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Heat waves over Andhra Pradesh : A case study of summer 2003

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सार – इस शोध पत्र में आंध्र प्रदेश के प्रमुख केन्द्रो के मानसून पूर्व के महीनों के दीर्घ–अवधि (1901–2002) के तापमान के आँकड़ों का विश्लेषण अधिकतम तापमान में आने वाले परिवर्तनों का पता लगाने के लिए किया गया है। लघु अवधि के तापमान के आँकड़ों (1986–2002) के विश्लेषण से उक्त अवधि के अंतिम दशक के दौरान प्रचंड उष्ण हवाओं की आवृत्ति में वृद्धि और उष्ण हवाओं के दौरों की अवधि का भी पता चला है । चूँकि आंध्र प्रदेश में मई–जून 2003 के दौरान प्रचंड लू के कारण कई जानें गई अतः इस प्रकार प्रचंड लू से संबद्ध सभी मौसम वैज्ञानिक प्राचलों का विस्तार से अध्ययन किया गया है तथा इनसे प्राप्त हुए परिणामों पर विचार विमर्श किया गया। तटीय केन्द्रों के लिए आकलित किए गए मानवीय सुख सुविधा सूचकांकों – ऊष्मा सूचकांक (एच. आई.), थॉमस के असुविधाजनक सूचकांक और वेब्स के सुख–सुविधा सूचकांक से लू की प्रचंडता का स्पष्ट रूप से पता चला है।

ABSTRACT. Temperature data of pre-monsoon months for major stations in Andhra Pradesh for long period (1901-2002) have been analysed to identify the variations in maximum temperature. Analysis of short period temperature data (1986-2002) has shown increase in the frequency of severe heat waves and also duration of heat wave spells during the last decade. Since the severe heat waves during May-June 2003 over Andhra Pradesh have claimed many lives, a detailed study of all meteorological parameters associated with such heat waves has been made and the results are discussed. Human comfort indices - Heat Index (HI), Thom's Discomfort Index & Webbs' Comfort Index computed in respect of coastal stations have clearly reflected the severity of heat waves.

Key words – Heat wave, Maximum temperature, Frequency, Human comfort index.

1. Introduction

Spells of above normal maximum temperatures occur in different parts of the country during the period from April to June, are referred to as "Heat Waves". The term heat wave is a description of the prevailing high temperature conditions relative to the daily normal value. The India Meteorological Department has laid down the following criteria for describing a heat wave and a severe heat wave.

1.1. Heat wave need not be considered till maximum temperature of a station reaches at least 40° C for plains and at least 30° C for Hilly regions.

1.2. When normal maximum temperature of a station is less than or equal to 40° C.

Heat wave	:	Departure from normal is + 5° to + 6° C
Severe heat wave	:	Departure from normal is + 7° C or more

1.3. When normal maximum temperature of a station is more than 40° C.

Heat wave	:	Departure from normal is + 4° to + 5° C
Severe heat wave	:	Departure from normal is + 6° C or more

1.4. When actual maximum temperature remains 45° C or more, for two consecutive days, irrespective of normal maximum temperature, heat wave is declared.

A climatological study of severe heat waves was made by Raghavan (1966). Based on short period data Subbaramayya and Surya Rao (1976) analysed heat wave and cold wave days in different parts of the country. The comfortability felt by a normal man has been parameterised in terms of basic meteorological elements. Thoms (1959) index, which is a function of dry bulb and wet bulb temperatures, was used by several authors (Venkiteswaran and Swaminathan (1967), Philip and Jeevananda Reddy (1974), Chowdhury and Ganesan

(1983), Lakshmanan (1984) to study the thermal comfort over India at selected cities and locations. Webb (1959) proposed a comfort index, which takes into account the effect of wind speed in addition to temperature parameters.

The maximum number of heat waves in India was seen to occur in Jammu & Kashmir with an average of three waves in two years. No severe heat wave has ever occurred over Coastal Karnataka, South Interior Karnataka, Kerala, Andaman & Nicobar Islands and Lakshadweep. The average period of a severe heat wave is two days while that of a moderate heat wave is 5 – 6 days. However, Jammu & Kashmir experienced a heat wave spell for 15 days in March 1921.

The state of Andhra Pradesh has experienced severe heat waves during the summer months of May and June 2003. Large number of deaths were reported due to heat waves from many parts of the state, more so from the coastal districts. As per the state Government official figures, the death toll reported was 3054. During summer months heat waves do occur almost every year in many parts of country over north and central India especially the Kalahandi region of Orissa, but deaths of this magnitude as reported in Andhra Pradesh this year is not only rare, but also unprecedented.

In this paper, it is attempted to study all the meteorological aspects responsible for such severe heat waves. Further, long period data (1901-2002) of maximum temperatures of major stations in Andhra Pradesh have been analysed to identify the trends. Popular human comfort indices like Heat Index, Thoms Index and Webbs Index are also computed for the coastal stations where more deaths were reported.

2. Historical temperature data and their analysis

Temperature data of major stations in Andhra Pradesh both for short period and long period are examined and their results are discussed in this section.

2.1. Maximum temperature data (March to June) of Andhra Pradesh for the recent period from 1986 to 2002 have been analysed. The main features of this analysis are as follows :

(*i*) From 1986 to 1993, the heat waves occurred were mainly of moderate nature with maximum duration of 7 days, 7 to 13 April, 1987. The highest maximum Temperature of 47° C was recorded at Rentachintala, Nalgonda and Ramagundam on 11 May 1988.

(*ii*) From 1994 onwards, the frequency of severe heat waves and the duration of heat wave spells have significantly increased. In 1997 (18 May to 5 June) and 1998 (23 May to 10 June) the duration of moderate to severe heat wave spell had extended up to 19 days.

(*iii*) In May 2002 the heat wave conditions especially in coastal districts of Andhra Pradesh were quite severe, where Vijayawada Airport (Gannavaram) recorded the highest maximum temperature of 48.8° C on 11 May. The duration of heat waves was in two spells of 7 and 6 days.

(*iv*) Another interesting feature noticed is that the highest maximum temperatures which used to be recorded hitherto in the interior districts of Andhra Pradesh like in Telangana, has remarkably shifted to coastal districts of the State, in recent years.

