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Study on hourly temperature features over Mumbai, Thiruvananthapuram and Minicoy during 1969-2012

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सार – सभी जलवायु विषयक कारकों में जलवायु परिवर्तन और इसके प्रभाव का पता लगाने और विश्लेषण करने में तापमान प्रमुख भूमिका निभाता है। तापमान में किसी प्रकार के परिवर्तन होने की स्थिति में सतह तापमान के स्थानिक समय की परिवर्तनशीलता की इस अध्ययन में जॉच की गई है। इसमें भू-उपयोग पैटर्न में अत्यधिक परिवर्तन वाले बृहत शहर, मुंबई, भू-उपयोग पैटर्न में सामान्य परिवर्तन सहित अर्ध शहरी तिरूवनंतपुरम और भू-उपयोग पैटर्न में बिना किसी अधिक परिवर्तन सहित द्वीपीय शहर मिनीकॉय के लिए प्राप्त हुए परिणामों के विश्लेषण प्रस्तुत किए गए है। ये तीनों स्थान भौगोलिक स्थानों और जलवायु विषयक स्थिति के अनुसार अपने आप में अलग है तथापि इनमें समुद्रवर्ती प्रभाव एक-समान है। संभावना के अनुरूप अन्य की तुलना में मुंबई में बहुत अधिक परिवर्तन पाए गए हैं। इस अध्ययन में तापमान और इसकी प्रवृत्तियों के स्थानिक समय के आधार पर एक नई प्रणाली विज्ञान प्रस्तावित की गई है जिसका उपयोग शहरों में आनुपातिक दर्जा देने व जलवायु परिवर्तन प्रतिबल के स्रोत तथा धंसने वाले क्षेत्रों का पता लगाने के लिए किया जा सकेगा। तापमानों के स्थानिक समय से आरंभिक दशक के माध्य तापमान के ऊपर बढ़ती हुई प्रवृत्ति और माध्य तापमान के नीचे घटती हुई प्रवृत्ति का पता चला है। मुंबई, तिरूवनंतपुरम और मिनीकॉय के लिए माध्य तापमानों में दशकीय रैखीय बढ़ती हुई प्रवृत्तियॉ क्रमश: 0.256 °C 0.159 °C और 0.146 °C प्रति दशक पाई गई है। इससे शहरी प्रभाव को न देखते हुए असमान रूप से भू-मंडलीय उष्णता की पुष्टि होती है। मुंबई, तिरूवनंतपुरम और मिनीकॉय के लिए गैर-मानसून ऋतु के दौरान माध्य तापमानों में दशकीय रैखीय बढी हुई प्रवृत्तियॉ प्रति दशक क्रमश: 0.315 °C, 0.155 °C और 0.181 °C है। मॉनसून ऋतु के दौरान मुंबई और मिनीकॉय के लिए माध्य तापमान में वृद्धि की दर क्रमश : 0.143 °C और 0.081 °C प्रति दशक पाई गई है जो वार्षिक माध्य में दशकीय प्रवृत्ति की अपेक्षा उल्लेखनीय रूप से कम है जो वर्षा की गतिविधि वार्षिक माध्य तापमान में बढ़ती हुई प्रवृत्ति के लिए संशोधित कारक माने गए है अन्यथा ये उच्चतर मान हो सकते है तथापि अध्ययन अवधि के लिए मॉनसून ऋतु के दौरान तिरूवनंतपुरम के लिए माध्य तापमान की वृद्धि की दर 0.172 °C प्रति दशक है जो वार्षिक माध्य में दशकीय प्रवृत्ति से कुछ अधिक है। मॉनसून ऋतु के दौरान स्थानिक समय में उल्लेखनीय परिवर्तन वर्षा पैटर्न में परिवर्तन के अनुरूप है।

