time (min)
Summer						
Ahmedabad ($N = 832$)	Ahmedabad	36.3 ± 3.4	26.9 ± 2.9	39.3 ± 2.8	29.5 ± 2	119 ± 26
Amreli ($N = 322$)	Bhavnagar, Rajkot	33.5 ± 2.4	26.5 ± 1.6	37.1 ± 1.9	29.4 ± 1.0	118 ± 12
Anand ($N = 645$)	Ahmedabad, Anand	36.4 ± 3.4	26.4 ± 2.4	39.5 ± 2.8	29.9 ± 1.4	113 ± 16
Banaskantha ($N = 808$)	Banaskantha, Mahesana	35.5 ± 3.1	26.6 ± 2.4	38.8 ± 2.5	29.3 ± 1.9	121 ± 25
Bharuch ($N = 635$)	Surat, Vadodara	32.4 ± 2.6	27.3 ± 1.7	36.3 ± 2.1	29.1 ± 1.1	118 ± 14
Bhavnagar ($N = 709$)	Bhavnagar	35.2 ± 3.3	26.7 ± 2.1	38.5 ± 2.7	29.5 ± 1.6	118 ± 19
Dahod ($N = 1,446$)	Vadodara, Sabarkantha	35.8 ± 3.1	26.7 ± 1.5	39 ± 2.5	30.3 ± 1.4	110 ± 16
The Dangs ($N = 637$)	Surat	32.3 ± 2.6	26.8 ± 1.2	36.2 ± 2.1	29.4 ± 1.4	119 ± 18
Gandhinagar ($N = 696$)	Ahmedabad, Kheda, Mahesana	35.6 ± 3.8	26.5 ± 2.4	38.8 ± 3.1	29.7 ± 1.7	117 ± 21
Jamnagar ($N = 673$)	Porbandar, Rajkot	31.1 ± 1.1	27.6 ± 0.8	35.2 ± 0.9	29.8 ± 0.7	113 ± 8
Junagadh ($N = 951$)	Veraval, Rajkot	32.2 ± 1.6	28.2 ± 1.4	36 ± 1.3	30 ± 1.4	112 ± 16
Kheda ($N = 1,461$)	Kheda, Sabarkantha	35.7 ± 3.3	26.7 ± 1.5	38.9 ± 2.6	30.3 ± 1.3	109 ± 14
Kutch ($N = 549$)	Kutch, Rann of Kutch	35.6 ± 2.6	27.1 ± 2.4	38.8 ± 2.1	29.5 ± 2.4	120 ± 35
Mahesana ($N = 744$)	Mahesana, Ahmedabad	36 ± 3.3	26.1 ± 2	39.1 ± 2.7	29.9 ± 1.4	114 ± 17
Narmada ($N = 654$)	Surat, Vadodara	35.8 ± 3	26.7 ± 1.4	39 ± 2.4	30.4 ± 1.2	108 ± 12
Navsari ($N = 620$)	Surat	32.8 ± 2.2	26.9 ± 1.3	36.6 ± 1.8	29.7 ± 0.9	116 ± 11
Panchmahals ($N = 739$)	Vadodara, Kheda	35.5 ± 3.1	27.1 ± 2.1	38.8 ± 2.5	30.5 ± 1.5	107 ± 14
Patan ($N = 894$)	Mahesana, Banaskantha	34.9 ± 3.1	26.7 ± 2.2	38.3 ± 2.5	29.9 ± 1.4	113 ± 16
Porbandar ($N = 525$)	Porbandar, Veraval	32.4 ± 2.0	27.3 ± 1.5	36.2 ± 1.6	29.6 ± 1.1	116 ± 12
Rajkot ($N = 667$)	Rajkot, Rann of Kutch	36 ± 3.5	26.2 ± 2.4	39.1 ± 2.9	29.2 ± 2.3	123 ± 34
Sabarkantha ($N = 750$)	Sabarkantha, Mahesana	35.5 ± 3	26.4 ± 2.1	38.8 ± 2.4	29.6 ± 1.6	117 ± 21
Surat ($N = 626$)	Surat	32.6 ± 2.5	26.9 ± 1.3	36.3 ± 2.1	29.6 ± 1.0	116 ± 11
Surendranagar ($N = 611$)	Ahmedabad, Rann of Kutch	32 ± 1.2	27.5 ± 0.8	35.9 ± 0.9	30 ± 0.7	111 ± 8
Valsad ($N = 650$)	Surat	32.4 ± 2.5	27 ± 1.4	36.2 ± 2	29.4 ± 1.2	118 ± 14
Vadodara ($N = 580$)	Vadodara	35.7 ± 3.4	27.1 ± 2.0	38.9 ± 2.7	30.1 ± 1.7	112 ± 20