Pre-monsoon (March to May) maximum temperature data of ten stations in Andhra Pradesh for the period 1901-2002 have been analysed to examine the long term variations. It is observed that out of ten stations, Nellore and Kurnool showed warming trend in the month of March, while Kakinada and Machilipatnam indicated similar trend in all the three months, prominently in May, in recent decades. The remaining stations, however, showed negative trend. Thus no homogeneity in the variation of maximum temperatures across the state, is noticed.

Unlike cyclonic storms, floods, droughts and earthquakes, heat waves are not classified as a natural disaster; although this extreme weather event has been claiming lives in the recent decade both regionally and globally. The year 2003 witnessed heat waves in some parts across the globe, especially, Europe in the month of August was in the grip of severe heat waves that claimed an estimated 35,000 lives. According to the recent IPCC (Intergovernmental Panel on Climate Change) assessment, the global temperatures have risen by 0.6° C over the twentieth century. However, the frequency and intensity of occurrence of heat waves in recent times cannot, perhaps, be attributed to the global warming because, occurrence of heat waves is a weather phenomenon associated with regional atmospheric circulation anomalies with a life cycle of around a couple of weeks.

3. Heat wave of 2003

This year the heat wave conditions over Andhra Pradesh initially have started over Telangana on 16 May where the highest maximum temperature of 46° C (5° above normal) was recorded at Nizamabad. By 18 May the heat waves spread over to south coastal Andhra and then by 20 May extended to north coastal districts of Andhra Pradesh. The heat wave conditions also prevailed over Rayalaseema from 25 May.

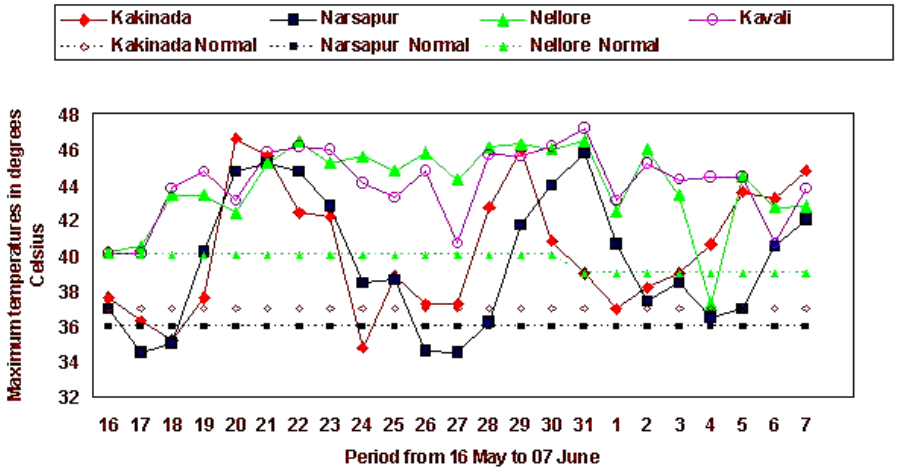

Fig. 1. Maximum temperatures over Andhra Pradesh during the period from 16 May 2003 to 07 June 2003

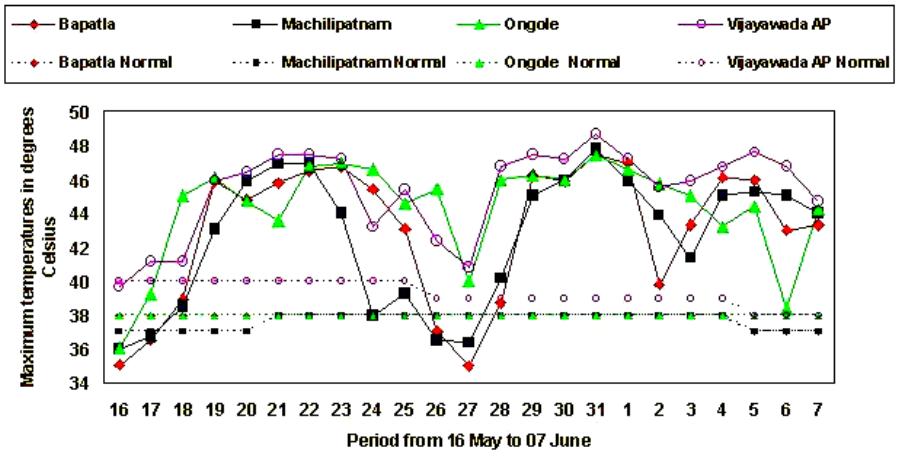

Fig. 2. Maximum temperatures over Andhra Pradesh during the period from 16 May 2003 to 07 June 2003

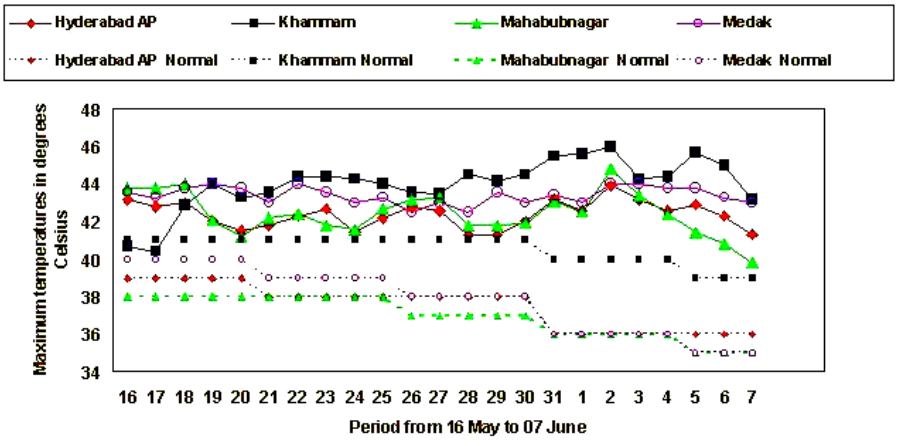

Fig. 3. Maximum temperatures over Andhra Pradesh during the period from 16 May 2003 to 07 June 2003