ABSTRACT. Amongst all the climatic elements, temperature plays a major role in detecting and analyzing climatic change and its impact. The variability in resident time of the surface temperature is studied to investigate whether any change in temperature has taken place. Analysis of the results is presented for Mumbai, a mega city with large change in land-use pattern, Thiruvananthapuram, a semi-urban city with moderate changes in land-use pattern and Minicoy, an Island city without much change in land-use pattern. These three places representing varying geographical locations and climatic conditions are unique in nature, however having uniform maritime influence. It is revealed that the change is large in Mumbai in comparison with others as expected. The study proposes a new methodology based on the resident time of temperatures and its trend and could be used as a tool for relative ranking of cities and to gauge the source and sink regions of climate change forcing. The resident time of temperatures shows increasing trend above the mean temperature and decreasing trend below the mean temperature of the initial decade. Decadal linear increasing trends in mean temperatures are 0.256 °C, 0.159 °C and 0.146 °C per decade for Mumbai, Thiruvananthapuram and Minicoy respectively. This confirms the effect of global warming unequivocally irrespective of urban effect. Decadal linear increasing trends in mean temperature during non-monsoon season for Mumbai, Thiruvananthapuram and Minicoy are 0.315 °C, 0.155 °C and 0.181 °C per decade respectively. The rate of increase of mean temperature for Mumbai and Minicoy during monsoon season is 0.143 °C and 0.081 °C per decade respectively, are significantly less than the decadal trend in annual mean, which suggests that rainfall activity seems to be the correction factor for the increasing trend in the annual mean temperature which otherwise would have been a higher value. However, the rate of increase of mean temperature for Thiruvananthapuram during monsoon season for the study period is 0.172 °C per decade, which is slightly higher than the decadal trend in annual mean. Noticeable changes in resident time during monsoon season are in conformity with change in rainfall patterns.

Key words – Resident time, Climate change, Global warming, Hourly autographic data, Characteristic equation, Trend.

1. Introduction

As per latest assessment report AR5 of Intergovernmental Panel on Climate Change (IPCC, 2014), warming of the climate system is unequivocal. Each of the last three decades has been successively warmer than any preceding decade since 1850. It is virtually certain that there will be more frequent hot and fewer cold temperature extremes as global mean temperatures increase (IPCC, 2013).

There is now incontrovertible evidence that the world's climate has been undergoing change due to global warming. The study on climate change in respect of any parameter essentially boils down to a detailed trend analysis of the time series in question (WMO, 1966). Surface temperature is the parameter likely to be impacted substantially in the climate change scenario. Jones *et al.* (2012) monthly time series for ERA-Interim and CRUTEM4 (both set as anomalies by month based on the period 1979-2010) shows positive trend for the northern hemisphere. Many observatories of IMD have continuous records of surface temperature, but maximum and minimum temperatures and its average are the most published and referred. Most of the regions of India show a warming trend for the period 1901-2009 (Attri and Tyagi, 2010; Santhosh and Niyas, 2014). The profile is similar to the global temperature index. It must be stated that the temperature rise as manifested over India could be partly due to urban heat island effect as most of the observatories of IMD are situated in towns and cities which has undergone rapid urbanization.

During the last century, surface temperature over India has shown significant increasing trend (Hingane *et al*., 1985). Rupa Kumar and Hingane (1988) investigated long-term variations of seasonal and annual surface air temperature at six Indian industrial and non-industrial cities each and have concluded that Mumbai has shown a significant linear warming trend. Rao *et al.* (2005) analyzed high and low temperatures in connection with the climate change over India and concluded that during summer 60-70% of the coastal stations are showing an increasing trend in critical extreme maximum day temperature and increase in night temperatures. Rao *et al.* (2004) studied the percentage frequency of the number of days with summer maximum temperatures >35 °C. Percentage number of days of maximum temperatures of >35 °C is increasing over Mumbai and significant at 95% level.

The study by Guhathakurta *et al.* (2010) revealed an increasing trend in frequency of heavy rainfall days over very few numbers of stations mostly in Konkan & Goa. The rate of increase in rain days (amount of rainfall of that day is 0.1 mm or more) has been observed to be around 40 to 50 days in 100 years in peninsular India.