(continued)

Table 5.1 (continued)

District name	Weather station	T_a (°C)	T_{wb} (°C)	T_g (°C)	WBGT (°C)	Tolerance time (min)
Winter						
Ahmedabad ($N = 767$)	Ahmedabad	26.4 ± 2.4	16.8 ± 2.4	31.4 ± 2.3	20.9 ± 2.3	266 ± 61
Amreli ($N = 304$)	Bhavnagar, Rajkot	26 ± 2.5	18 ± 3.4	31 ± 2	21.3 ± 2.3	256 ± 54
Anand ($N = 685$)	Ahmedabad, Anand	26.3 ± 2.8	16.8 ± 2.2	31.3 ± 2.3	21.1 ± 2.0	255 ± 46
Banaskantha ($N = 786$)	Banaskantha, Mahesana	26.1 ± 3.2	16.6 ± 2.3	31.1 ± 2.6	20.8 ± 2.2	267 ± 62
Bharuch ($N = 656$)	Surat, Vadodara	28.3 ± 2.7	19.0 ± 2.6	32.9 ± 2.2	22.6 ± 2.4	228 ± 58
Bhavnagar ($N = 630$)	Bhavnagar	26.4 ± 2.7	17.3 ± 2.4	31.3 ± 2.2	21.3 ± 2.0	255 ± 48
Dahod ($N = 811$)	Vadodara, Sabarkantha	28.2 ± 2.8	18.7 ± 2.3	32.8 ± 2.2	22.6 ± 2.5	229 ± 64
The Dangs ($N = 661$)	Surat	28 ± 2.8	19 ± 2.5	32.7 ± 2.2	22.4 ± 2.7	235 ± 71
Gandhinagar ($N = 760$)	Ahmedabad, Kheda, Mahesana	27.4 ± 2.8	17.5 ± 2.4	32.1 ± 2.3	21.7 ± 2.3	271 ± 71
Jamnagar ($N = 743$)	Porbandar, Rajkot	26 ± 2.3	17.8 ± 2.7	31 ± 1.8	21.8 ± 8	244 ± 50
Junagadh ($N = 922$)	Veraval, Rajkot	28.6 ± 2.2	19.7 ± 3.6	33.1 ± 1.8	23.2 ± 3.1	218 ± 70
Kheda ($N = 1,600$)	Kheda, Sabarkantha	28.4 ± 2.8	18.9 ± 2.3	33 ± 2.3	22.8 ± 2.4	227 ± 63
Kutch ($N = 656$)	Kutch, Rann of Kutch	25.2 ± 3.2	17.2 ± 4	30.4 ± 2.6	20.3 ± 3.4	287 ± 88
Mahesana ($N = 764$)	Mahesana, Ahmedabad	26.4 ± 2.8	16.8 ± 2.4	31.4 ± 2.3	20.9 ± 2.1	264 ± 54
Narmada ($N = 855$)	Surat, Vadodara	28.4 ± 2.8	19 ± 2.6	32.9 ± 2.2	22.5 ± 2.6	230 ± 64
Navsari ($N = 622$)	Surat	28.2 ± 2.7	19 ± 2.7	32.8 ± 2.2	22.5 ± 2.4	230 ± 60
Panchmahals ($N = 853$)	Vadodara, Kheda	28.7 ± 2.8	19 ± 2.6	32.9 ± 2.3	22.9 ± 2.3	220 ± 48
Patan ($N = 753$)	Mahesana, Banaskantha	26.5 ± 2.8	16.5 ± 3.4	31.4 ± 2.3	20.6 ± 2.8	275 ± 71
Porbandar ($N = 514$)	Porbandar, Veraval	28.7 ± 2.8	17.8 ± 3.2	33.2 ± 2.3	22 ± 2.7	242 ± 63
Rajkot ($N = 633$)	Rajkot, Rann of Kutch	26.9 ± 3.1	16.6 ± 2.7	31.8 ± 2.5	20.9 ± 2.3	266 ± 60
Sabarkantha ($N = 792$)	Sabarkantha, Mahesana	26.1 ± 3.2	16.7 ± 2.4	31.1 ± 2.6	20.8 ± 2.2	268 ± 58
Surat ($N = 670$)	Surat	28.4 ± 2.8	19 ± 2.5	33 ± 2.2	22.8 ± 2.3	223 ± 54
Surendranagar ($N = 620$)	Ahmedabad, Rann of Kutch	27.4 ± 1.8	18.3 ± 2.5	30.1 ± 1.6	21.8 ± 2.1	243 ± 48
Valsad ($N = 663$)	Surat	28.2 ± 2.7	19.2 ± 2.9	32.8 ± 2.2	22.5 ± 2.3	228 ± 54
Vadodara ($N = 613$)	Vadodara	28.4 ± 2.9	18.8 ± 2.2	33 ± 2.3	22.9 ± 2.3	221 ± 51