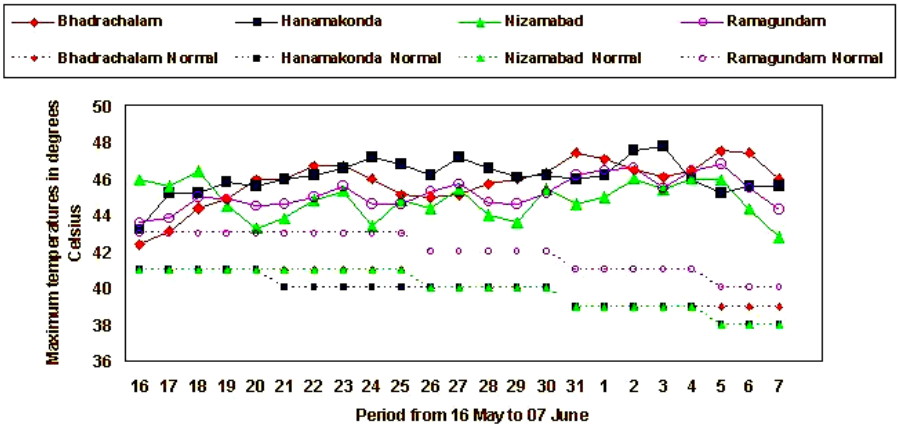

Fig. 4. Maximum temperatures over Andhra Pradesh during the period from 16 May 2003 to 07 June 2003

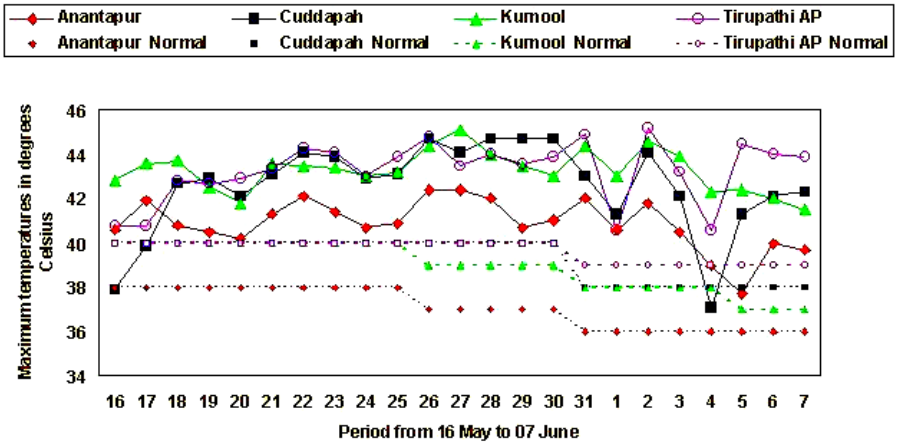

Fig. 5. Maximum temperatures over Andhra Pradesh during the period from 16 May 2003 to 07 June 2003

The maximum temperatures alongwith the normal values in respect of important stations for the period from 16 May to 07 June 2003 are graphically depicted in Figs. 1 to 5. The maximum temperatures at many places over coastal Andhra and Telangana were in the range of 42° C to 47° C with 9 degrees above normal at Kakinada, Narsapur, Machilipatnam and Bapatla during 20 to 23 May. The temperatures although fell over coastal Andhra from 24 to 27 May, they rose again from 28 May onwards. There was, however, no change in maximum temperatures over Telangana region. The intensity of heat wave was very severe during the period from 28 May to 1 June in many parts of the state. The maximum temperatures were 10 degrees above normal at Vijayawada Airport (Gannavaram), Machilipatnam & Narsapur, with Vijayawada Airport recording the highest maximum of 48.7° C on 30 May 2003. Severe heat wave to heat wave conditions have prolonged upto 11 June, thus making the total duration of heat waves to an all time record of 27 days over Andhra Pradesh in 2003. Station wise highest maximum temperatures recorded during the period are shown in Table 1.

The meteorological conditions associated with such an unprecedented heat wave spell are discussed in the following section.

3.1. *Chief synoptic situation and associated weather*

On sea level chart, axis of a trough was seen extending from east Madhya Pradesh/Orissa to extreme south Peninsula either across coastal Andhra Pradesh or along & off Andhra coast on most of the days from 16 May. This north-south trough was responsible for generating strong northerly or north-westerly winds leading to severe heat wave conditions over many parts of Andhra Pradesh, Orissa and Tamilnadu states. Since the above mentioned trough was more marked and

TABLE 1

Highest maximum temperature (°C) recorded station wise in Andhra Pradesh during the period 16 May to 11 June 2003

S. No.	Station (district)	Max. temperature / Date (°C)	Remarks *previous record temperature
		(a) Coastal Andhra Pradesh	
1.	Kakinada (East Godavari)	46.6 / 19 May	
2.	Narsapur (West Godavari)	45.8 / 30 May	
3.	Machilipatnam (Krishna)	47.8 / 30 May	
4.	Bapatla* (Guntur)	47.4 / 30 May	*47.2 on 22 May 1980
5.	Ongole* (Prakasam)	47.4 / 30 May	*47.2 on 01 Jun 1998
6.	Kavali* (Nellore)	47.2 / 30 May	*45.8 on 01 Jun 1998
7.	Nellore (Nellore)	46.5 / 30 May	
8.	Vijayawada AP (Krishna)	48.7 / 30 May	
9.	Nandigama* (Krishna)	47.1 / 30 May	*46.2 on 27 May 1998
10.	Tuni (East Godavari)	46.0 / 19 May	
11.	Visakhapatnam AP (Vizag.)	41.0 / 24 May	
		(b) Telangana	
1.	Bhadrachalam (Khammam)	47.4 / 30 May	
2.	Hanamkonda (Warangal)	47.8 / 02 Jun	
3.	Nizamabad (Nizamabad)	46.4 / 17 May	
4.	Ramagundam (Karinagar)	46.8 / 04 Jun	
5.	Hyderabad Ap (Hyderabad)	43.9 / 01 Jun	
6.	Mahabubnagar (M'bubnagar)	44.8 / 01 Jun	
7.	Medak (Medak)	44.0 / 18,21 May & 01 Jun	
		(c) Rayalaseema	
1.	Ananthapur (Anantapur)	42.4 / 25 & 26 May	
2.	Kurnool (Kurnool)	45.1 / 26 May	
3.	Nandyal (Kurnool)	45.4 / 26 May & 1 Jun	
4.	Cuddapah (Cuddapah)	44.9 / 26 May	
5.	Tirupati AP* (Chittoor)	45.2 / 01 Jun	*45.0 on 01 May 1996

