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Recent trends in climate of Bangalore

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सार - इस शोध-पत्र में वर्ष 1960 से 1995 तक की अवधि के आंकड़ों के आधार पर बंगलौर शहर और बंगलौर के हवाई अड्डे पर भारतीय मानक समय के अनुसार 0830 तथा 1730 बजे की मासिक, ऋतुनिष्ठ और वार्षिक माध्य अधिकतम तापमान की रैखिक प्रवृत्तियों, न्यूनतम तापमान, औसत तापमान, तापमान की दैनिक दूरी, वर्षा, सापेक्षिक आर्द्रताओं का विश्लेषण किया गया है। मौसम के प्राचलों पर पड़ने वाले शहरीकरण के संगठन का पता लगाने के लिए उपर्युक्त अवधियों में बंगलौर शहर में सतही पवन की भिन्नताओं का भी अध्ययन किया गया है। इस अध्ययन से यह पता चला है कि अधिकतम माध्य और न्यूनतम माध्य तापमानों के कारण बंगलौर शहर अधिक उष्ण होता जा रहा है। शीत ऋतु में बंगलौर हवाई अड्डे की अपेक्षा बंगलौर शहर (केंद्रीय वेधशाला) में वृद्धि की यह दर आश्चर्यजनक रूप से अधिक पाई गई है। इसी प्रकार शीत ऋतु में अक्तूबर से अप्रैल माह के दौरान बंगलौर हवाई अड्डे की अपेक्षा बंगलौर शहर के औसत तापमान में वृद्धि की प्रवृति आश्चर्यजनक रूप से अधिक पाई गई है। बंगलौर हवाई अड्डे की तुलना में बंगलौर शहर में वृद्धि की प्रवृति अधिक होने के कारण शीत ऋतु के महीनों में बंगलौर शहर के तापमान की दैनिक दूरी भी अधिक हो गई है। हालांकि वर्षा के कारण किसी उल्लेखनीय प्रवृति का पता नहीं चला है किन्तु बंगलौर हवाई अड्डे की तुलना में बंगलौर शहर में मानसून के दौरान वृद्धि की प्रवृति तथा मानसून समाप्ति के दौरान ह्रास की प्रवृति अधिक पाई गई है। यद्यपि जिस समय बंगलौर शहर और बंगलौर हवाई अड्डे दोनों में शीत ऋतु के दौरान भारतीय मानक समय के अनुसार 0830 बजे माध्य सापेक्षिक आर्द्रता में अधिकतम वृद्धि की प्रवृति का पता चला है उस समय बंगलौर शहर में वृद्धि की दर कम पाई गई है। इसी प्रकार जिस समय 1730 बजे भारतीय मानक समय के अनुसार सभी ऋतुओं के दौरान सापेक्षिक आर्द्रता में ह्रास की प्रवृति का पता चलता है, उस समय मानसून समाप्त होने की ऋतु को छोड़कर सभी ऋतुओं में बंगलौर शहर में ह्रास की दर कम पाई गई है। अधिकतम न्यूनतम माध्य तथा औसत तापमानों और सापेक्षिक आर्द्रताओं से वर्षा के दौरान उनकी मासिक प्रवृति के गुणांकों में आवृति की भिन्नताओं का पता चलता है।

ABSTRACT. The linear trends in the monthly, seasonal and annual mean maximum temperature, minimum temperature, average temperature, diurnal range of temperature, rainfall, relative humidities at 0830 & 1730 hr IST of Bangalore city and airport have been analysed based on the data for the period from 1960-95. The variation in surface wind over Bangalore during above period has also been studied to find out impact of urbanisation on weather parameters. It is found that Bangalore city is becoming warmer in terms of mean maximum & mean minimum temperatures. Rate of increase is significantly higher over Bangalore city (central observatory) than that over airport during winter months. Similarly the rising trend of average temperature of Bangalore city is higher than of Bangalore airport during October to April being significantly so during winter season. Also the diurnal range of temperature of Bangalore is becoming larger in winter months with the rising trend being higher over Bangalore city than over airport. Even though rainfall does not show any significant trend, the rising trend during monsoon & falling trend during post monsoon season over Bangalore city are higher than that of Bangalore airport. Also though both Bangalore city & airport show maximum rising trend in mean relative humidity at 0830 hr IST during winter, the rate of rise is less over Bangalore city. Similarly though the relative humidity at 1730 hr IST shows decreasing trend during all the seasons, the rate of decrease is less over Bangalore city for all seasons except post monsoon season. The mean maximum, minimum and average temperatures and relative humidities show cyclic variation of their monthly trend coefficients during the year.

Key words – Trend coefficient, Maximum temperature, Minimum temperature, Average temperature, Diurnal range, Rainfall, Relative humidity, Surface wind.

1. Introduction

The variation in temperature of a city has been a central point of research in urban climatology. The temperature of a city may vary spatially and temporally with different trends & periodicities. Here an attempt has been made to study the impact of urbanisation on weather parameters over Bangalore based on the data for the period from 1960-95. It may be mentioned here that Bangalore airport observatory is located at the outskirts of

