

Unprecedented rainfall over Bangalore city during October, 2005

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सार – भारत मौसम विज्ञान विभाग की पैलेस रोड बंगलुरु स्थित केन्द्रीय वेधशाला से अक्टूबर 2005 में 604 मि. मी. की रिकॉर्ड अधिकतम मासिक वर्षा का पता चला है। बंगलुरु शहर में रिकॉर्ड की गई यह सबसे अधिकतम मासिक वर्षा है। तथापि, बंगलुरु जिले के आसपास के केन्द्रों में कम वर्षा रिकॉर्ड की गई। इस वर्षा की भौतिक प्रक्रियाओं का पता लगाने के लिए अक्टूबर 2005 में बंगलुरु के शहरी और ग्रामीण जिलों के विभिन्न केन्द्रों में वर्षा के अभिलक्षणों और उनसे संबंधित सिनॉप्टिक और तापगतिकीय लक्षणों का विश्लेषण किया गया है। शहरी ऊष्ण द्वीप (यू. एच. आई.) प्रभाव और प्रदूषण प्राचलों की भूमिका तथा इस वर्षा के साथ उनके संबंध का भी इस शोध पत्र में विश्लेषण किया गया है। इस अध्ययन का उपयोग वर्षा पर, विशेष रूप से भारी वर्षा पर, शहरीकरण और प्रदूषण के दुष्प्रभाव को बेहतर ढंग से समझने के लिए किया जा सकता है। इससे शहरी केन्द्रों में भारी वर्षा की घटनाओं का पूर्वानुमान लगाने में भी सहायता मिलेगी।

यह अध्ययन पहले के परिणामों की पुष्टि करता है कि यू. एच. आई. प्रभाव के कारण नमी का अभिसरण होता है और प्रदूषक, उस क्षेत्र में आर्द्रताग्राही केन्द्रक के रूप में कार्य करते हैं जिससे शहर के आस-पास वर्षा में वृद्धि होती है।

ABSTRACT. The Central Observatory of India Meteorological Department (IMD) at Palace Road, Bangalore reported a record highest monthly rainfall of 604 mm during October, 2005. It was the highest ever monthly rainfall recorded over Bangalore city. However, the surrounding stations in Bangalore district recorded less rainfall. To find out the physical processes leading to this rainfall, the characteristics of rainfall over different stations in Bangalore urban and rural districts during October, 2005 and associated synoptic and thermodynamic features during the month are analysed. The Urban Heat Island (UHI) effect and role of pollution parameters and their relationship with this rainfall have also been analysed. This study can be utilized in better understanding of the impact of urbanization and pollution on rainfall, especially heavy rainfall. It can also help in predicting the heavy rainfall events over the urban centres.

The study endorses the earlier finding that the UHI effect leads to moisture convergence and pollutants may work as hygroscopic nuclei over the region to enhance rainfall near the urban centre.

Key words – Rainfall, Synoptic feature, Urban heat island effect.

1. Introduction

The Central Observatory of India Meteorological Department (IMD) at Palace Road, Bangalore (Henceforth called as Bangalore city observatory) reported a record highest monthly rainfall of 604 mm during October, 2005 (IMD, 1999). The analysis of the monthly rainfall over different stations in Bangalore urban and rural districts indicated that the rainfall was maximum over Bangalore city and less over the outskirts of the city. Of course, all the stations in Bangalore urban and rural districts recorded higher than normal rainfall during October, 2005. Further analysis indicated that this unprecedented rainfall over Bangalore city was mainly due to the higher rainfall (> 5

cm) on five days, viz., 5th, 9th, 18th, 23rd and 26th October, 2005. Bangalore city experienced flash floods during these days. Further, the analysis of the monthly rainfall over different meteorological subdivisions over southeast peninsula during October, 2005 indicated that highly excess rainfall (rainfall departure from normal; 20%) occurred over all these subdivisions (IMD, 2005a & b).

Kishtawal *et al.* (2009) analyzed the long-term rainfall data and found urban regions have more statistically significant precipitation occurrence as compared to the rural regions. Studies such as Braham and Wilson (1978), Shepherd and Burian (2003) and Niyogi *et al.* (2006) have shown that urban land surface can

influence local storm structure causing enhanced convection and increased precipitation. The detailed review in this aspect is given by Lei *et al.* (2008).