Values are mean ± SD (2001–2011)

Table 5.2 Weather station-wise estimation WBGT and tolerance time future projection of Gujarat

	Linear regression analysis			
Weather station	WBGT (°C)	R^2	Tolerance time (min)	R^2
Summer month				
Ahmedabad	0.69 (year)–1,351.2	0.78	8,797.5–4.35 (year)	0.76
Mahesana	0.78 (year)–1,525.7	0.77	9,352.8–4.62 (year)	0.7
Bhavnagar	0.24 (year)–438.3	0.51	3,601.8–1.75 (year)	0.5
Kheda	0.08 (year)–133.3	0.12	1,443.9–0.67 (year)	0.11
Veraval	0.18 (year)–321.5	0.41	3,021.8–1.46 (year)	0.41
Kutch	0.37 (year)–701.9	0.48	5,176.7–2.54 (year)	0.43
Porbandar	0.49 (year)–941.3	0.73	7,433.6–3.67 (year)	0.72
Rajkot	0.68 (year)–1,330.0	0.72	8,577.8–4.23 (year)	0.54
Surat	0.4 (year)–765.4	0.51	6,059.2–2.98 (year)	0.52
Vadodara	0.56 (year)–1,086.4	0.58	6,966.1–3.44 (year)	0.53
Banaskantha	0.19 (year)–355.8	0.62	6,966.1–3.44 (year)	0.53
Sabarkantha	0.64 (year)–1,243.2	0.4	12,005–5.94 (year)	0.44
Anand	0.07 (year)–110.2	0.45	13,590–6.72 (year)	0.72
Rann of Kutch	0.03 (year)–19.5	0.16	879.7–0.42 (year)	0.27
Winter month				
Ahmedabad	0.45 (year)–868.6	0.37	12,259–6.03 (year)	0.32
Mahesana	0.3 (year)–583.9	0.35	9,598.4–4.70 (year)	0.31
Bhavnagar	0.37 (year)–707.7	0.21	8,957.1–4.39 (year)	0.15
Kheda	0.278 (year)–531.1	0.2	7,628–3.72 (year)	0.17
Veraval	0.479 (year)–932.5	0.61	11,345–5.59 (year)	0.57
Kutch	2.22 (year)–4,443.4	0.47	52,487–25.98 (year)	0.48
Porbandar	0.55 (year)–1,082.6	0.49	15,380–7.59 (year)	0.51
Rajkot	0.22 (year)–409.5	0.11	6,260.3–3.04 (year)	0.1
Surat	0.25 (year)–481.3	0.19	6,056.2–2.95 (year)	0.17
Vadodara	0.29 (year)–559.97	0.15	6,600.2–3.22 (year)	0.11
Banaskantha	0.22 (year)–417.2	0.16	6,734.2–3.28 (year)	0.15
Sabarkantha	0.87 (year)–1,718.9	0.35	2,884.6–14.24 (year)	0.33
Anand	0.22 (year)–417.2	0.16	6,734.2–3.28 (year)	0.15
Rann of Kutch	0.75 (year)–1,480.2	0.52	14,989–7.38 (year)	0.42