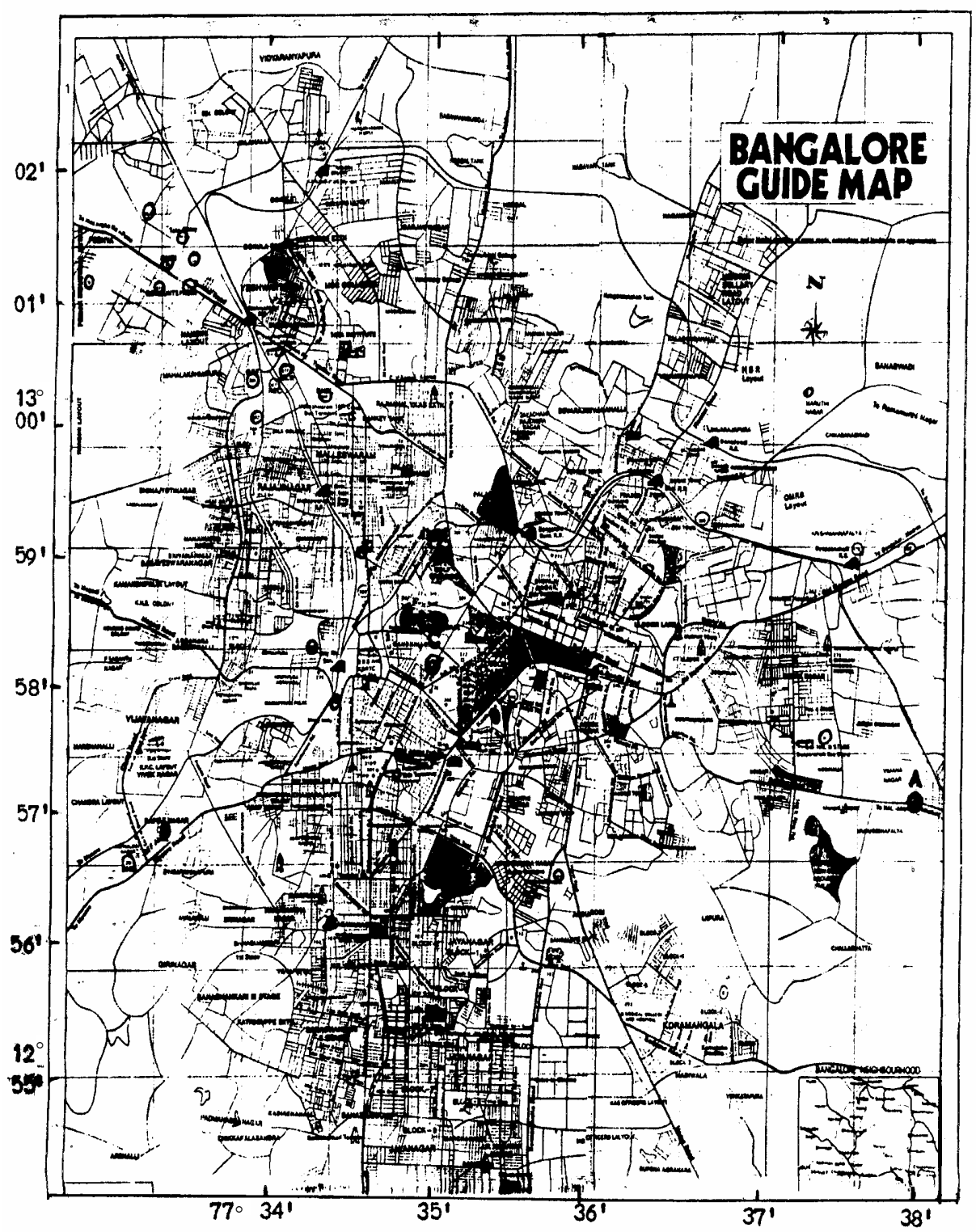


Fig. 1. The map of Bangalore describing in detail the location of residential, residential cum commercial and industrial areas
A : Airport observatory, C : Central observatory, O : Major industrial concerns

TABLE 1

Linear trend in mean maximum temperature (°C/ decade)

Place	Period																
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Winter Season	Pre-monsoon Season	Monsoon Season	Post- monsoon Season	Year
A	+0.22 (S')	+0.33 (S)	+0.19	+0.22 (S')	+0.26	-0.11	+0.03	-0.03	+0.24 (S')	+0.13	+0.23 (S')	+0.22 (S')	+0.23 (S)	+0.23 (S)	+0.03	+0.19 (S)	+0.16 (S)
B	+0.05	+0.15	+0.01	+0.02	+0.17	-0.08	0.0	+0.01	+0.21 (S')	+0.07	+0.14	+0.06	+0.10	+0.07	+0.04	+0.09	+0.07
C	+0.18 (S)	+0.18 (S)	+0.19 (S')	+0.20 (S)	+0.08	-0.03	+0.03	-0.03	+0.03	+0.06	+0.09	+0.16 (S')	+0.18 (S)	+0.16 (S)	0.0	+0.10	+0.09 (S')

A : Bangalore Central Observatory , B : Bangalore airport, C : Difference of observation at Bangalore Central Observatory & airport (A-B).
S : Significant at 0.95 level, S' : Significant at 0.90 level.

the city & it lies on the eastern side of Bangalore central observatory at a distance of about 15 km (Fig.1). Figure 1 describes the detailed location of residential areas, residential cum commercial areas and industrial areas of Bangalore. It indicates that the areas around the central observatory at Palace Road, Bangalore are densely populated with a number of residential areas and residential cum commercial areas. The observatory is also surrounded by a number of commercial & human activities centres such as banks, cinema halls, bus stands, railway stations, clubs/associations, educational institutions, Government offices including the state secretariat and head of the department offices, hospitals, hotels and restaurants, markets, social/cultural centres and religious institutions. The major industrial concerns are generally located in the close vicinity but in the west and northwest direction from the central observatory at Palace road, Bangalore. In comparison the observatory at HAL airport, Bangalore is surrounded by the areas of less population density and less commercial activities. Also the industrial concern around the observatory at airport are very less. In brief during the period from 1960-95, maximum urbanisation had taken place in the areas surrounding the central observatory, while the rate of urbanisation around the observatory at HAL airport has been slow in comparison. Considering the rapid urbanisation of Bangalore city, an attempt has been made in this study to find out the monthly, seasonal and annual trends in the mean maximum, mean minimum, average and diurnal range of temperatures. The monthly, seasonal and annual trends in the total rainfall and mean relative humidity at 0830 & 1730 hr IST have also been analysed as all these parameters may vary significantly due to variation in temperatures. Also the variation in the surface wind pattern over Bangalore has been analysed, as the surface wind also gets modified by the process of urbanisation.

The degree of impact of urbanisation on weather parameters at Bangalore city in comparison to that at Bangalore airport has also been studied by finding out the trend in the time series of difference of observations for a given parameter (observation at central observatory minus observation at airport observatory).

The effect of urbanisation on weather and climate has been studied in great detail by various workers (Chandler, 1965; Bornstin, 1968; Bahl & Padmanabhamurthy, 1977; Krishnanand & Maske, 1981; Padmanabhamurty & Bahl, 1982) Keeping in view the ongoing climate change due to enhanced green house effect, the variations in different meteorological parameters of a city need to be examined in details to distinguish between the normal changes similar to the changes in the neighbourhood and the changes due to the increased activity at urban centres. Mohapatra & Vijayraghvan (1997) studied the variation of mean maximum, mean minimum, highest maximum and lowest minimum temperatures of Bangalore central observatory on monthly basis & found that the rising trend is maximum in winter months and is minimum in southwest monsoon months.