pronounced over the coastal districts of Andhra Pradesh, the impact of heat wave conditions was felt more in these areas. The associated upper winds in the lower tropospheric levels also were northerly to north-westerly leading to a dry and completely stable atmosphere. The relevant weather charts of a typical day on sea level on 31 May 2003 and wind patterns at 0.6 km & 0.9 km above sea level on 30 May 2003 are shown in Figs. 6 to 8,which shows prevailing dry continental westerlies and complete absence of maritime easterlies. The westerly to northwesterly flow was seen to extend upto 500 hPa (5.8 km a.s.l.) indicating the dry conditions over the area.

On examining the variation of temperature with Relative Humidity (RH) during the hours from 1130 to 2030 IST for the periods (18 – 20 May 2003, 28 – 31 May 2003) in respect of coastal stations – Kakinada, Narsapur, Machilipatnam, Bapatla, Ongole and Nellore , it is found that sea breeze practically did not set in at these stations in view of low RH values. Evidently, the strong northerly to north-westerly winds in association with above mentioned north–south trough, have prevented the sea breeze to set in at many of the coastal stations.

TABLE 2

Comparative rainfall data in mm for the month of May 2002 & 2003

	Actual rainfall May		Normal rainfall May	Percent departure May	
	2002	2003		2002	2003
Coastal Andhra Pradesh	41.4	9.6	51.0	-19 (Normal)	-81 (Scanty)
Telangana	33.3	0.6	26.8	24 (Excess)	-98 (Scanty)
Rayalaseema	61. 9	1.6	55.2	12 (Normal)	-97 (Scanty)
AP State	46.1	5.4	43.8	5 (Normal)	-88 (Scanty)

Formation of a cyclonic storm in Bay of Bengal in the first week of May 2003 and its subsequent movement northeastwards towards Myanmar coast has possibly offset the atmospheric circulation pattern. Accordingly, the anticyclonic flow normally seen from Bay of Bengal and Arabian Sea to the peninsular India in the lowest levels of the atmosphere was replaced by dry north-

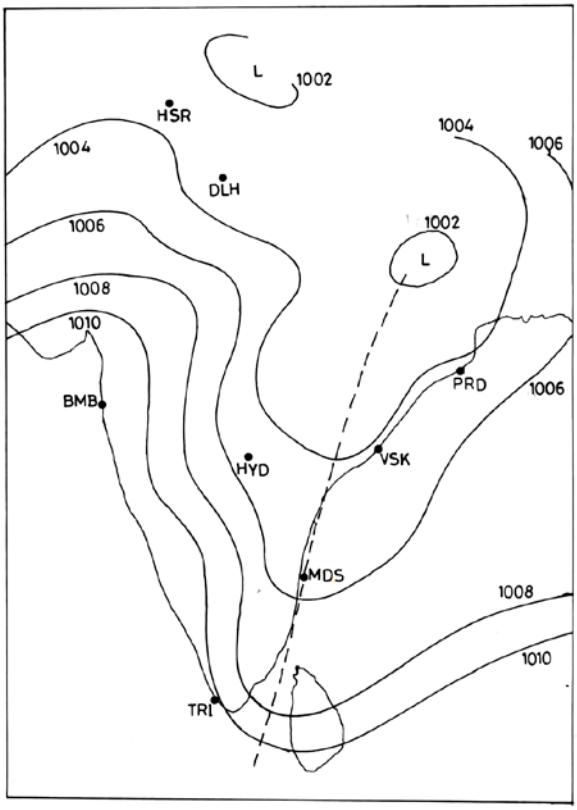

Fig. 6. Surface weather map at 0830 hrs IST on 31 May 2003

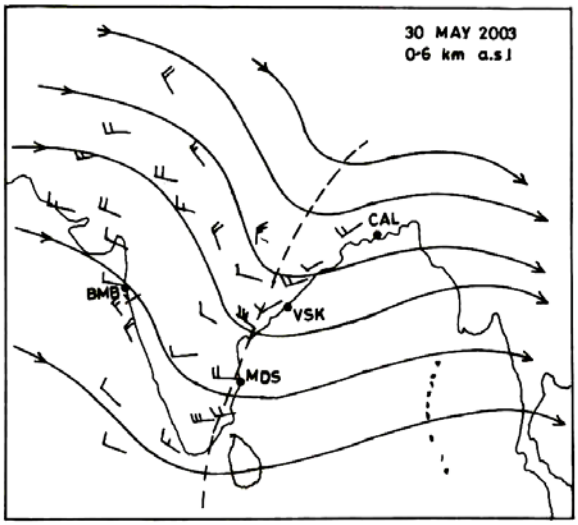

Fig. 7. Wind flow at 0530 hrs IST on 30 May 2003 at 0.6 km above sea level

westerly flow. This has resulted in complete dry spell over peninsular India especially over Andhra Pradesh in the month of May 2003. Comparative rainfall figures (mm) for the three meteorological sub-divisions of Andhra Pradesh for May 2002 & 2003 are given in Table 2.

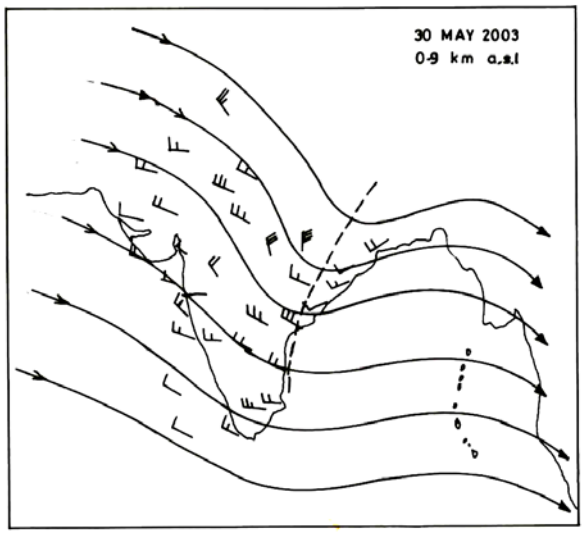

Fig. 8. Wind flow at 0530 hrs IST on 30 May 2003 at 0.9 km above sea level

Summer showers in the month of May generally would bring respite from the rising temperatures and heat wave conditions, but this year absence of such rainfall activity has significantly contributed to the severity of heat wave conditions in the state. It may be mentioned that delay of onset of monsoon in 2003 is also one important factor for the prolonged heat wave spell through first week of June.