All R^2 values were statistically significant

influence on environmental warmth perception and one's tolerance time to work in hot environment, the present prediction is a general direction of environmental warmth and tolerance in the respective districts. These predictions can be further refined by longitudinal responses of people from different regions. As the number of data points across the districts and seasons were unequal, there was variation in the coefficients of determinations.

5.4 WBGT and Tolerance Time a Tool for Climate Change Assessment

Climate modeling with respect to human health as well as biophysiological indicators is important to determine the vulnerability limit of population. The IMD possesses a vast weather observational network and is involved in regular data collection, data bank management, research, and weather forecasting for national policy needs. With the trend of climatic change recorded for the decade 2001–2011, it was evident that the state like Gujarat faced increased length and intensity of heat exposure, with consequent effects on human physiological and pathological processes. For example, the meteorological data presented in Table 5.1 were further treated for GIS visualization. Further extrapolation and application may be very much possible to the block or ward level, depending on the input data.

Figure 5.1 shows the spatial pattern of warming of the districts of Gujarat. During the summer of 2001, the districts like Dahod, Panchmahal, Kheda,

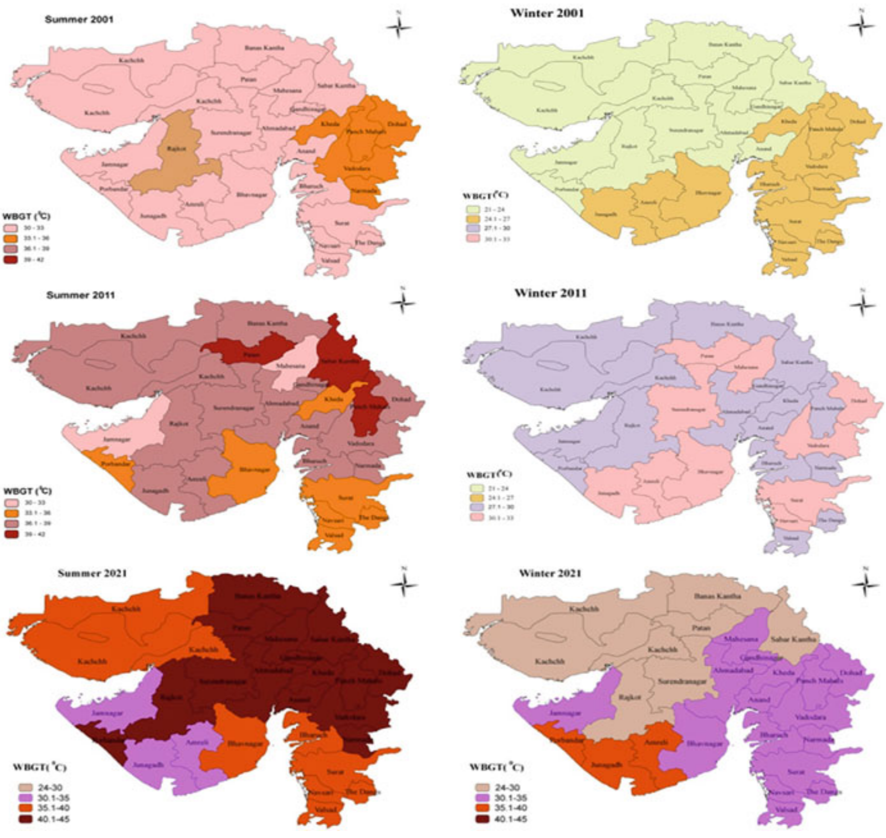

Fig. 5.1 Environmental warmth in terms of WBGT index in different districts of Gujarat