2. Data and methodology

The meteorological data of Bangalore central observatory and airport for the period from 1960 to 1995 have been considered in this study. The meteorological parameters studied include monthly, seasonal and annual mean values of maximum temperature, minimum temperature, average temperature, diurnal range of temperature, relative humidity at 0830 & 1730 hr IST and mean surface wind at 0830 & 1730 hr IST. The average of maximum & minimum temperatures *i.e.* $(T_{max}+T_{min})/2$ has been considered as average temperature. Also the monthly, seasonal & annual total

TABLE 2

Linear trend in mean minimum temperature (°C/ decade)

Place	Period																
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Winter Season	Pre-monsoon Season	Monsoon Season	Post- monsoon Season	Year
A	+0.08	+0.33 (S)	+0.26	+0.23 (S)	+0.16 (S)	+0.12 (S')	+0.06	+0.10	+0.17 (S)	+0.18 (S')	+0.27 (S')	+0.05	+0.17	+0.19 (S)	+0.11 (S')	+0.17 (S')	+0.15 (S)
B	+0.02	+0.16	+0.12	+0.17	+0.26 (S)	+0.28 (S')	0.19 (S)	+0.25 (S')	+0.33 (S)	+0.24 (S)	+0.29 (S')	+0.05	+0.05	+0.18 (S')	+0.26 (S)	+0.19 (S')	+0.19 (S)
C	+0.03	+0.17 (S)	+0.14	+0.06	-0.09	-0.17	-0.13	-0.16	-0.16 (S)	-0.06	-0.02	0.0	+0.12 (S)	+0.03	-0.15	-0.03	-0.03

A : Bangalore Central Observatory , B : Bangalore airport, C : Difference of observation at Bangalore Central Observatory & airport (A-B).
S : Significant at 0.95 level, S' : Significant at 0.90 level.

rainfall recorded at two observatories have been studied for the same period.

The time series of all the above mentioned parameters except surface wind and the time series of the difference of values of the parameters (observation at Bangalore central observatory minus observation at Bangalore airport) have been subjected to linear trend analysis by least square technique. The statistical significance of the trend coefficients has also been tested. Comparing the wind roses at 0830 & 1730 hr IST for the periods 1955-64 and 1982-91; the change in surface wind over Bangalore has been studied. The mean wind pattern in these two periods may represent the mean wind pattern at the beginning and end of the period of study.

3. Results and discussion

3.1. *Mean maximum temperature*

Mean maximum temperature of Bangalore city shows rising trend for all the months, except June & August (Table 1). During these two months the trend coefficients are negative. The trend coefficients are statistically significant at 0.95 level for the month of February, winter season, pre-monsoon season, post monsoon season and also for the year as a whole. The trend coefficients are less significant *i.e.*, at 0.90 level for the months of January, April, September, November and December. However the winter season has maximum rising trend *i.e.*, +0.28° C per decade.

The mean maximum temperature of Bangalore airport shows the rising trend for all the months except June. It also shows the rising trend for all the seasons and year as a whole. However unlike the city temperature, the trend coefficients in this case are not statistically significant.

The difference of mean maximum temperature of Bangalore city & airport shows rising trend for all the individual months except June and August. During these two months it shows the negative trend. Also the seasonal and annual mean maximum temperatures show the rising trend. However the trend coefficients are statistically significant at 0.95 level only for the months of January, February, April and at 0.90 level for the months of March & December. Similarly the coefficients are significant at 0.95 level for winter & pre-monsoon seasons and at 0.90 level for annual mean maximum temperature. The positive trend coefficients for the months from December to April and for winter & pre-monsoon seasons are approximately 0.2° C per decade. Hence it may be concluded that the Bangalore city is becoming warmer in terms of maximum temperature being significantly so during December to April or during winter & pre-monsoon seasons. Also it is found that the rising trend is most significant *i.e.*, at 0.99 level during winter season and specifically in February month.

3.2. *Mean minimum temperature*

The results of the analysis are shown in Table 2. It is found that the mean minimum temperature of Bangalore city shows rising trend for all the individual months, seasons and the year as a whole. The trend coefficients are significant at 0.95 level only for February, April, May & September and at 0.90 level for June, October & November. Also the trend coefficients are significant at 0.95 level for pre-monsoon season and at 0.90 level for monsoon & post monsoon seasons. The rising trend is maximum (+0.33° C/decade) in the month of February.

TABLE 3

Linear trend in diurnal range of temperature (°C/ decade)

Place	Period																
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Winter Season	Pre-monsoon Season	Monsoon Season	Post- monsoon Season	Year
A	+0.16	+0.03	-0.004	-0.004	+0.03	-0.23 (S')	-0.03	-0.12	+0.07	-0.06	-0.04	+0.17	+0.19	+0.03	-0.03	+0.02	+0.02
B	+0.02	+0.04	-0.11	-0.14	-0.03	-0.36 (S)	-0.19	-0.25	-0.12	-0.17	-0.15	+0.01	+0.11	-0.11	-0.23 (S)	-0.10	-0.11
C	+0.14 (S')	+0.05	+0.11	+0.14	+0.17 (S)	+0.13	+0.16	+0.12	+0.18 (S')	+0.12	+0.12	+0.15	+0.03	+0.14 (S')	+0.15	+0.13	+0.14 (S')

A : Bangalore Central Observatory , B : Bangalore airport, C : Difference of observation at Bangalore Central Observatory & airport (A-B).
S : Significant at 0.95 level, S' : Significant at 0.90 level.

TABLE 4

Linear trend in average temperature (°C/ decade)

Place	Period																
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Winter Season	Pre-monsoon Season	Monsoon Season	Post- monsoon Season	Year
A	+0.14	+0.34 (S)	+0.17	+0.22	+0.21 (S)	+0.002	+0.05	+0.03	+0.20 (S)	+0.15 (S)	+0.25 (S)	+0.14 (S')	+0.23 (S)	+0.20 (S)	+0.07	+0.18 (S)	+0.17 (S)
B	+0.03	+0.12	+0.07	+0.09	+0.22 (S)	+0.10	+0.10	+0.13	+0.27 (S)	+0.15 (S')	+0.22 (S)	+0.06	+0.05	+0.13	+0.15 (S)	+0.14 (S')	+0.12
C	+0.11 (S')	+0.21 (S)	+0.10	+0.13 (S)	-0.004	-0.10	-0.05	-0.10	-0.07 (S')	0.0	+0.03	+0.08	+0.18 (S)	+0.07	-0.08 (S')	+0.04	+0.05

A : Bangalore Central Observatory , B : Bangalore airport, C : Difference of observation at Bangalore Central Observatory & airport (A-B).
S : Significant at 0.95 level, S' : Significant at 0.90 level.

The mean minimum temperature of Bangalore airport shows the similar type of trend as that of Bangalore city with the difference in significance of the trend coefficients. The trend coefficients are significant at 0.95 level for the months of May, July, September & October and at 0.90 level for the months of June, August & November. These are also significant during monsoon season at 0.95 level. The rising trend is maximum during September (+0.33° C/decade).