4. Human comfort indices

Human comfort indices were calculated using following popularly known equations for six coastal stations Kakinada, Narsapur, Machilipatnam, Bapatla, Ongole and Nellore representing East Godavari, West Godavari, Krishna, Guntur, Prakasam and Nellore districts respectively where reported deaths due to heat wave were higher.

(*i*) Heat Index (HI) followed in USA is given below :

$$HI = -42.38 + 2.049T + 10.14R - 0.2248\ T\ R - 0.006838\ T^2 - 0.05482R^2 + 0.001229T^2R + 0.0008528TR^2 - 0.00000199T^2R^2$$

Where T temperature (°F) and R relative humidity (%)

Heat index range	*Heat wave hazard*
130 and above	Heat stroke highly likely with continued exposure
105 to 130	Heat stroke likely with prolonged exposure
90 to 105	Heat stroke possible with prolonged exposure

TABLE 3

Human comfort indices for six coastal stations

Date	Heat Index (HI) Time of observation (UTC)					Thom's Discomfort Index Time of observation (UTC)					Webbs' Comfort Index Time of observation (UTC)					Max. temp. (°C)
	0300	0600	0900	1200	1500	0300	0600	0900	1200	1500	0300	0600	0900	1200	1500	
Station : Kakinada (East Godavari District)																
14 May	94	101	105	98	96	80	82	83	82	81	6	7	7	6	6	31.8
15 May	98	110	109	106	105	81	86	87	**83**	83	6	**11**	9	10	9	37.6
16 May	102	115	108	103	103	83	87	**85**	**83**	82	8	**11**	10	9	8	36.3
17 May	107	110	118	116	108	84	87	87	86	84	9	10	**12**	**12**	9	35.2
18 May	108	124	128	127	116	84	89	89	88	85	9	**12**	**12**	**12**	**11**	37.6
19 May	113	119	114	110	102	86	**91**	**92**	90	85	9	**13**	**13**	**12**	9	46.6
20 May	119	116	122	112	105	87	90	**92**	**91**	84	**11**	**12**	**13**	**12**	10	45.6
21 May	112	114	**130**	118	109	86	90	**91**	88	85	10	**12**	**13**	**12**	8	42.4
22 May	118	121	**135**	122	110	87	90	**92**	88	85	**11**	**12**	**14**	**12**	9	42.2
23 May	112	117	119	113	109	85	87	87	85	84	10	**11**	**12**	**11**	10	34.8
24 May	114	116	132	121	111	86	89	89	87	84	9	**11**	**13**	**11**	10	38.8
25 May	113	118	122	113	107	85	88	89	86	84	8	**11**	**13**	**11**	10	37.2
26 May	113	119	126	115	106	86	88	89	86	83	9	**12**	**13**	**11**	10	37.2
27 May	117	122	**138**	124	111	86	90	**93**	88	85	**11**	**13**	**15**	**13**	9	42.7
28 May	115	122	121	**133**	115	86	**91**	**94**	90	86	10	**13**	**14**	**13**	**11**	46.0
29 May	111	117	**148**	127	123	86	90	**93**	88	87	**11**	**12**	**16**	**13**	10	40.8
30 May	116	**135**	**135**	117	109	86	90	90	88	87	9	**14**	**14**	**12**	10	39.0
31 May	119	123	125	121	113	86	88	89	88	85	9	**12**	**13**	**11**	10	37.0
1 Jun	117	124	127	115	114	85	88	90	87	85	10	**13**	**13**	**11**	**11**	38.2
2 Jun	114	121	**134**	121	108	86	90	90	87	85	10	**12**	**13**	**12**	10	39.0
3 Jun	110	121	**130**	121	107	85	89	**92**	88	84	10	**12**	**14**	**12**	10	40.6
4 Jun	110	119	122	114	109	85	90	**92**	87	85	10	**12**	**14**	**12**	**11**	43.6
5 Jun	112	110	117	108	102	86	88	**91**	86	83	**11**	**12**	**13**	**11**	9	43.2
6 Jun	112	118	116	116	103	85	90	**92**	88	84	10	**12**	**13**	**12**	10	44.8
7 Jun	114	117	119	127	105	86	90	**92**	90	84	**11**	**13**	**13**	**13**	10	**45.0**
8 Jun	109	111	118	114	103	85	88	**91**	86	83	10	**12**	**13**	**12**	9	43.4
9 Jun	110	118	124	117	105	85	90	**91**	87	83	10	**13**	**14**	**12**	10	40.8
10 Jun	105	114	114	110	105	84	87	88	85	84	10	**12**	**12**	**11**	10	39.0
Station : Narsapur (West Godavari District)																
14 May	97	100	106	107	103	81	82	84	84	83	6	7	7	8	9	32.0
15 May	104	111	117	112	107	83	85	88	85	83	7	8	**11**	10	9	37.0
16 May	108	114	114	108	110	84	86	86	84	84	8	10	**11**	9	9	34.5
17 May	113	110	114	115	114	85	85	86	85	84	10	9	10	10	10	35.0
18 May	115	120	127	120	113	85	88	**91**	87	85	8	10	**11**	**11**	10	40.2
19 May	114	108	115	115	108	85	88	**91**	**91**	86	10	**11**	**13**	**12**	9	44.7
20 May	113	115	116	125	107	86	90	**92**	**91**	85	10	**12**	**13**	**13**	8	**45.2**
21 May	119	111	115	122	119	87	89	**91**	88	86	**11**	**12**	**12**	**12**	**11**	44.7
22 May	113	121	124	122	111	86	89	89	88	85	**11**	**12**	**13**	**11**	10	38.3
23 May	117	118	124	118	110	85	88	89	86	84	**11**	**12**	**13**	**11**	10	38.4
24 May	114	122	125	121	116	85	88	90	87	85	10	**12**	**13**	**11**	10	38.6
25 May	112	114	118	114	111	85	86	87	85	84	10	**11**	**11**	**11**	10	34.6
26 May	115	118	116	113	112	85	86	86	85	84	10	**11**	**11**	**11**	10	34.5
27 May	118	120	121	119	114	86	87	88	87	85	10	**11**	**12**	**11**	10	36.2
28 May	119	118	125	122	110	86	89	90	89	85	9	**11**	**12**	**12**	10	41.7
29 May	119	115	121	125	111	86	89	**92**	90	86	9	**11**	**13**	**12**	8	44.0
30 May	117	110	117	**130**	109	87	89	**92**	89	86	9	**11**	**13**	**12**	**11**	**45.8**
31 May	104	118	122	121	118	84	89	89	87	86	9	**12**	**13**	**11**	9	40.6
1 Jun	115	117	119	117	117	84	88	88	87	85	10	**11**	**11**	9	**11**	37.4
2 Jun	118	122	123	115	112	86	89	89	86	85	9	**12**	**12**	**11**	10	38.4
3 Jun	115	120	122	113	111	85	87	88	86	85	10	**11**	**12**	**11**	10	36.5
4 Jun	110	122	119	115	113	84	88	88	86	85	10	**11**	**11**	**11**	10	37.0
5 Jun	116	113	124	107	109	86	88	90	85	84	10	**11**	**13**	**11**	10	40.5
6 Jun	117	114	124	112	109	86	89	90	86	84	10	**12**	**13**	**11**	10	42.0
7 Jun	116	116	120	119	113	86	89	**92**	88	85	**11**	**12**	**14**	**12**	10	43.0
8 Jun	110	121	115	114	107	85	89	87	86	84	10	**12**	**12**	**11**	10	37.7
9 Jun	110	119	119	115	111	84	86	87	85	84	10	**11**	**11**	10	10	34.8
10 Jun	110	112	113	111	107	84	85	85	84	83	10	9	10	10	**7**	33.2