Bangalore is a major city in peninsular India and is considered as the country's information technology (IT) capital. It is also a major commercial centre and capital of Karnataka state. The population of Bangalore city is about 6.5 million as per the population census report of 2001 (Government of India, 2001). The decadal percentage growth has been about 35% over Bangalore city and about 12% over the nearby rural regions from 1991 to 2001. The city is experiencing rapid urbanization and such densely populated cities with an aging infrastructure are vulnerable to natural disasters. Therefore, it is important to assess the possible impact of the urbanization of Bangalore on heavy rainfall events. However, the studies on role of urban landscape on the heavy rain over the synoptically active peninsular region during northeast monsoon season are limited.

Our hypothesis is that the rainfall intensity was significantly enhanced near Bangalore city centre due to UHI effect and hence moisture convergence at the urban centre during above mentioned days of significant rainfall leading to record monthly rainfall. Further, the region including Bangalore city received higher rainfall in association with the favourable synoptic and large scale features.

To examine the above hypothesis, the characteristics of rainfall over different stations in Bangalore urban and rural districts during October, 2005 are analysed. UHI effect leading to the occurrence of 5 significant rainfall events over Bangalore city are also analysed in detail based on analysis of temperature and pollution data. The data and methodology used in the study are presented in Section 2. The results and discussion are presented and analysed in Section 3 and broad conclusions of the study are mentioned in Section 4. This study can be utilized for better understanding of the impact of urbanization on rainfall, especially heavy rainfall. It can also help in predicting the heavy rainfall events over the urban centres.

2. Data and methodology

To analyse the large-scale rainfall over the peninsular region during October, 2005, the rainfall over meteorological sub-divisions of the peninsular region has been analysed. The rainfall data for this purpose have been collected from the Weekly Weather Reports published by IMD (2005b). To find out the mesoscale distribution of rainfall, the daily and monthly rainfall over all the stations under district-wise rainfall monitoring

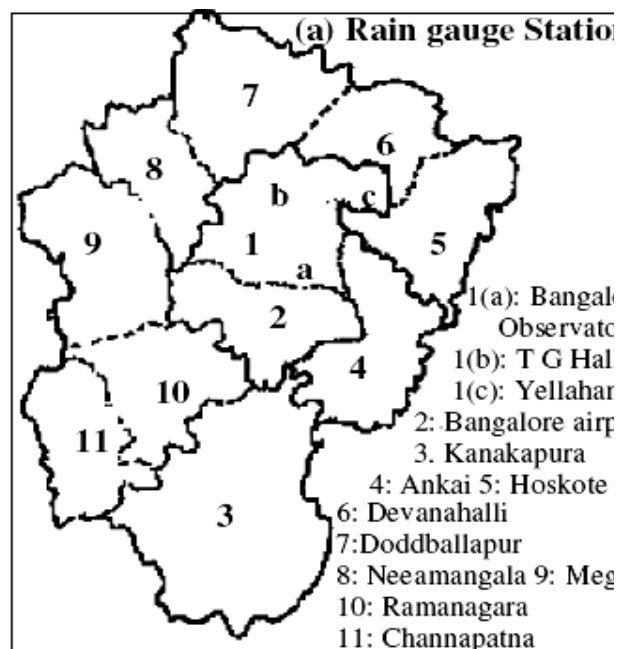


Fig. 1. Selected rain gauge stations

scheme (DRMS) has been collected from Meteorological Centre, Bangalore and analysed. The stations under consideration are shown in Fig. 1. The past 24 hours cumulative rainfall data as measured at 0300 UTC of the day have been considered. To analyse the mesoscale features, the radiosonde data observed at Bangalore at 0000 UTC of these significant rainfall days have been collected from Meteorological Centre, Bangalore and analysed.

The synoptic scale systems affecting the Peninsular region during October, 2005 have been analysed to find out their role on rainfall over Bangalore. For this purpose, the data on synoptic systems like low pressure systems and upper air cyclonic circulations developing over the Bay of Bengal and moving westwards across the Peninsular India as observed at 0300 UTC of the day have been collected from India Daily Weather Reports (IMD, 2005a). The synoptic systems associated with the 5 significant rainfall events over Bangalore have been analysed.