The time series of the difference of mean minimum temperatures of Bangalore city and airport has positive trend coefficient for the months of January, February, March, April and negative trend coefficient for the months of May to November. During December there is no trend. The trend coefficients are positive for winter and pre-monsoon seasons. They are negative for monsoon and post monsoon seasons. The difference of annual mean minimum temperatures shows the decreasing trend. The trend coefficients are significant at 0.95 level for the months of February & September and also for the winter season. Other trend coefficients are not significant even at 0.90 level. The rising trend is maximum (+0.17° C/ decade) for February and the falling trend is maximum (–0.17° C per decade) for June. Among the seasons the winter season has maximum rising trend *i.e.* (+0.12° C/ decade).

3.3. *Diurnal range of temperature*

The results of the analysis are given in Table 3. It is found that the Bangalore city shows increasing trend for the months of December to February, May & September

TABLE 5

Linear trend in relative humidity at 0830 hr IST (percent/ decade)

Place	Period																
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Winter Season	Pre-monsoon Season	Monsoon Season	Post- monsoon Season	Year
A	+0.8	+1.6	+0.3	-0.1	-0.8	+0.7 (S')	-0.5	-0.1	-0.8	-0.2	+0.4	+0.3	+1.2	-0.2	-0.2	+0.2	+0.1
B	+1.8 (S)	+2.0 (S')	-0.1	-1.0	-1.1 (S')	+0.6	-0.6	-0.1	-0.9 (S')	0.0	+1.3 (S')	+1.1 (S)	+1.9 (S)	-0.7	-0.3	+0.8 (S)	+0.3
C	-1.1 (S')	-0.4	+0.4	+0.9	+0.3	+0.1	+0.1	0.0	+0.2	-0.1	-1.0 (S')	-0.8 (S')	-0.7	+0.5	+0.1	-0.6 (S')	-0.1

A : Bangalore Central Observatory , B : Bangalore airport, C : Difference of observation at Bangalore Central Observatory & airport (A-B).
S : Significant at 0.95 level, S' : Significant at 0.90 level.

TABLE 6

Linear trend in relative humidity at 1730 hr IST (percent/ decade)

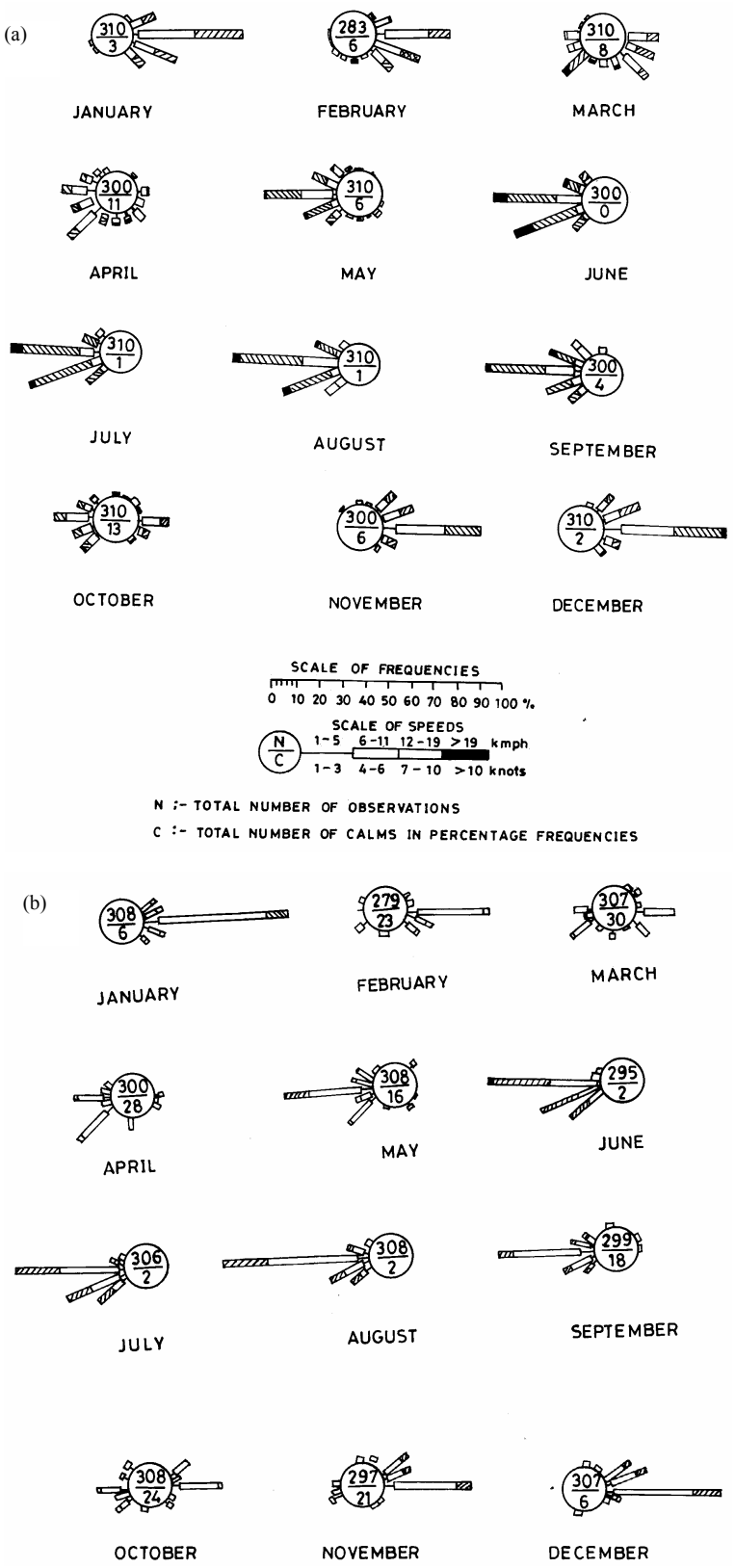
Place	Period																
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Winter Season	Pre-monsoon Season	Monsoon Season	Post- monsoon Season	Year
A	-1.3	-0.6	-0.8	-1.5 (S')	-0.9	+1.2	-1.1	-0.5	-1.6	-0.4	-1.5	-1.9	-1.0	-1.1 (S')	-0.5	-1.2 (S')	-0.9 (S)
B	-0.6	-1.9	-1.6 (S)	-2.2 (S)	-1.2	+1.2	-1.8 (S')	-1.9 (S)	-2.4 (S)	-0.3	-0.9	-0.3	-1.2	-1.7 (S)	-1.2 (S')	-0.5	-1.2 (S)
C	-0.8	+1.2	+0.7	+0.7	+0.3	-0.04	+0.7	+0.8	+0.8	-0.03	-0.5	-1.5 (S)	+0.2	+0.6	+0.7	-0.7	+0.25

A : Bangalore Central Observatory , B : Bangalore airport, C : Difference of observation at Bangalore Central Observatory & airport (A-B).
S : Significant at 0.95 level, S' : Significant at 0.90 level.