TABLE 3 (*Contd.*)

Date	Heat Index (HI) Time of observation (UTC)					Thom's Discomfort Index. Time of observation (UTC)					Webbs' Comfort Index. Time of observation (UTC)					Max. temp. (°C)
	0300	0600	0900	1200	1500	0300	0600	0900	1200	1500	0300	0600	0900	1200	1500	
Station : Machilipatnam (Krishna District)																
14 May	97	104	103	102	98	81	84	84	83	81	6	8	7	9	8	34.8
15 May	105	105	114	106	105	83	84	87	84	83	9	9	**11**	**11**	10	36.0
16 May	107	115	109	107	104	84	88	86	84	83	8	**11**	10	10	9	36.8
17 May	105	115	120	116	109	83	87	88	86	84	9	**11**	**12**	**11**	**11**	38.5
18 May	113	115	126	116	106	85	88	90	87	84	10	**12**	**13**	**11**	10	43.1
19 May	94	107	112	109	104	81	88	**91**	89	85	8	**12**	**14**	**13**	8	45.9
20 May	100	112	118	110	104	84	90	**93**	90	85	10	**13**	**13**	**11**	10	46.9
21 May	105	112	118	119	99	86	90	**93**	90	83	**11**	**13**	**14**	**13**	10	47.0
22 May	108	113	123	117	110	84	90	89	89	85	9	**13**	**14**	**13**	**11**	44.0
23 May	115	120	122	112	105	85	88	88	85	83	9	**12**	**13**	**11**	9	38.0
24 May	113	118	125	121	110	85	89	90	88	85	**11**	**12**	**12**	**12**	10	39.3
25 May	114	119	117	113	114	86	88	87	86	84	10	**12**	**12**	**11**	**11**	36.5
26 May	111	114	119	111	105	85	87	88	85	83	**11**	**12**	**12**	**11**	10	36.4
27 May	118	124	124	117	110	87	**91**	90	88	85	**11**	**13**	**14**	**12**	**11**	40.2
28 May	118	115	120	119	107	87	90	**92**	89	85	**11**	**12**	**14**	**12**	10	45.0
29 May	116	**131**	118	111	103	87	**94**	**92**	89	85	**11**	**15**	**13**	**12**	9	46.0
30 May	101	114	117	107	110	85	**91**	**93**	**91**	86	9	**13**	**14**	**12**	10	**47.8**
31 May	114	128	122	117	114	87	**92**	**92**	88	86	9	**15**	**14**	**12**	**11**	45.9
1 Jun	109	113	121	111	109	84	89	**91**	87	84	8	**12**	**14**	**11**	10	43.9
2 Jun	112	118	122	111	105	85	90	90	86	84	8	**12**	**14**	**12**	10	41.4
3 Jun	113	121	121	117	108	86	90	**93**	89	85	10	**12**	**15**	**13**	10	45.0
4 Jun	108	108	128	121	101	85	88	**92**	88	85	10	**11**	**15**	**13**	9	45.3
5 Jun	104	113	118	108	103	85	90	**92**	87	85	10	**13**	**13**	**12**	10	45.0
6 Jun	105	109	114	115	107	85	88	**91**	88	84	10	**12**	**12**	**12**	10	44.0
7 Jun	111	110	113	112	107	86	89	90	90	85	**11**	**13**	**13**	**12**	10	44.3
8 Jun	102	114	128	107	102	84	90	**92**	87	83	9	**12**	**15**	**11**	10	44.5
9 Jun	112	119	125	111	104	86	90	**91**	87	83	10	**12**	**14**	**13**	9	40.9
10 Jun	105	111	115	98	94	84	87	87	83	80	8	9	**12**	7	7	38.5
Station : Bapatla (Guntur District)																
14 May	99	105	104	103	103	82	85	85	83	83	6	8	9	9	9	35.1
15 May	106	109	116	109	106	83	87	88	85	83	7	9	**11**	10	10	37.3
16 May	111	108	111	109	105	85	86	86	85	83	10	**11**	**11**	**11**	10	36.5
17 May	109	114	122	114	107	84	88	89	86	84	10	**12**	**13**	**11**	10	38.9
18 May	109	110	116	110	111	85	89	**92**	87	85	**11**	**13**	**14**	**12**	**11**	**45.9**
19 May	100	110	114	115	107	84	89	**91**	**91**	85	**11**	**13**	**14**	**13**	9	44.8
20 May	100	111	125	119	106	85	89	**94**	90	86	10	**13**	**15**	**13**	10	45.8
21 May	104	114	119	113	111	86	**91**	**93**	89	85	**11**	**14**	**15**	**12**	**11**	46.5
22 May	102	109	112	109	101	85	89	**91**	88	85	**11**	**13**	**13**	**11**	10	46.7
23 May	104	109	112	113	108	85	89	**91**	87	84	10	**13**	**13**	**11**	**11**	45.4
24 May	115	115	114	121	112	86	89	90	88	85	9	**12**	**12**	**13**	**11**	43.1
25 May	113	121	120	113	111	85	88	88	85	84	**11**	**12**	**13**	**11**	**11**	37.0
26 May	113	112	114	110	108	85	84	86	85	84	**11**	**11**	**12**	**11**	**11**	35.0
27 May	115	121	121	117	111	86	89	89	87	85	**11**	**13**	**13**	**12**	**11**	38.7
28 May	107	109	111	110	114	86	89	**91**	88	86	**11**	**13**	**13**	**12**	**11**	**46.3**
29 May	98	112	109	108	105	83	90	90	89	85	8	**13**	**12**	**12**	10	45.9
30 May	97	109	112	109	103	83	90	**92**	88	84	9	**13**	**13**	**11**	9	47.4
31 May	111	110	112	112	108	87	90	**91**	88	87	10	**13**	**13**	**12**	10	47.0
1 Jun	102	111	112	112	108	85	88	88	86	84	9	**11**	**12**	**12**	9	39.8
2 Jun	100	111	117	109	105	83	89	90	85	84	9	**12**	**13**	**11**	9	43.3
3 Jun	109	109	112	116	108	84	88	**91**	89	86	10	**13**	**13**	**12**	**11**	46.1
4 Jun	101	113	118	111	109	84	90	**92**	87	84	10	**13**	**14**	**11**	10	46.0
5 Jun	101	106	114	109	102	84	87	90	88	83	10	**11**	**13**	**12**	10	43.0
6 Jun	104	112	117	109	107	85	89	90	86	84	**11**	**13**	**13**	**12**	**11**	43.3
7 Jun	105	113	121	110	102	86	89	**91**	87	83	**11**	**13**	**14**	**12**	10	**43.5**
8 Jun	102	112	110	99	101	84	89	85	83	82	10	**13**	**11**	10	9	42.8
9 Jun	109	111	114	107	106	85	88	89	86	84	10	**11**	**13**	**11**	10	40.4
10 Jun	105	113	100	93	91	84	87	83	80	79	7	**11**	9	8	5	37.3