The trends in maximum, minimum and mean temperatures are documented the most. However, the temperatures to which we are exposed to the most and its trends are equally important in global climate change prospective. Total number of hours in which a temperature (one degree interval) resides is the resident time of that particular temperature for a day. By using this concept, the entire spectrum of temperatures is used to find out the resident time of each degree of temperature for a month, for a year and for a decade. An attempt is made in this study for finding out the trend in mean temperatures and also the trends in resident time of the lower and higher temperature regimes which together constitute at least 20 per cent of the resident time of the initial decade.

2. Data and methodology

All available hourly autographic data of temperatures for Mumbai, Thiruvananthapuram and Minicoy were collected from IMD, Pune. The period 1969-2012 is common to all the three stations and hence selected for the study. In order to avoid the loss of available valuable data, a ten year period starting from 1969 to 1978 is taken as the first decade instead of the calendar decade of 1971 to 1980. Mumbai is an urban city with large change in land-use pattern. Thiruvananthapuram is a semi-urban city with moderate change in land-use pattern that too in recent decades. Minicoy is an Island city without much change in land-use pattern. However, maritime effect is common for all the stations. After checking the homogeneity and homogenizing the series the climatic data were put to trend analysis. Linear regression method which is widely used across the globe (Rupa Kumar and Hingane, 1988; Amit *et al*., 2009) to find long-term trends is utilized in this study for deriving trends in temperature.

The present study aimed at quantifying the change in surface air temperature at these diverse Indian cities.

TABLE 1

Percentage frequency of resident time of temperature for Mumbai during 1969-78

1969-78	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
14.0-14.9	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.0-15.9	0.12	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
16.0-16.9	0.53	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
17.0-17.9	1.76	0.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.24
18.0-18.9	3.12	1.81	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.73	0.47
19.0-19.9	6.64	3.49	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	3.45	1.15
20.0-20.9	**10.55**	6.17	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95	6.27	2.02
21.0-21.9	**12.14**	9.99	2.14	0.00	0.00	0.00	0.00	0.00	0.00	0.01	3.05	7.37	2.85
22.0-22.9	**12.19**	11.99	5.13	0.07	0.00	0.00	0.00	0.00	0.00	0.20	7.52	11.00	3.96
23.0-23.9	**11.32**	13.66	9.18	0.50	0.00	0.10	0.08	0.15	0.27	0.98	7.87	10.97	4.54
24.0-24.9	**10.67**	13.07	11.90	2.07	0.03	1.83	2.04	2.95	4.55	4.71	8.99	11.25	6.13
25.0-25.9	9.40	11.54	13.83	6.10	0.61	6.45	8.90	11.78	15.94	10.78	11.01	11.11	9.77
26.0-26.9	8.11	9.03	13.25	12.57	2.66	10.26	16.35	26.85	25.85	18.63	11.77	10.25	13.82
27.0-27.9	5.78	7.97	12.83	16.79	7.98	11.94	31.32	33.46	22.90	16.50	11.26	7.94	15.61
28.0-28.9	3.25	5.44	11.33	19.93	20.36	20.72	22.69	13.66	12.45	14.32	10.52	5.58	13.40
29.0-29.9	1.97	2.52	9.74	13.20	24.04	20.90	11.71	8.84	11.07	10.93	7.79	4.25	10.63
30.0-30.9	1.21	0.81	5.77	11.62	12.87	11.43	6.05	2.19	5.46	9.00	7.13	3.61	6.45
31.0-31.9	0.56	0.52	2.11	10.95	12.29	8.57	0.84	0.12	1.09	6.51	5.01	2.65	4.29
32.0-32.9	0.38	0.30	1.17	5.60	14.22	5.15	0.00	0.00	0.29	3.71	3.31	1.94	3.03
33.0-33.9	0.16	0.16	0.39	0.53	4.61	2.33	0.01	0.00	0.08	2.08	1.88	1.08	1.12
34.0-34.9	0.11	0.16	0.29	0.06	0.34	0.33	0.00	0.00	0.04	0.79	0.95	0.29	0.28
35.0-35.9	0.00	0.04	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.52	0.11	0.11
36.0-36.9	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.17	0.00	0.04
37.0-37.9	0.00	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.07	0.00	0.02
38.0-38.9	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39.0-39.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40.0-40.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 2