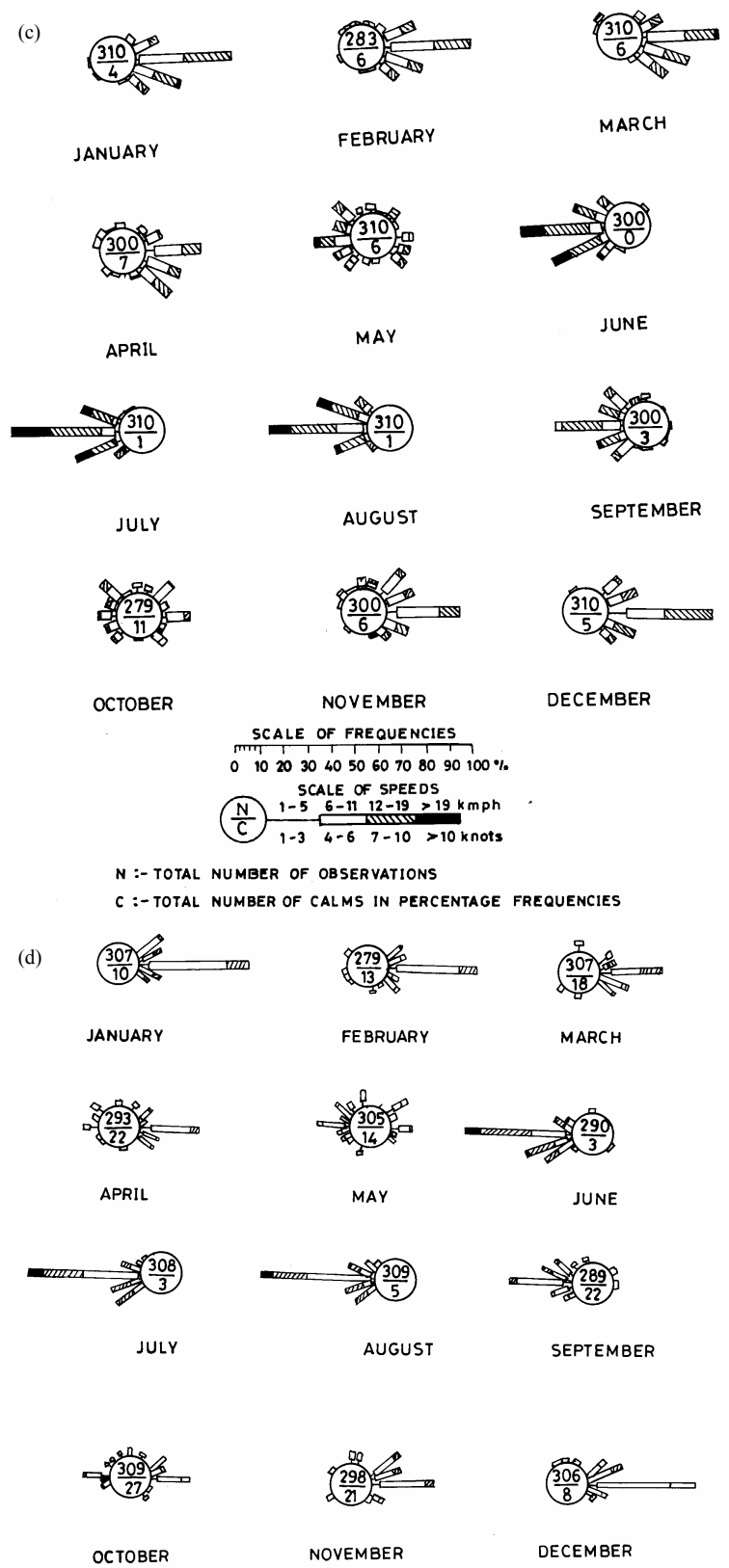
and decreasing trend for the rest of the months. It also shows increasing trend for all the seasons and the year as a whole except monsoon season. It has decreasing trend in monsoon season. The trend coefficient is maximum in winter (+0.19° C/decade) among all the seasons. Among the months, increasing trend is maximum in December (+0.17° C / decade) and the decreasing trend is maximum in June (–0.23° C/decade). However the trend is significant only for the month of June at 0.90 level.

Bangalore airport shows increasing trend in diurnal range of temperature during the months of December, January & February and decreasing trend during rest of the months. Among the seasons, it shows rising trend in winter & falling trend in other seasons. Considering the year as a whole, it has a negative trend. The increasing trend is maximum in February (+0.04° C/decade) & the decreasing trend is maximum in June (–0.36° C/decade) which is also significant at 0.95 level.

Considering the time series of difference of diurnal range of Bangalore city & airport, it is found that the trend coefficients are positive for all the months, seasons and the year as a whole. Also the trend coefficients are significant at 0.95 level for the month of May and at 0.90 level for the months of January, September, pre-monsoon season & the year as a whole. The diurnal ranges of temperatures of Bangalore city and airport are becoming larger during winter months. But rate of increase is higher over Bangalore city than over airport. The rising trend is maximum in September (+0.18°C/decade) followed by May (+0.17° C/decade) among the months. It is maximum in monsoon season (+0.15° C/decade) among all the seasons.



Figs. 2(a&b). Wind roses of Bangalore city based on observations at 0830 hr IST during (a) 1955-64 and (b) 1982-91



Figs. 2(c&d). Wind roses of Bangalore city based on observations at 1730 hr IST during (c) 1955-64 and (d) 1982-91

3.4. *Average temperature*

The average temperatures of both Bangalore city & airport show rising trend for all the months, seasons and the year as a whole (Table 4). The rising trend is maximum in February (+0.34° C/decade) and September (+0.27° C/decade) for Bangalore city and airport respectively. Among the seasons the rising trend is maximum in winter (+0.23° C/decade) & monsoon season (+0.15° C/decade) for Bangalore city & airport respectively. The trend coefficients are significant during months of February, May, September, November and winter, pre-monsoon & post-monsoon seasons at 0.95 level for Bangalore city. It is also significant for the year as a whole for Bangalore city at 0.95 level. For Bangalore airport the trend coefficients are significant at 0.95 level during May, September, November and monsoon season. Considering the time series of difference of average temperature of Bangalore city and airport, it is found that there is increasing trend for the months from October to April & decreasing trend for the months from May to September. The trend coefficient is significant at 0.95 level during February & April and at 0.90 level during January & September. All the seasons except monsoon season show rising trend and monsoon season shows falling trend. The annual average temperature difference also shows rising trend. However the trend is significant at 0.95 level during winter and at 0.90 level during monsoon season. The trend coefficient is maximum during winter (+0.18° C / decade) among the seasons. Among different months rising trend is maximum in February and decreasing trend is maximum in June and August. Hence it may be concluded that the rising trend of average temperature of Bangalore city is higher than that of Bangalore airport during October to April being significantly so during winter season.