TABLE 3 (*Contd.*)

Date	Heat Index (HI) Time of observation (UTC)					Thom's Discomfort Index Time of observation (UTC)					Webbs' Comfort Index Time of observation (UTC)					Max. temp. (°C)
	0300	0600	0900	1200	1500	0300	0600	0900	1200	1500	0300	0600	0900	1200	1500	
Station : Ongole (Prakasam District)																
14 May	97	97	105	94	103	81	83	85	82	84	6	7	8	8	7	36.1
15 May	97	107	121	104	105	82	87	89	85	84	6	9	**12**	9	7	40.2
16 May	105	112	114	111	109	84	88	87	86	84	7	9	**11**	**11**	10	39.2
17 May	108	110	123	109	106	88	87	**93**	87	84	10	9	**12**	9	10	45.0
18 May	99	107	114	111	110	84	88	**92**	90	87	9	**11**	**13**	**12**	9	46.1
19 May	98	106	112	114	100	83	87	90	**91**	85	9	**11**	**12**	**12**	9	44.7
20 May	100	109	113	112	105	84	89	**91**	90	86	9	**12**	**13**	**12**	10	46.6
21 May	104	113	113	111	109	86	**91**	**92**	89	86	10	**13**	**13**	**11**	10	46.8
22 May	103	112	115	115	101	85	90	**92**	**92**	85	10	**12**	**13**	**13**	9	**47.0**
23 May	102	108	116	124	109	85	89	**92**	90	85	9	**12**	**13**	**12**	10	46.6
24 May	111	112	129	124	114	85	89	**93**	90	86	8	**12**	**14**	**12**	**11**	44.6
25 May	105	113	122	117	113	84	90	**91**	88	85	9	**12**	**13**	**12**	**11**	45.4
26 May	113	120	124	114	98	85	89	90	86	83	10	**12**	**13**	9	9	40.0
27 May	105	120	120	117	111	85	**92**	**93**	90	86	10	**13**	**13**	**12**	10	46.0
28 May	98	113	115	113	107	83	90	**92**	90	86	8	**12**	**12**	**12**	8	46.2
29 May	101	113	113	112	104	85	90	**91**	**91**	86	9	**12**	**13**	**12**	8	46.0
30 May	101	110	114	115	107	85	90	**92**	**91**	86	7	**12**	**13**	**12**	9	**47.4**
31 May	106	119	120	117	103	86	**91**	**93**	**91**	85	10	**13**	**13**	**13**	10	46.6
1 Jun	100	111	120	119	110	84	89	**92**	90	86	7	**12**	**13**	**12**	**11**	45.7
2 Jun	97	115	117	111	105	83	89	**92**	87	85	9	**12**	**13**	**11**	10	45.0
3 Jun	102	103	115	115	107	83	84	90	**91**	87	9	9	**12**	**12**	**11**	43.2
4 Jun	105	113	118	118	114	85	89	**91**	**91**	86	**11**	**13**	**13**	**13**	10	**44.4**
5 Jun	97	98	106	106	104	82	83	87	87	84	9	9	**11**	10	9	38.4
6 Jun	102	110	117	110	107	84	88	**91**	87	84	10	**12**	**12**	**11**	10	44.2
7 Jun	102	111	117	111	108	85	88	**91**	88	85	9	**11**	**13**	**11**	10	**44.4**
8 Jun	100	111	115	100	101	84	88	**91**	84	84	10	**11**	**12**	9	7	44.0
9 Jun	102	108	116	110	101	84	88	**91**	87	84	7	10	**12**	**11**	9	43.9
10 Jun	104	109	115	110	99	85	88	90	86	82	10	**11**	**12**	**11**	7	42.8
Station : Nellore (Nellore District)																
14 May	95	104	107	104	100	81	84	86	84	82	6	9	10	9	8	36.1
15 May	95	107	112	115	105	81	86	88	88	84	8	10	**11**	**11**	10	40.2
16 May	103	111	118	115	111	83	87	90	87	85	9	**11**	**12**	**11**	10	40.5
17 May	100	109	117	117	108	83	87	**91**	**91**	85	9	**11**	**13**	**13**	9	43.4
18 May	99	106	110	112	101	83	86	89	89	85	9	**11**	**11**	**12**	9	43.4
19 May	94	106	113	111	104	81	86	89	89	86	9	**12**	**13**	**12**	8	42.4
20 May	106	119	123	115	112	86	86	**93**	**91**	86	**11**	**13**	**14**	**12**	**11**	45.2
21 May	109	120	120	121	115	87	**91**	**93**	89	87	**11**	**13**	**14**	**13**	**11**	**46.4**
22 May	104	115	125	116	117	85	89	**93**	**91**	87	10	**13**	**14**	**12**	**11**	45.2
23 May	108	114	117	113	117	86	89	**92**	89	86	**12**	**13**	**13**	**12**	**11**	45.6
24 May	104	117	128	123	109	85	90	**94**	89	85	10	**13**	**15**	**12**	10	44.8
25 May	109	122	129	124	120	86	**91**	**95**	89	87	10	**13**	**15**	**13**	**11**	45.8
26 May	106	124	129	118	114	85	**91**	**92**	88	86	8	**13**	**14**	**11**	**11**	44.3
27 May	111	118	123	125	115	86	**91**	**94**	**91**	86	10	**15**	**14**	**13**	**11**	46.1