Percentage frequency of resident time of temperature for Mumbai during 1979-88

1979-1988	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
14.0-14.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00
15.0-15.9	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
16.0-16.9	0.16	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.03
17.0-17.9	0.45	0.28	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.09
18.0-18.9	1.96	1.28	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.82	0.34
19.0-19.9	4.45	2.58	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	1.71	0.74
20.0-20.9	7.41	6.64	0.70	0.01	0.00	0.00	0.00	0.00	0.00	0.00	1.10	3.55	1.60
21.0-21.9	10.67	8.36	1.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.98	7.04	2.56
22.0-22.9	12.54	10.79	4.04	0.25	0.00	0.03	0.00	0.00	0.00	0.13	5.13	11.53	3.68
23.0-23.9	12.06	12.55	7.97	0.66	0.00	0.38	0.04	0.08	0.24	1.21	7.89	14.04	4.73
24.0-24.9	10.75	12.52	11.57	2.53	0.03	1.47	1.32	3.01	2.78	4.01	9.94	10.87	5.87
25.0-25.9	10.35	11.34	15.32	7.94	0.43	5.76	9.41	14.91	10.07	9.80	11.21	10.79	9.78
26.0-26.9	9.27	10.40	13.03	13.68	2.32	8.80	18.66	27.62	23.16	14.46	13.10	9.44	13.67
27.0-27.9	7.69	8.79	11.39	16.41	9.34	12.98	24.50	26.25	24.27	19.54	12.74	8.24	15.20
28.0-28.9	5.58	6.49	10.98	15.27	21.27	18.07	25.30	13.80	14.56	14.27	9.33	6.69	13.51
29.0-29.9	2.99	3.52	9.25	12.20	21.02	18.65	10.57	8.17	10.49	11.08	7.87	4.49	10.05
30.0-30.9	1.78	2.20	6.97	11.12	12.46	13.83	7.46	5.05	9.70	10.08	5.98	4.09	7.57
31.0-31.9	0.92	1.09	3.62	9.36	10.66	7.69	2.66	1.07	3.84	6.79	4.54	2.56	4.57
32.0-32.9	0.54	0.52	1.55	6.61	11.32	6.13	0.08	0.03	0.78	4.07	3.36	1.86	3.08
33.0-33.9	0.26	0.27	0.61	3.12	8.70	4.62	0.00	0.00	0.11	2.65	2.52	1.12	2.01
34.0-34.9	0.16	0.16	0.36	0.70	2.21	1.49	0.00	0.00	0.00	1.36	1.40	0.46	0.69
35.0-35.9	0.00	0.09	0.18	0.06	0.16	0.11	0.00	0.00	0.00	0.40	0.70	0.12	0.15
36.0-36.9	0.00	0.07	0.12	0.03	0.07	0.00	0.00	0.00	0.00	0.12	0.17	0.01	0.05
37.0-37.9	0.00	0.01	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.01
38.0-38.9	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39.0-39.9	0.00	0.00	0.07	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
40.0-40.9	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 3