3.5. *Relative humidity (0830 hr IST)*

The results of the trend analysis are shown in Table 5. The mean relative humidity of Bangalore city at 0830 hours IST shows increasing trend during January, February, March, June, November & December and decreasing trend during rest of the months. The trend coefficients are positive for winter & post-monsoon seasons and negative for pre-monsoon & monsoon seasons. The annual mean relative humidity shows the increasing trend. The trend coefficients are not statistically significant for all the months, seasons & year except for the months of October & June. It is significant at 0.95 level for October & at 0.90 level for June. The positive trend coefficient is maximum for the month of February & negative trend coefficient is maximum for May and September (0.8% per decade). The winter season has the maximum rising trend *i.e*., 1.2% per decade.

The mean relative humidity of Bangalore airport at 0830 hr IST shows increasing trend for the months of January, February, June, November & December and decreasing trend for the months of March, April, May, July, August & September. It does not show any trend during October. The trend coefficients are positive for winter & post monsoon seasons and negative for pre-monsoon & monsoon seasons. The annual mean relative humidity at 0830 hr IST shows rising trend. The trend coefficients are significant at 0.95 level for the months of January & December and for winter & post monsoon season. The trend coefficients are significant at 0.90 level for the months of February, May, September and November.

The time series of difference of mean relative humidity of Bangalore city & airport at 0830 hr IST shows that there is rising trend for the months from March to September and falling trend for the months from October to February. Similarly the pre-monsoon and monsoon seasons show rising trend and the winter & post-monsoon seasons show the falling trend. The year as a whole shows negative trend. The trend coefficients for all the months, seasons and the year are not statistically significant. However the trend coefficients of November, December, January and post monsoon season are significant at 0.90 level. Among different months the positive trend is maximum for April (0.9% per decade) and the negative trend is maximum for January (–1.1% per decade). Among the seasons winter season shows maximum negative trend and pre-monsoon season shows maximum positive trend. It indicates that the rising trend in winter over Bangalore city is less than that over Bangalore airport.

3.6. *Relative humidity (1730 hr IST)*

The results of the trend analysis are given in Table 6. The mean relative humidity of Bangalore city at 1730 hr IST shows increasing trend for the month of June and decreasing trend for all other months, all seasons & the year also. The negative trend is maximum during December (–1.95% per decade) followed by September (–1.6% per decade) among different months. Among the seasons the negative trend is maximum during post- monsoon season (–1.2% per decade). The trend coefficient is statistically significant at 0.95 level for annual mean relative humidity at 1730 hr IST. The trend coefficient is significant at 0.90 level for the month of April and pre-monsoon & post-monsoon seasons.

TABLE 7

Linear trend in total rainfall (mm/ decade)

Place	Period																
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Winter	Pre-monsoon Season	Monsoon Season	Post- monsoon Season	Year
A	-0.1	+0.2	+4.8	-8.8	-1.4	+11.4	+0.1	-7.0	+10.7	-9.1	-14.4	-4.9	0.0	-1.8	+3.8	-9.5 (S')	-1.5
B	-0.2	+0.2	+4.7	-6.4	-6.1	+6.6	+1.4	-7.7	+1.7	-2.5	-13.9	-0.8	0.0	-2.6	+0.5	-5.7	-1.9
C	+0.1	-0.1	+0.1	-2.3	+4.8	+4.7	-1.3	+0.7	+9.0	-6.6	-0.6	-4.1	+0.01	+0.8	+3.3	-3.8	+0.4

A : Bangalore Central Observatory , B : Bangalore airport, C : Difference of observation at Bangalore Central Observatory & airport (A-B).
S : Significant at 0.95 level, S' : Significant at 0.90 level.

The mean relative humidity of Bangalore airport at 1730 hr IST shows almost the same trend as that of Bangalore city. The trend coefficient is positive for the month of June and is negative for other months, all the seasons & the year as a whole. The trend coefficients are significant at 0.95 level during March, April, August, September pre-monsoon season & the year as a whole. They are significant at 0.90 level during July and monsoon season. The negative trend is maximum in September (–2.4.% per decade) followed by April (–2.3% per decade) among all the months. The pre-monsoon season has the maximum negative trend (–1.7% per decade) among all the seasons. Also it is found that the rate of decrease over airport is more than that over city for all the seasons except post-monsoon season.

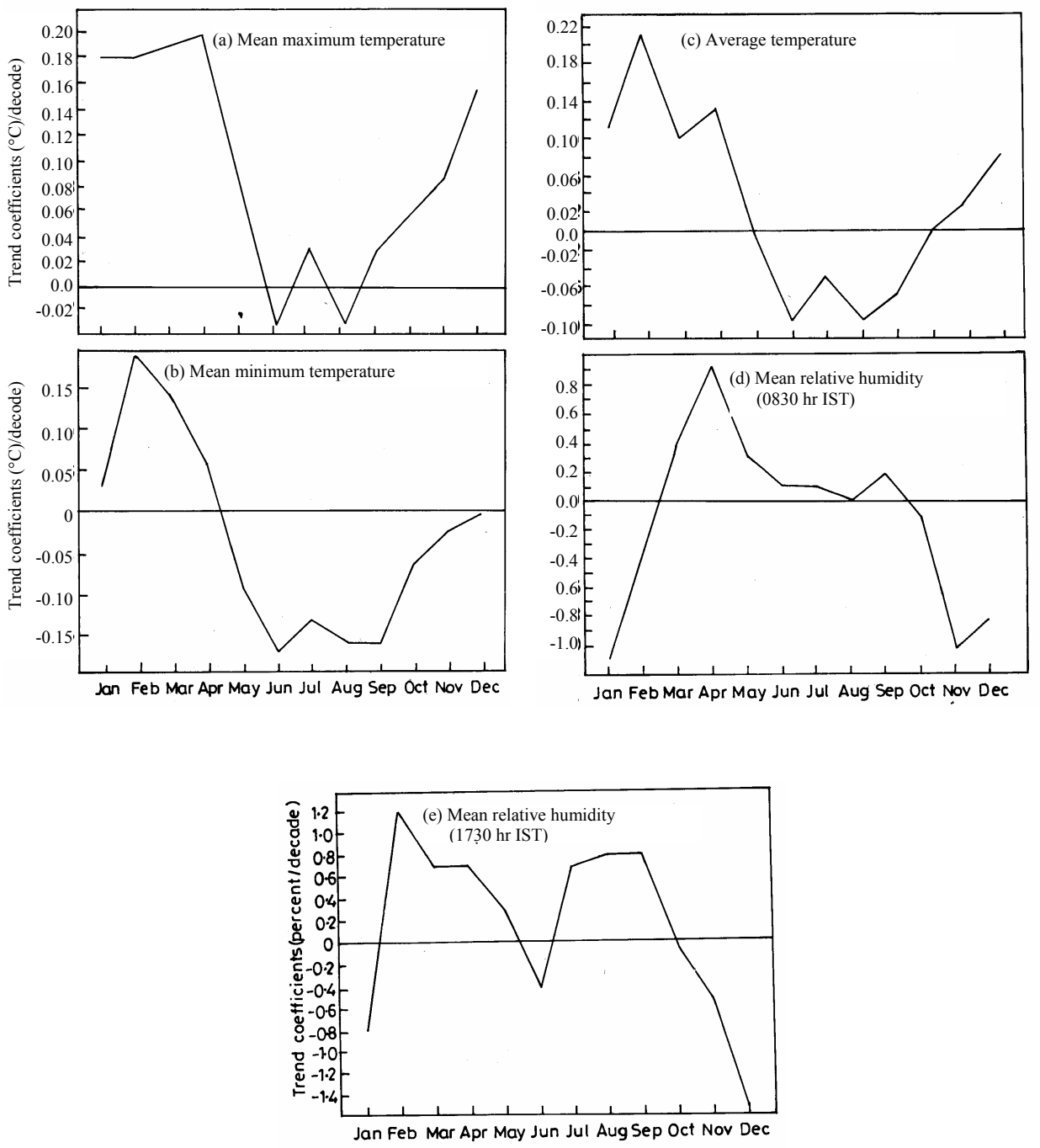
The time series of difference of mean relative humidity of Bangalore city and airport at 1730 hr IST shows that there is increasing trend for the months from February to May & July to September. There is decreasing trend for rest of the months. The trend coefficient is significant at 0.95 level for the month of December and post monsoon season. The negative trend is maximum during December (–1.5% per decade) and the positive trend is maximum during February (+1.2% per decade) among all the months. Among the seasons the rising trend is maximum during monsoon season (0.7% per decade).