28 May	113	120	117	112	109	87	**91**	**92**	89	86	**11**	**13**	**13**	**12**	10	46.3
29 May	107	115	119	117	118	86	90	**93**	**92**	88	**11**	**13**	**14**	**13**	**11**	46.0
30 May	103	109	116	121	112	85	89	**92**	**92**	87	10	**12**	**13**	**13**	**11**	**46.5**
31 May	101	106	116	120	103	84	86	90	**91**	85	9	**11**	**13**	**13**	9	42.5
1 Jun	104	120	119	116	107	85	**92**	**93**	89	85	10	**13**	**14**	**12**	10	**46.0**
2 Jun	101	110	115	114	105	84	88	90	88	84	7	**11**	**12**	**11**	9	43.4
3 Jun	103	104	107	110	109	84	84	86	87	85	9	10	10	10	10	37.2
4 Jun	113	115	117	112	112	87	90	**91**	87	86	**11**	**13**	**13**	**11**	10	**44.5**
5 Jun	99	104	115	112	111	83	86	90	87	85	8	10	**12**	**11**	10	42.7
6 Jun	99	111	113	115	109	84	88	90	88	85	9	**12**	**12**	**11**	10	42.8
7 Jun	105	113	117	115	108	85	89	**91**	88	85	10	**12**	**13**	**12**	9	**43.3**
8 Jun	103	114	117	93	97	84	89	90	81	82	9	**11**	**12**	8	8	43.2
9 Jun	103	113	116	109	100	84	88	90	86	83	9	**12**	**12**	10	9	41.8
10 Jun	109	112	119	109	97	86	88	**91**	86	82	10	**11**	**12**	**11**	8	42.5

(*ii*) Thom's Discomfort Index.

$$D.I. = 0.72 (T_d + T_w) + 40.6$$

T_d and T_w are the dry and wet bulb temperatures (°C)

Discomfort index range	*Hazard*	*Discomfort index range*	*Hazard*
60-65	50% of people feel uncomfortable due to chillness	80-85	Uncomfortable in small areas due to hot weather
65-75	Quite Comfortable	85-90	Uncomfortable in large area due to hot weather
75-80	About half the people are uncomfortable due to hot weather	More than 90	Uncomfortable in most areas due to severe hot weather

(*iii*) Webbs' Comfort Index

$$CI = 0.464t + 0.164p + 0.762\sqrt{v} - 12.93$$

Where t is atmospheric temperature (°C), p is vapour pressure in hPa and v is prevailing wind speed in kmph.

Comfort index	*Hazard*	*Comfort index*	*Hazard*
6	Neither cool nor warm	9	Hot
7	Comfortably warm	10	Very hot
8	Warm	Greater than 10	Severely hot

The above three indices have been computed station wise from 14 May to 10 June 2003 and are presented in Table 3. The higher Index values on some of the days clearly reflect the severity of heat waves. The impact of heat wave in East Godavari and West Godavari districts was mainly due to high temperature and Relative Humidity as indicated by Heat Index and Thoms Index values. However, Webbs Index values suggest that the severity of heat wave in the coastal districts was predominantly due to high speed dry and hot winds, of the order of 6 to 26 kmph.

5. Conclusions

The present study on heat waves over Andhra Pradesh has brought out the following salient features :

(*i*) During the last decade, the frequency of severe heat waves and duration of heat wave spells over Andhra Pradesh have significantly increased.

(*ii*) The highest maximum temperatures, which used to be recorded hitherto in interior districts of the state have remarkably shifted to the coastal districts, in recent years. This is basically due to the synoptic situation of north-south trough (on the sea level) along and off Andhra Coast, as discussed during May-June 2003.

(*iii*) Analysis of long period maximum temperature data (1901-2002) of Andhra Pradesh has indicated no definite variations or trends in maximum temperature across the state.

(*iv*) Human comfort index values (Heat Index, Thoms Index and Webbs Index) in respect of coastal stations have clearly indicated the severity of heat waves. Especially, higher values of Webb's Index showed how the impact of strong and hot dry winds contributed to the severity of heat waves in coastal stations of Andhra Pradesh.

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