Vadodara, Narmada, and Rajkot showed a higher range of the WBGT temperature (33.1–36 °C), as compared to other districts of the state (30–33 °C). But in 2011, all districts showed the WBGT in the range of 36.1–42 °C, only with the exception of Jamnagar and Mahesana where the WBGT values were 31.2 °C and 33.7 °C, respectively. The overall environmental warmth (WBGT) elevated in the range of 2–3 °C from 2001 to 2011.

In the winter months of 2001, the WBGT levels in southern districts varied from 21 to 24 °C and in northern part 24.1–27 °C. The situation was very clear in 2011 showing that around 15 districts such as Banaskantha, Kutch, Sabarkantha, Gandhinagar, Jamnagar, Porbandar, Rajkot, Ahmedabad, Kheda, Panchmahal, Anand, Bharuch, Narmada, Valsad, and The Dang recorded the WBGT in between 27.1 and 30 °C and the remaining 10 districts such as Patan, Mahesana, Surendranagar, Junagadh, Amreli, Bhavnagar, Dahod, Vadodara, Surat, and Navsari ranged between 30.1 and 33 °C.

Apart from the variables included in the WBGT assessment (i.e., humidity and mean radiant field), other environmental factors, such as rainfall, cloud, and wind velocity, may also influence the environmental condition and, consequently, environmental warmth, as perceived by humans. The exposure pattern of the decade may repeat itself with the changing climate. In the present analysis, the internationally recognized the WBGT index was applied to indicate that the environmental warmth had distinctive changing pattern 2001–2011, during summer, as well as in winter months. In the year 2001, the WBGT ranged between 21 and 24 °C in winter, and 30 and 33 °C in summer. But, in 2011, the WBGT ranged from 31.2 to 42.5 °C. From 2001 to 2011, the WBGT increased in summer months by 2.08 °C and about 1.5 °C in winter, respectively. It was evident that the working population in different districts of Gujarat are at high level of exposure of environmental warmth as per standardize recommended the WBGT temperature in all different seasons.

The linear regression analysis yielded for the year 2021 shows that the temperatures build-up might be at a rate of 2 °C, since the environmental warmth assessment of the WBGT is based on humidity and mean radiant temperature.

5.4.1 Tolerance Time

The calculated WBGT can be compared with critical WBGT for calculating tolerance time. Human tolerance time for exposure to high heat was calculated based on experimental observations, the meteorological data recorded, and presented in GIS map (Fig. 5.2). The tolerance time is arrived at based on the rate of body core temperature (T_{cr}) build up from the basal level to the critical level of ~39 °C. Beyond this level of T_{cr}, a person may be at risk of hyperthermia and at critical state of thermoregulatory adjustment.

The average tolerance time for 2001–2011 arrived at 82 ± 16 and 159 ± 36 min for the months of summer and winter, respectively. During the summer of 2001, the tolerance time predicted for the district like Rajkot, Bhavnagar, Kheda,