Percentage frequency of resident time of temperature for Mumbai during 1989-98

1989-1998	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
14.0-14.9	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.0-15.9	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.03
16.0-16.9	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.03
17.0-17.9	0.83	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.09
18.0-18.9	2.30	1.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.28
19.0-19.9	4.12	3.06	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.09	0.66
20.0-20.9	7.77	5.90	0.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.56	1.34
21.0-21.9	10.19	8.48	1.80	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.28	7.25	2.25
22.0-22.9	12.09	10.10	5.06	0.17	0.00	0.00	0.00	0.00	0.00	0.00	1.79	12.08	3.36
23.0-23.9	11.13	10.82	7.77	1.19	0.00	0.25	0.03	0.28	0.10	0.18	5.63	12.74	4.11
24.0-24.9	10.64	12.94	10.65	3.68	0.11	1.26	0.94	2.24	1.96	3.13	9.94	10.53	5.56
25.0-25.9	9.78	11.50	13.11	8.17	0.59	4.23	7.37	12.93	11.37	10.01	12.85	9.52	9.17
26.0-26.9	9.04	10.31	13.04	12.02	2.30	7.28	16.08	23.24	21.08	14.57	11.77	10.23	12.47
27.0-27.9	7.52	9.07	11.93	15.91	6.70	9.83	25.31	24.69	21.63	19.56	13.90	9.24	14.61
28.0-28.9	4.93	6.49	10.48	16.75	18.47	15.42	22.47	19.76	18.83	15.91	11.81	6.83	14.14
29.0-29.9	3.61	3.56	9.86	11.66	20.92	19.03	16.07	9.60	11.29	12.08	9.41	5.19	11.20
30.0-30.9	2.48	2.51	7.20	11.57	15.42	18.61	7.27	5.20	8.12	9.09	7.82	4.19	8.41
31.0-31.9	1.44	1.36	4.55	8.60	10.06	10.03	3.08	1.79	4.47	6.85	5.39	3.32	5.15
32.0-32.9	0.98	1.36	2.14	6.48	10.36	6.31	1.08	0.27	0.83	4.17	4.06	2.57	3.48
33.0-33.9	0.32	0.55	0.91	2.94	9.10	4.29	0.30	0.00	0.20	2.25	2.98	1.38	2.18
34.0-34.9	0.10	0.61	0.30	0.60	4.92	2.68	0.00	0.00	0.06	1.24	1.65	0.63	1.11
35.0-35.9	0.10	0.22	0.17	0.14	1.04	0.76	0.00	0.00	0.06	0.62	0.66	0.09	0.33
36.0-36.9	0.03	0.00	0.08	0.05	0.03	0.00	0.00	0.00	0.00	0.25	0.05	0.01	0.04
37.0-37.9	0.00	0.00	0.02	0.02	0.00	0.02	0.00	0.00	0.00	0.08	0.00	0.00	0.01
38.0-38.9	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39.0-39.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40.0-40.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 4

Percentage frequency of resident time of temperature for Mumbai during 1999-2008

1999-2008	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
14.0-14.9	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.0-15.9	0.04	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
16.0-16.9	0.11	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.04
17.0-17.9	0.71	0.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.12
18.0-18.9	2.02	0.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.29
19.0-19.9	4.11	1.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.94	0.55
20.0-20.9	7.62	3.98	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.52	1.30
21.0-21.9	10.07	6.99	1.26	0.00	0.00	0.01	0.03	0.00	0.00	0.00	0.74	7.36	2.23
22.0-22.9	11.20	11.43	3.40	0.00	0.00	0.00	0.01	0.01	0.00	0.07	2.18	9.92	3.21
23.0-23.9	11.48	11.96	5.81	0.13	0.00	0.09	0.07	0.11	0.40	0.60	6.03	11.73	4.08
24.0-24.9	11.13	12.09	9.37	1.29	0.09	0.47	1.08	2.81	2.51	2.97	10.94	10.86	5.53
25.0-25.9	10.99	11.38	14.46	4.71	0.43	4.67	9.44	13.27	11.00	8.00	12.24	10.02	9.34
26.0-26.9	9.29	10.19	13.60	10.96	2.15	10.72	17.82	26.30	25.52	14.77	10.60	9.99	13.63
27.0-27.9	7.59	9.16	13.16	18.91	7.27	15.23	23.52	28.44	24.00	17.06	12.39	9.05	15.56
28.0-28.9	4.62	7.42	10.69	17.25	17.19	19.27	23.37	14.54	14.51	14.84	10.76	6.84	13.38
29.0-29.9	3.39	5.01	9.74	12.13	23.67	19.38	12.92	8.35	10.32	12.00	9.01	6.19	10.88
30.0-30.9	2.35	3.12	8.63	10.88	14.65	12.59	7.90	4.76	7.39	9.80	7.38	4.68	7.76
31.0-31.9	1.56	1.55	5.46	10.39	9.92	7.47	3.56	1.28	3.58	7.18	5.97	3.36	5.03
32.0-32.9	1.03	1.05	2.55	9.14	11.39	4.95	0.28	0.13	0.57	5.34	4.82	2.57	3.55
33.0-33.9	0.54	0.54	0.85	3.63	9.72	3.20	0.00	0.00	0.18	3.48	4.03	1.53	2.24
34.0-34.9	0.11	0.37	0.44	0.48	3.08	1.78	0.00	0.00	0.00	2.45	2.15	0.67	0.94
35.0-35.9	0.03	0.19	0.17	0.07	0.36	0.16	0.00	0.00	0.00	1.24	0.63	0.12	0.25
36.0-36.9	0.00	0.06	0.09	0.03	0.03	0.00	0.00	0.00	0.00	0.20	0.08	0.03	0.04
37.0-37.9	0.01	0.03	0.01	0.00	0.04	0.00	0.00	0.00	0.00	0.01	0.06	0.00	0.01
38.0-38.9	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
39.0-39.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
40.0-40.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 5