To find out the relation between the daily rainfall and the UHI effect, the surface daily maximum and minimum temperatures over the Peninsular region during October, 2005 have been collected from India daily weather reports (IDWR) and analysed. The fact that an UHI receives more rainfall compared to surrounding areas is well known. The pollutants work as hygroscopic nuclei and aid in enhancement of rainfall amounts. Hence, it is

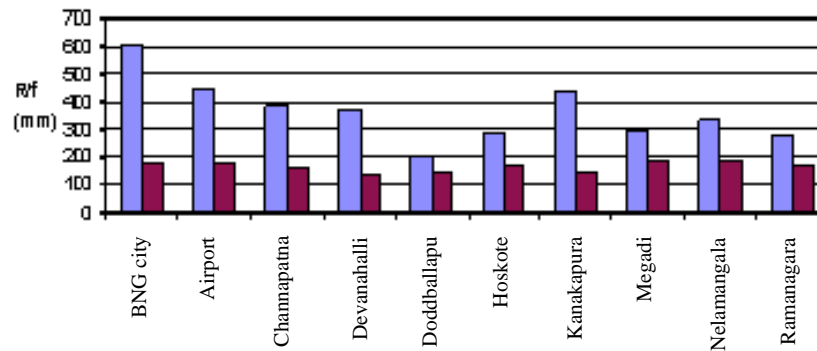


Fig. 2. Actual and mean monthly rainfall over Bangalore district during Oct, 2005

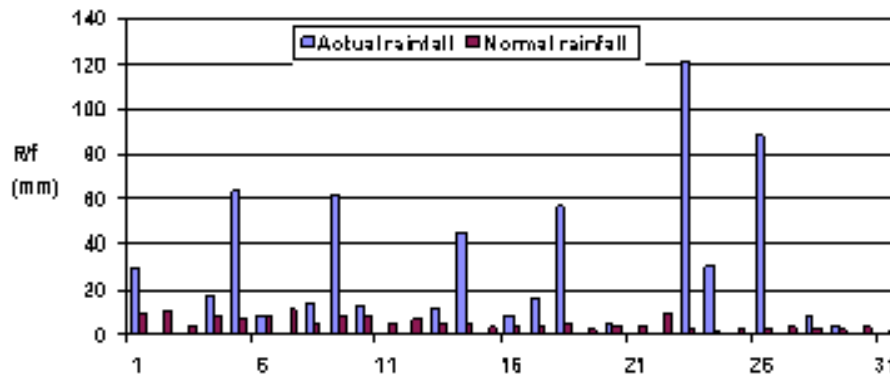


Fig. 3. Daily normal and actual rainfall over Bangalore city during Oct, 2005

important to establish that UHI characteristics over Bangalore were responsible for enhanced rainfall near the centre of Bangalore city on given occasions. To find out the contribution of pollutants to the enhanced rainfall, the daily concentrations of various pollutants as measured by Karnataka State Pollution Control Board have been analysed. There are following seven pollution monitoring stations over Bangalore and neighbourhood:

- (i) International machine tools accessories, Peenya
- (ii) Amco Batteries, Mysore Road, Bangalore
- (iii) Victoria Hospital, K.R Market, Bangalore
- (iv) K.H.B Industrial Area, Yelahanka, Bangalore
- (v) Peenya Industrial Area, Peenya, Bangalore
- (vi) Yeshwanthpura Police Station, Bangalore
- (vii) Graphite India, Whitefield, Bangalore

However, daily values of different pollutants are not available for all the stations during October 2005. The