3.7. *Surface wind*

The comparison of wind roses of airport observatory and central observatory indicates that the wind pattern at airport observatory had not under gone any significant change during the period of study. However the wind pattern at central observatory indicates significant changes during the period of study. The wind rose diagrams for central observatory at Palace Road, Bangalore for each individual month based on the observations taken at 0830 & 1730 hr IST for the period from 1955-64 and for the period from 1982-91 (Fig. 2) have been considered to find out the changes in wind pattern through the period from 60's to 90's.

3.7.1. *Comparison of wind roses based on observation at 0830 hr IST*

The comparison of the wind roses based on 0830 hr IST observation for the period 1955-64 with that for the period 1982-91 indicate that during January & February even though the winds were generally north easterly to south easterly with maximum frequency of easterly winds, in both the periods, the easterly winds were more frequent during the period 1982-91. During the period 1982-91, the wind speed was less; ranging from 4 to 6 knots in most occasions where as during 1955-64; the wind speed was 7 to 10 knots in about 50% & 40% of the cases during January & February respectively. Similarly the frequency of calm days was more in 1982-91 than in 1955-64 being significantly so in February. The frequency of days with wind speeds 1-3 knots also increased during 1982-91. Comparing the wind rose diagrams for pre-monsoon months it was found that even though there was no significant change in the wind directions during March, April and May, the wind speed was less during 1982-91 than during 1955-64. the wind speed ranged from 4 to 6 knots in many occasions during these months of 1982-91 where as it ranged between 7 to 10 knots in some occasions during all the pre-monsoon months of 1955-1964. There was no occasion of wind speed becoming > 10 knots during pre-monsoon months of 1982-91. The frequency of calm days was significantly higher in the pre-monsoon months being maximum in March of 1982-91 than in 1955-64. The frequency of days with wind speed 1-3 knots also were more during 1982-91. The comparison of the wind roses based on 0830 hr IST observation during the southwest monsoon season



Figs. 3(a-e). Monthly variation of trend coefficients of difference of observation (O_1 minus O_2). O_1 Observation at Bangalore central observatory and O_2 Observation at Bangalore airport

(June-September) indicated that the frequency distribution of wind direction during southwest monsoon months remained almost same in both the periods being north-westerly to southwesterly with maximum frequency of westerly winds. The wind speed changed significantly in all the individual monsoon months. The wind speed was less in 1982-91 than in 1955-64. It ranged between 4-6 knots in 50% of the cases in June & July of 1982-91 while it was ≥ 7 knots in 90% of the cases being >10 knots in 30% of the cases during June & July of 1955-64. The

difference was more in August & September than in June & July with the frequency of lighter wind being more in August & September of 1982-91 than those in 1955-64. The wind speed in these two months ranged from 4 to 6 knows in about 70% of the cases during 1982-91 while it was ≥ 7 knots in about 90% of the cases during 1955-64. There was no occasion during September of 1982-91 of wind speed becoming > 10 knots. The frequency of wind speed > 10 knots was almost negligible during August of 1982-91. However there was no significant difference in the frequency of calm days for all the individual monsoon months except September. During September, the frequency of calm days in 1982-91 was significantly higher than that in 1955-64. The frequency of days with wind speed 1-3 knots also increased during 1982-91.

The comparison of the wind roses of post-monsoon months based on 0830 hr IST observations indicated that the frequency distribution of the prevailing wind direction remained almost same in both the periods except in October. While the wind was more frequently westerly during October of 1955-64, it was more frequently easterly during October of 1982-91. The wind speed was less during 1982-91 than during 1955-64 for all individual months during post monsoon season. It was predominantly ranging between 4-6 knots during 1982-91 while the wind speed was almost equally frequent in the ranges of 4-6 and 7-10 knots during 1955-64. The frequency of calm days was also higher during 1982-91 than during 1955-64 for all individual months being significantly so during October and November.

3.7.2. *Comparison of wind roses based on observations at 1730 hr IST*

During winter months it was found that the frequency distribution of wind direction remained almost same in both the periods being northeasterly to south-easterly with maximum frequency of easterly winds. However the wind became lighter with speed ranging from 4 to 6 knots in most occasions during 1982-91. The frequency of calm days were higher in 1982-91 than in 1955-64.