Percentage frequency of resident time of temperature for Mumbai during 2009-2012

2009-2012	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
14.0-14.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.0-15.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16.0-16.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17.0-17.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.01
18.0-18.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.01
19.0-19.9	0.74	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.92	0.32
20.0-20.9	1.81	1.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.88	0.85
21.0-21.9	4.70	4.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.61	1.45
22.0-22.9	9.21	8.78	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.00	8.66	2.33
23.0-23.9	14.25	14.29	1.61	0.00	0.00	0.00	0.00	0.00	0.00	2.02	0.42	10.15	3.77
24.0-24.9	12.16	14.21	5.65	0.21	0.00	0.76	0.54	0.54	0.42	1.21	4.18	9.47	4.29
25.0-25.9	11.69	11.31	12.70	2.15	0.00	6.53	9.81	14.92	4.86	4.57	11.84	12.04	8.24
26.0-26.9	10.48	10.86	15.26	4.17	0.13	10.00	23.92	19.49	10.97	11.96	20.33	9.74	11.72
27.0-27.9	9.81	9.90	15.79	13.19	2.16	10.42	29.91	26.88	29.58	17.88	15.18	8.53	14.81
28.0-28.9	6.99	9.90	12.10	18.82	9.44	11.11	18.28	20.03	18.19	16.53	14.76	5.95	13.10
29.0-29.9	6.45	7.22	10.55	16.53	23.20	13.19	9.68	8.60	10.42	14.52	10.72	3.65	11.69
30.0-30.9	4.17	3.65	10.22	10.35	19.89	19.31	5.24	6.32	9.44	11.16	6.96	2.98	9.63
31.0-31.9	2.96	1.79	8.74	9.93	9.64	9.79	2.02	2.96	7.92	8.33	5.71	2.98	6.21
32.0-32.9	2.42	0.89	4.70	10.56	9.24	4.31	0.60	0.27	5.14	3.49	4.32	1.62	4.24
33.0-33.9	1.61	0.67	1.95	8.19	11.33	4.79	0.00	0.00	1.81	4.97	2.65	0.54	3.54
34.0-34.9	0.34	0.52	0.54	4.72	9.58	4.65	0.00	0.00	0.97	2.28	2.65	0.00	2.46
35.0-35.9	0.13	0.00	0.07	1.04	4.72	4.58	0.00	0.00	0.28	0.81	0.28	0.00	1.19
36.0-36.9	0.07	0.00	0.07	0.14	0.61	0.56	0.00	0.00	0.00	0.00	0.00	0.00	0.15
37.0-37.9	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
38.0-38.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39.0-39.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40.0-40.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 6

Percentage frequency of resident time of temperature for Thiruvananthapuram during 1969-78