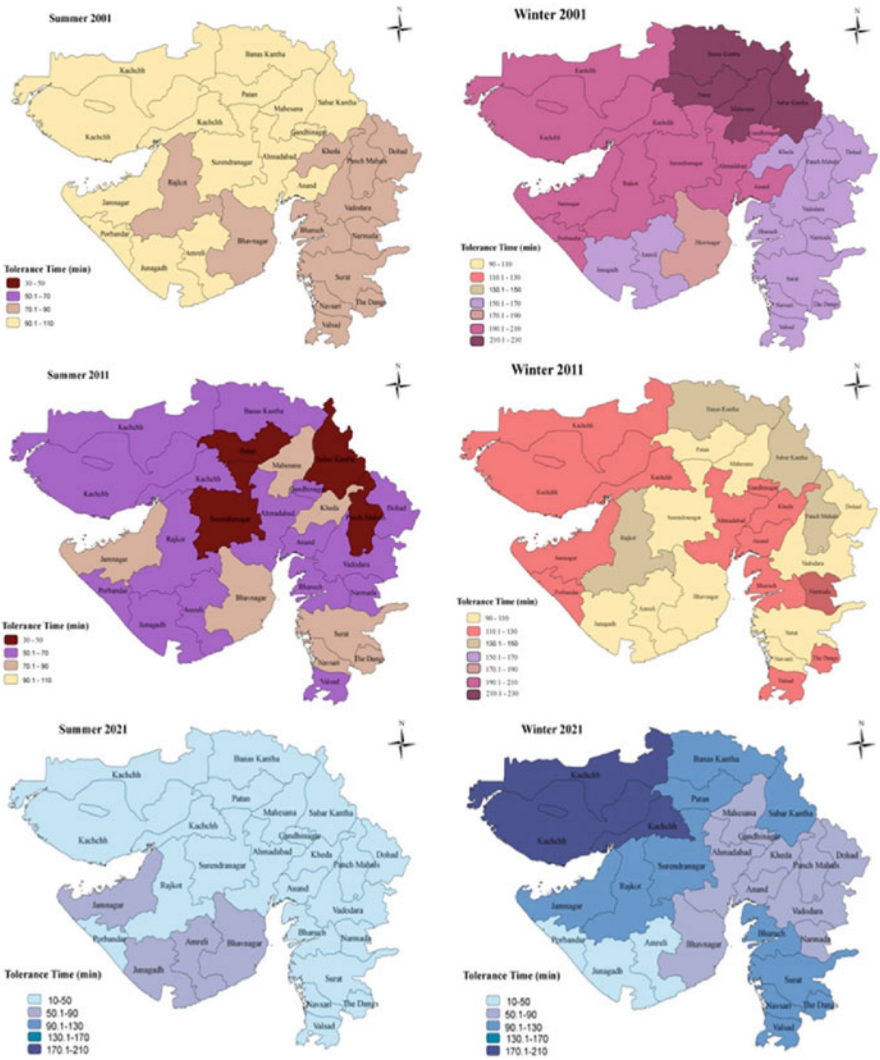

Fig. 5.2 Predicted heat tolerance time for human exposure in different districts of Gujarat

Panchmahals, Dahod, Vadodara, Bharuch, Narmada, Surat, Navsari, The Dangs, and Valsad as 70–90 min. In 2011, the estimated tolerance time decreased to a great extent in these districts. Surendranagar, Patan, Sabarkantha, and Panchmahal were recorded estimated lowest tolerance time in 2011 as 30–50 min.

Regions or places encounter extreme heat wave situation in the summer months further a little deviation in climatic condition from winter to summer, the humans pushed over threshold that manifest at places with higher morbidity and mortality among people in certain geographical regions.

Due to a variety of modifying factors, the estimated increase of ambient temperature may not be linear for a whole century. Despite uncertainty to degree of climate change and temperature build up, any increase in environmental warmth will cause significant impacts on physiological parameters for adjustment and tolerability. When the human ability to tolerate heat is hampered, the work dimensions like productivity, quality of work, and performance are also hampered. Fatigue increases with potential risk to workplace accidents and injuries (Parsons 2009). The prediction suggests that 1 °C increase in environmental warmth as the WBGT might cause 8 min loss in tolerance time.

5.5 Discussion

The WBGT map depicts that the climate change is taking place and if these scenarios prevailed then the working population may be more affected due to interruption of heat dissipating mechanism. The changing climate and warming may become worse in coming decades. There is a perceived realization that the climatic variability with respect to extreme heat potentially causes direct and indirect health effects and loss of productivity of people in different occupational settings (WMO 2011; Ladochy et al. 2007).