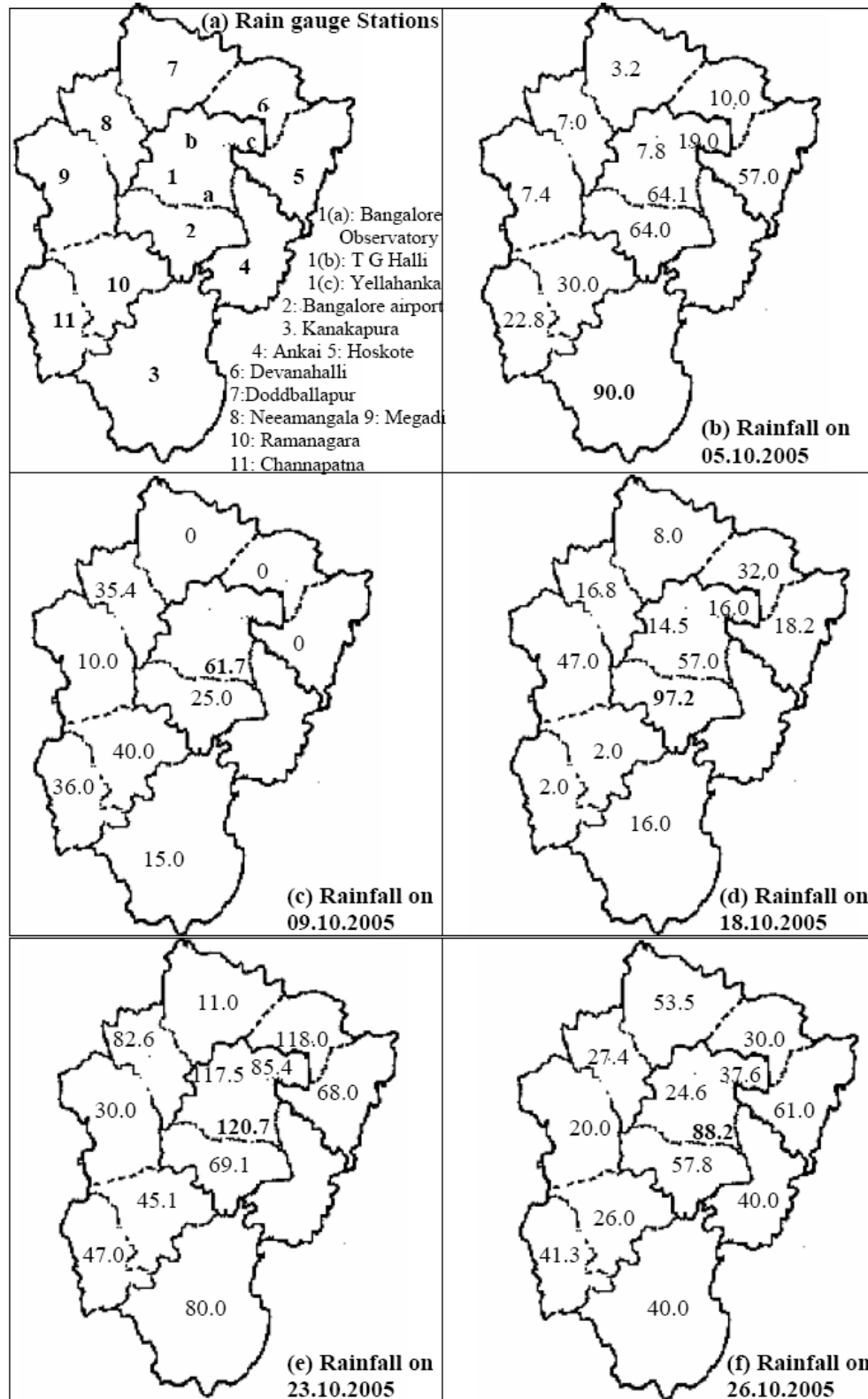
daily values are available for maximum number days only over Yelahanka. The daily data of this station has been analysed. The parameters include sulfur dioxide (SO₂), Nitrogen oxide (NO₂), suspended particulate matters (SPM) and respirable suspended particulate matters (RSPM). The results and discussions are presented in following sections.

3. Results and discussion

The rainfall characteristics over south peninsula and especially over Bangalore region during October, 2005 are analysed in Sec. 3.1. The synoptic features and thermodynamic features are presented and analysed in Sec. 3.2 and Sec. 3.3 respectively. The impact of urbanization on the rainfall over Bangalore are presented and discussed in Sec. 3.4.

3.1. Rainfall characteristic over Bangalore during October, 2005

The analysis of the monthly rainfall over different stations in Bangalore urban and rural districts (Fig. 2) indicated that the rainfall was maximum over Bangalore



Figs. 4(a-f). (a) Selected rain gauge stations and (b-f) daily rainfall distribution (cm) on days of significant rainfall (> 5 cm) over Bangalore city

TABLE 1
Different parameters/index over Bangalore during significant rainfall days