1969-1978	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
19.0-19.9	0.14	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.03
20.0-20.9	1.21	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.43	0.18
21.0-21.9	4.30	1.83	0.11	0.05	0.00	0.29	0.06	0.05	0.00	0.25	0.31	1.73	0.77
22.0-22.9	6.68	4.57	0.89	0.51	0.25	2.43	3.13	2.43	0.86	1.29	2.75	4.01	2.51
23.0-23.9	9.55	7.77	3.68	1.75	3.60	9.41	13.15	12.51	7.59	8.79	10.50	10.83	8.29
24.0-24.9	11.89	11.82	7.93	6.03	8.97	14.98	18.30	22.28	19.42	20.89	16.94	15.52	14.62
25.0-25.9	11.56	12.43	12.64	10.39	13.64	14.72	17.58	19.55	20.54	20.28	16.79	13.80	15.34
26.0-26.9	10.27	11.68	13.78	14.70	15.46	14.83	14.17	13.76	15.19	14.08	13.62	11.67	13.57
27.0-27.9	9.41	10.52	11.58	13.72	14.52	13.70	12.36	10.74	11.92	11.47	11.39	10.26	11.76
28.0-28.9	8.82	9.20	10.94	11.51	12.26	11.23	9.62	8.93	9.83	9.63	9.68	8.78	10.01
29.0-29.9	11.30	9.32	10.02	11.57	11.13	9.13	7.26	6.65	8.56	7.97	8.96	9.32	9.26
30.0-30.9	10.18	11.27	10.63	10.14	9.53	5.50	3.41	2.49	5.00	3.88	5.63	8.25	7.17
31.0-31.9	3.86	7.11	10.55	10.45	6.62	3.31	0.77	0.62	1.07	1.39	2.33	4.59	4.38
32.0-32.9	0.73	1.71	6.03	7.47	2.90	0.42	0.15	0.00	0.03	0.08	1.00	0.62	1.74
33.0-33.9	0.08	0.22	1.07	1.52	0.85	0.06	0.06	0.00	0.00	0.00	0.07	0.04	0.33
34.0-34.9	0.01	0.01	0.10	0.19	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
35.0-35.9	0.00	0.00	0.03	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
36.0-36.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
37.0-37.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 7

Percentage frequency of resident time of temperature for Thiruvananthapuram during 1979-88

1979-1988	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
19.0-19.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20.0-20.9	0.28	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.04
21.0-21.9	1.51	0.43	0.04	0.00	0.00	0.00	0.10	0.08	0.00	0.11	0.18	0.78	0.27
22.0-22.9	4.83	2.16	0.07	0.01	0.08	1.06	1.71	1.66	0.48	0.75	1.42	2.40	1.39
23.0-23.9	9.45	6.55	1.50	1.10	1.68	8.67	9.92	8.52	6.12	4.71	9.40	7.09	6.22
24.0-24.9	12.26	12.12	5.57	4.57	4.87	17.36	18.60	20.31	18.52	17.02	17.88	14.36	13.61
25.0-25.9	12.50	13.66	11.24	7.53	7.52	20.51	20.46	21.77	22.49	19.57	18.63	16.19	15.99
26.0-26.9	11.41	11.56	13.30	14.10	13.27	15.20	14.79	14.61	15.11	15.53	12.70	11.65	13.61
27.0-27.9	10.57	11.87	12.52	14.43	16.53	11.44	11.70	9.63	10.48	12.06	11.32	11.14	11.98
28.0-28.9	7.49	8.64	13.40	11.89	13.14	9.94	9.92	10.35	8.98	9.85	9.51	8.63	10.16
29.0-29.9	8.17	8.02	9.97	12.48	11.31	8.29	7.47	9.07	8.84	9.30	9.00	8.66	9.22
30.0-30.9	11.41	11.54	8.13	9.56	10.31	5.34	4.07	3.59	6.51	8.30	7.63	11.64	8.16
31.0-31.9	7.78	10.13	11.46	9.15	11.19	1.87	1.19	0.37	2.25	2.42	2.04	5.84	5.47
32.0-32.9	1.83	2.82	9.71	11.09	8.20	0.28	0.08	0.04	0.19	0.37	0.27	1.13	3.01
33.0-33.9	0.44	0.43	2.65	3.70	1.77	0.03	0.00	0.00	0.03	0.01	0.03	0.23	0.78
34.0-34.9	0.06	0.04	0.32	0.34	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.08
35.0-35.9	0.01	0.01	0.07	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
36.0-36.9	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
37.0-37.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 8