Davis and Kalkstein (1990) established threshold temperatures, which represent the temperature beyond which human mortality significantly increases, for cities throughout the United States. He further explains that the significant excess in mortality rate at New York occurs when the apparent temperatures exceed 32 °C during the summer. Nakai et al. (1996) revealed that the death from heat stroke in the occupational field occurred at 27 °C or more WBGT. Kalkstein (1991) reported heat-related disorder mainly in summer at 41 °C.

As the Western India being a rapidly industrializing region, the local climate change in the districts of Gujarat though depend on geographic and meteorological conditions are influenced by urbanization, industrialization, power plants, and burning of fossil fuels, and also on concerted actions to limit green gas emissions. And the inevitable health problem ranges from mild to even serious life-threatening scenarios. Early action by municipalities, health officials, and governmental institute are imperative to help face heat health vulnerability of people in the region and to build resilience in protecting human health. Heat acclimatization is specific to environmental conditions and depends on the body composition profile of population involved. The likely heat-intolerant population living in an area of low environmental heat load may be less at risk than a group living in an area of high heat load.

Therefore, information of the WBGT and the type of work being performed are required in determining how long a person can safely work or remain in a particular hot environment. The ambient temperature is a dominant factor shaping the distribution of the human habitat with overarching effect that result from the influence of temperature on physiological and thermal responses. At high temperatures, there is an increased secretion of sweat, with simultaneous loss of water and salts from the body, which lead to exhaustion and impairment of body functions (Bates and Miller 2008). In the process of thermoregulation, the physiological changes take place to prevent muscles from producing heat. These changes are associated with tiredness, tendency to sleep and fatigue, leading to performance decrement, errors, and accidents. It is suggested that the population in the susceptible regions to be fully aware of the necessity to avoid dehydration through systematic fluid supplement.

The biophysical derivations to arrive at the limit of tolerance time of human exposure to heat might be taken to ascertain vulnerability of a population group. During the months of summer, people in most districts were limited by the prevailing climatic conditions and the tolerance time might be in the range of 40–100 min, or less for habitual exposures. Researchers have found that human physical comfort not only depends on temperature but also is related to the interaction of physical characteristics and thermoregulatory adjustment (Kenney and Havenith 1993).

Vast populations in indoor and outdoor environment are engaged in manual labor. These workers are face-to-face with the fury of extreme heat in summer and post-monsoon months. Calosi et al. (2008) have shown the physical strain of humans in the tropics and its direct effect on the limits of tolerance. Better understanding of physiological mechanism and the limits of exposure of different population groups, including young workers, pregnant mothers, and elderly, would be useful to predict the direct impact of climatic warming on the vulnerable population. Environmental warmth depends on the characteristics of environment and anthropogenic activities, which reflect on the physiological and biophysical criteria of heat stress and strain.

The marked extra circulatory and thermal strain observed in the present study of heat stress indicates that continuous work at the WBGT value of about 40.8 °C (beyond tolerance limit) should be avoided and rest pauses in shade shelters should be incorporated into the work-shift. This may help to improve preparedness from heat extremities for detrimental health effects and give some idea for preparedness for future.

5.6 Conclusion

To summarize, the study proves that Gujarat exhibits extreme heat-related physiological stress in summer months. Given the scenarios of regional warming during the next decades, the expected change in tolerance time due to direct climate effects in Gujarat districts is alarming. Gujarat may be less prone to heat-related stress in winter. Projections of future climate change can be used as inputs into models that assess the physiological impact of climate change on public health. With the known ambient temperature, establishing relationships between spatial, demographic, biophysical, and environmental factors may yield a robust approach to provide working personnel a practical tool to better prepare for heat-related eventuality and tailor intervention measures for spatial examination of vulnerability. Preparing for the health consequences of climate change requires skill professionals, public health, and other physiological and biophysical surveillance data to provide effective health communication to vulnerable population.

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