Parameters/Index on previous day	Days of significant rainfall (≥ 5 cm)					Mean
	05 Oct 2005	09 Oct 2005	18 Oct 2005	23 Oct 2005	26 Oct 2005	
Showalter index	-01.61	-02.17	-02.54	-03.60	-04.88	-02.96
Lifted index	-03.06	-02.98	-04.17	03.18	-05.44	-03.77
K index	37.0	37.80	36.30	41.40	42.10	38.92
Cross total index	21.80	22.40	22.10	24.60	25.30	23.24
Vertical total index	26.50	22.50	23.90	24.90	25.50	24.66
Totals total index	48.30	44.90	46.0	49.50	50.80	47.90
CAPE (J)	1142.81	1116.72	1602.38	1175.26	2462.78	1499.99
CINE (J/kg)	-29.24	0.0	-0.33	-04.36	-0.03	-06.79
Level of free convection (hPa)	774.43	863.47	830.47	814.65	855.39	827.68
Temperature at lifting condensation level ($^{\circ}$ K)	290.04	263.01	293.60	289.95	292.77	291.87
Pressure at lifting condensation level (hPa)	860.71	869.27	847.20	856.71	878.87	862.55
Precipitable water (mm)	47.50	41.32	44.47	42.08	47.69	44.61

city and less over the outskirts of the city. Of course, all the stations in Bangalore urban and rural districts recorded higher than normal rainfall during October, 2005. This could be attributed to the large scale synoptic processes conducive for heavy rainfall during the month.

According to IMD (1999), Bangalore city observatory normally gets more rainfall than the airport observatory nearer to the outskirt. To find out the spatial variation of rainfall over Bangalore region, daily rainfall over Bangalore city was further analysed for October, 2005. It was found that the record monthly rainfall was mainly due to the higher rainfall (≥ 5 cm) on five days viz., 5th, 9th, 18th, 23rd and 26th October 2005 (Fig. 3). The comparison of daily rainfall over Bangalore city and other observatories during October, 2005 also indicated that Bangalore city got more rainfall than others on 5th, 9th, 18th, 23rd and 26th, the days of significant rainfall [Figs. 4(a-f)].

3.2. Synoptic systems over the peninsular India and adjoining sea areas

Deep easterly waves prevailed over the Bay of Bengal even extending up to northern part of west central Bay of Bengal (IMD, 2005a). They were very often embedded with the low pressure system (LPS)/cyclonic

circulations (cycir). Four LPS including 1 deep depression affected the region moving westwards from the southwest and adjoining west central Bay of Bengal. In addition, a number of upper air cycirs extending upto lower/middle tropospheric levels moved westwards from the Bay of Bengal to Arabian Sea across the peninsula during October (Mausam, 2006).

The associated synoptic systems for five significant rainfall events as mentioned in the Section 1 were investigated in detail. The broad synoptic systems leading to these events are described below:

- (i) 05th Oct, 2005 : A cycir extending upto mid-tropospheric level (MTL) lay over southeast and adjoining southwest Bay of Bengal on 4th and over southwest Bay of Bengal on 5th.
- (ii) 09th Oct, 2005 : A cycir extending upto 3.6 km above mean sea level lay over southeast and adjoining southwest Bay of Bengal on 8th. Under its influence, a low pressure area formed over southwest and adjoining west central Bay of Bengal on 9th morning.

TABLE 2

Daily average, maximum and standard concentrations of SO₂, NO₂, SPM and RSPM as observed over Yelahanka during October 2005

Date	SO ₂			NO ₂			SPM			RSPM		
	AVG	MAX	ST	AVG	MAX	ST	AVG	MAX	ST	AVG	MAX	ST
04 Oct 2005	7.9	10	30	34	44	30	122	180	100	77	102	75
06 Oct 2005	7.3	10	30	31	38	30	160	207	100	99	134	75
10 Oct 2005	8.1	10	30	39	44	30	123	183	100	75	100	75
17 Oct 2005	4.6	5.4	30	24	29	30	108	120	100	39	60	75
20 Oct 2005	5.3	8.3	30	26	37	30	50	63	100	29	40	75
24 Oct 2005	7	9.6	30	30	41	30	123	144	100	79	97	75
26 Oct 2005	8.4	11	30	30	42	30	72	111	100	27	30	75
28 Oct 2005	5	6	30	22	31	30	87	154	100	41	79	75
31 Oct 2005	34	48	30	51	55	30	81	89	100	40	57	75
Mean	9.7	13.1	30	31.9	40.1	30	102.9	139	100	56.2	77.7	75
SD	9.2	13.2	0	8.8	7.7	0	33.4	47.3	0	26.3	33.7	0
CV (%)	94.6	100.5	0	27.7	19.2	0	32.5	34.0	0	46.7	43.4	0

- (iii) 18th Oct, 2005 : A cycir extending upto MTL lay over central part of south Bay of Bengal on 17th.
- (iv) 23rd Oct, 2005 : A cycir lay over coastal Tamil Nadu and neighborhood extending upto 3.1 km above mean sea level on 22nd.
- (v) 26th Oct, 2005 : A low pressure area formed over southeast and adjoining southwest Bay of Bengal on 25th morning and became well marked in the same evening. It concentrated into a depression at 0830 hrs IST of 26th near Long. 84.5° E / Lat. 12.0° N, about 500 km east southeast of Chennai.