During pre-monsoon months it was found that there was no significant difference in the frequency distribution of wind direction for all the individual months in 1955-64 and 1982-91, However the mean wind speed was less during 1982-91 than during 1955-64 with wind speed varying between 4-6 knots in many occasion during 1982-91 where as it was ≥ 7 knots in more than 50% of the days during 1955-64. The frequency of calm days was also higher during 1982-91 than during 1955-64. During southwest monsoon months, it was found that there was no significant difference in the frequency distribution of wind directions for both the periods. However the wind became lighter in all the months during 1982-91 than during 1955-64 being significantly so during September. Winds were generally northwesterly to southwesterly with maximum frequency of westerlies for both the periods. There was no significant rise in frequency of calm days during monsoon months of 1982-91 as compared to that during 1955-64 except during September. During September the frequency of calm days in 1982-91 was significantly higher than that during 1955-64. Comparing the wind roses during post monsoon months, it was found that there was no significant difference in the frequency distribution of wind directions for the periods 1955-64 and 1982-91 except in the month of October. The frequency of easterly winds in October of 1982-91 was higher than that in October of 1955-64. However the wind became lighter also in 1982-91 than in 1955-64 for all the individual months.

3.8. *Rainfall*

The results of the trend analysis of the total rainfall for the individual months, seasons and the year as a whole are given in Table 7. The rainfall over Bangalore city shows increasing trend during February, March, June, July & September and decreasing trend during rest of the months. Among the seasons there is no trend during winter, increasing trend during monsoon and decreasing trend during pre-monsoon & post-monsoon seasons. The annual rainfall also shows a decreasing trend. The trend coefficients are not statistically significant. However the trend coefficient for post-monsoon rainfall is significant at 0.90 level. Positive trend coefficient is maximum for the month of June (+11.4 mm per decade) followed by September (+10.7 mm per decade). The negative trend coefficient is maximum for the month of November (–14.4 mm per decade).

The rainfall over Bangalore airport shows the similar trend for all the individual months, seasons and year like that of Bangalore city. Bangalore airport also has maximum increasing trend during June (+6.6 mm per decade) and maximum decreasing trend during November (–13.9 mm per decade). The trend coefficients are also not statistically significant even at 0.90 level.

The time series of difference of total rainfall of Bangalore city & airport has positive trend coefficient for the months of January, March, May, June, August & September and negative trend coefficients for rest of the months. It has positive trend coefficient for winter, pre-monsoon & monsoon seasons and negative trend coefficient for post-monsoon season. The difference of annual rainfall has positive trend coefficient. Though the trend coefficients for all the months, seasons & year are

not statistically significant even at 0.90 level; these area practically significant during months of May, June, September, October & December and monsoon & post monsoon seasons. The positive trend coefficient is maximum during September (+9.0 mm/decade) & negative trend coefficient is maximum during October (−6.6 mm/ decade). The results also indicate that the rising trend during monsoon & falling trend during post monsoon seasons over Bangalore city are higher than that of Bangalore airport.

The trends in rainfall over Bangalore may be attributed to the following. It was found that the wind speed in all the individual months was lighter and the frequency of calm days was also more during 1982-91 than during 1955-64. Also the frequency distribution of wind directions in all the individual months except October remained almost same during both periods of 1982-91 and 1955-64. It changed from westerlies in 1955-64 to easterlies in 1982-91 for the month of October. As the normal date of withdrawal of southwest monsoon from Bangalore is 15 November and Bangalore is affected by northeast monsoon afterwards the normal wind pattern over Bangalore during May to 15 November is generally westerly and mainly easterly afterwards till end of April. During monsoon months & the season, westerlies being rain bearing winds the weakening of westerlies near Bangalore city compared to that near Bangalore out skirts enhances the local convergence leading to rise in rainfall at Bangalore city compared to that over Bangalore airport. The decrease in wind speed near Bangalore city being maximum in September, the positive trend coefficient of the difference in rainfall of Bangalore city & airport also has become maximum in September.

During post monsoon months of October, the westerlies being the rain bearing winds due to southwest monsoon flow over the region the change in wind pattern from strong westerlies in 1955-64 to weaker easterlies in 1982-91 near Bangalore city may be the cause for maximum decreasing trend in the difference of rainfall of Bangalore city and airport. During the month of November and December there is weakening of easterlies near Bangalore central observatory compared to that near Bangalore airport. The weakening of easterlies near Bangalore central observatory leads to local divergence. Hence during November and December, the weakening of easterlies results in decrease in relative humidity & rainfall over city than over airport. During post-monsoon season as a whole the rate of decrease in rainfall over city is higher than that over airport. It may also be attributed to the reasons mentioned above.

3.9. *Cyclic variation of trend coefficients*

The monthly variation of trend coefficients for different parameters are shown in Fig. 3. The trend coefficients of the series of differences of Bangalore city & airport observations of mean maximum, mean minimum and average temperatures show cyclic variation during the year. The trend in mean maximum temperature shows positive peak during April & negative peak during June. The mean minimum and average temperatures show positive peak during February & negative peak during June. The trend coefficients of relative humidity at 0830 & 1730 hr IST also show cyclic variation during the year. Relative humidity at 0830 hr IST shows positive peak during April & negative peak during November. Relative humidity at 1730 hr IST shows double positive peak during February & September and negative peak during December & June. The rainfall and the diurnal range of temperatures do not show any such systematic variation in their trend coefficients.

4. Conclusion

(*i*) Bangalore city is becoming warmer in terms of mean maximum & mean minimum temperatures for all the months & season. The rise is more significant during February. Rate of increase is significantly higher over Bangalore city than over Bangalore airport during winter season and specifically during month of February.

(*ii*) The diurnal range of temperature of Bangalore city is becoming larger in winter months also.

(*iii*) The average temperatures of both Bangalore city & airport show rising trend for all the months, seasons and year as a whole. The rising trend of Bangalore city is higher than that of Bangalore airport for the months from October to April being significantly so during winter season.

(*iv*) The surface wind speed in all the individual months was lighter and the frequency of calm days was also higher during 1982-91 than those during 1955-64 near Bangalore city.

(*v*) Both Bangalore city & airport show maximum rising trend in mean relative humidity at 0830 hr IST during winter season. But rate of rise is less over Bangalore city than over Bangalore airport.

(*vi*) The mean relative humidity at 1730 hr IST shows decreasing trend during all the seasons & year as a whole. But rate of decrease is less over Bangalore city than over Bangalore airport during all the seasons except post monsoon season.

(*vii*) In case of rainfall, the trend coefficients are not significant. However the rising trend is maximum during monsoon season and falling trend is maximum during post monsoon season at both Bangalore city & airport. The rising trend during monsoon and falling trend during post monsoon seasons over Bangalore city are higher than that of Bangalore airport. The change in rainfall pattern may be attributed to the change in surface wind pattern near Bangalore city.

(*viii*) The mean maximum, mean minimum & average temperatures and mean relative humidities at 0830 & 1730 hr IST show cyclic variation of their monthly trend coefficients during the year.

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