All these indicated that the five significant rainfall events were associated with low-pressure systems/ cyclonic circulations over the southwest Bay of Bengal and adjoining areas.

3.3. Thermodynamic features

The analysis of thermodynamic features at 0000 UTC over Bangalore leading to five significant rainfall events indicated that the atmosphere was unstable with higher CAPE ranging between 1117-2463 and lower CINE (varying from 0 to -29) during all these days (Table 1). Hence CAPE & CINE were favourable for convective rainfall over Bangalore. There was convective instability and relative humidity was higher in lower and middle tropospheric levels over Bangalore during all these days. The Precipitable water content of the atmosphere over Bangalore was also higher and ranged from 41 to 48 mm during these days. The total total index varies between 45 and 51 with an average value of about 48.

3.4. Impact of urbanization

The rainfall distribution over Bangalore urban and rural districts based on data of representative stations in different revenue subdivisions (Taluk) during the days with significant amount (5 cm) of rainfall over Bangalore central observatories (Fig. 4) clearly indicates

the urban bias in the rainfall distribution in association with the favourable synoptic situations. There has been higher rainfall either over Bangalore city or airport observatories than over their surrounding stations. The impact of UHI effect and pollutants on the rainfall has been discussed in Sec. 3.4.1 and 3.4.2 respectively.

3.4.1. *Impact of UHI effect*

Study based on data of 1961-1995 shows UHI effect over Bangalore (Mohapatra, 2003). According to this study, there has been significant rise in minimum temperature over Bangalore city in the month of October.

Considering the monthly mean maximum temperature over Bangalore city and airport observatory during October, 2005, the maximum temperature over Bangalore city was slightly higher as it recorded monthly mean maximum temperature of 27.4° C against 27.2° C recorded over Bangalore airport. The monthly mean minimum temperature over Bangalore city was also slightly higher than that over Bangalore airport as Bangalore city and airport recorded monthly mean minimum temperatures of 19.8° C and 19.7° C respectively. Considering 5 significant days of rainfall as mentioned in Sec. 1, the maximum temperature on previous day over Bangalore city was higher than that over airport observatory, as they recorded mean daily maximum temperature of 29.1° C and 28.4° C respectively. Similarly, the mean minimum temperatures were 20.4° C and 20.3° C respectively over Bangalore city and airport. It all indicated existence of UHI effect prior to occurrence of higher rainfall over Bangalore city. Simulating the 26th July, 2005 heavy rain event in Mumbai, Chang *et al.* (2009) and Lei *et al.* (2008) have demonstrated that the urban landscape caused an UHI, which in turn may cause mesoscale convergence zone. This convergence zone appears to be a major reason for the moisture transport and heavy rain. A number of studies have found that the UHI is an important feature in regional meteorology, especially in terms of its impact on mesoscale convection and precipitation (Lei *et al.*, 2008).

3.4.2. *Impact of pollution parameters*

The daily concentration of various pollutants measured over Yelahanka along with the standard values is presented in Table 2. The SO₂ concentration during October, 2005 was below normal during all the days under consideration except on 31st October, 2005 when it was near the standard value. Comparing with days of occurrence of enhanced rainfall, SO₂ concentration was significantly less during and prior to the occurrence of enhanced rainfall. The average and maximum

concentration of NO₂ were near to the standard values and higher than standard values respectively, during and prior to the occurrence of enhanced rainfall. Similar was the concentration of SPM and RSPM. Hence, it can be summarized that the enhanced rainfall over city centre was associated with higher concentration of NO₂, SPM and RSPM in the atmosphere as these pollutants work as hygroscopic nuclei.

4. Conclusions

The following broad conclusions may be drawn from the above results and discussion:

- (i) The study confirms the earlier findings that the UHI effect leads to moisture convergence over the region and hence the enhancements of rainfall near the urban centre. However, the enhancement becomes significant leading to occurrence of heavy rainfall only in association with favourable synoptic situations.
- (ii) The enhanced rainfall over city centre can also be attributed to higher concentration of pollutants like NO₂, SPM and RSPM in the atmosphere.

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