Percentage frequency of resident time of temperature for Thiruvananthapuram during 1989-98

1989-1998	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
19.0-19.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20.0-20.9	0.07	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.03
21.0-21.9	1.00	0.50	0.15	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.41	0.17
22.0-22.9	4.60	1.87	0.46	0.00	0.00	0.22	1.64	0.37	0.29	0.25	0.53	2.27	1.04
23.0-23.9	8.30	5.18	1.94	0.60	0.88	5.25	10.76	5.70	3.32	7.36	6.66	6.48	5.21
24.0-24.9	12.92	10.44	4.29	2.35	5.50	14.44	20.52	17.39	13.55	18.30	18.62	14.23	12.72
25.0-25.9	13.04	12.79	9.98	6.70	9.77	20.43	20.52	25.52	22.56	22.98	20.24	15.74	16.69
26.0-26.9	11.58	12.43	13.34	9.68	13.31	17.68	15.42	16.35	17.95	14.85	13.83	12.70	14.09
27.0-27.9	10.56	11.68	13.34	16.33	15.22	14.16	11.57	12.21	13.58	10.86	11.60	11.63	12.73
28.0-28.9	8.07	10.94	12.57	14.27	14.16	11.49	10.82	11.68	9.68	9.17	9.63	9.25	10.97
29.0-29.9	9.07	8.60	10.86	12.92	11.87	9.98	6.81	8.12	9.17	9.29	9.73	8.69	9.59
30.0-30.9	11.80	10.92	9.18	10.17	10.81	4.05	1.76	2.48	7.84	5.87	7.29	9.76	7.65
31.0-31.9	6.36	8.31	11.57	10.42	9.19	1.56	0.18	0.14	1.91	1.03	1.58	6.54	4.89
32.0-32.9	2.18	4.80	8.38	11.53	7.02	0.63	0.00	0.02	0.15	0.03	0.25	1.81	3.06
33.0-33.9	0.37	1.13	3.23	4.51	2.18	0.09	0.00	0.00	0.00	0.00	0.05	0.33	0.99
34.0-34.9	0.07	0.30	0.60	0.43	0.09	0.02	0.00	0.00	0.00	0.00	0.00	0.08	0.13
35.0-35.9	0.00	0.00	0.12	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
36.0-36.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
37.0-37.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 9

Percentage frequency of resident time of temperature for Thiruvananthapuram during 1999-2008

1999-2008	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
19.0-19.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20.0-20.9	0.24	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.04
21.0-21.9	1.16	0.07	0.01	0.00	0.00	0.07	0.01	0.03	0.13	0.00	0.18	1.47	0.27
22.0-22.9	3.57	1.14	0.03	0.00	0.13	0.64	0.96	1.06	0.64	0.47	1.07	3.97	1.15
23.0-23.9	7.38	4.85	1.26	1.35	1.90	7.04	7.78	5.02	4.51	6.25	6.58	7.62	5.13
24.0-24.9	12.53	9.87	5.13	5.60	5.69	12.95	18.53	16.63	14.59	18.69	18.17	14.15	12.69
25.0-25.9	13.62	14.75	9.54	10.36	10.32	17.13	21.46	22.38	21.09	21.52	19.70	14.85	16.35
26.0-26.9	11.35	12.81	14.52	15.00	13.91	17.30	15.23	15.51	15.46	13.84	12.40	10.77	13.99
27.0-27.9	10.35	11.23	13.80	14.61	17.57	13.30	11.11	11.24	10.97	10.52	9.90	9.63	12.03
28.0-28.9	8.28	9.63	12.11	10.77	12.78	10.27	10.14	9.26	8.82	9.00	9.50	8.01	9.89
29.0-29.9	7.76	7.89	10.24	10.70	10.48	9.58	8.73	9.09	8.74	8.12	7.81	7.26	8.87
30.0-30.9	9.80	8.66	8.19	9.41	9.68	7.26	4.78	7.03	7.86	7.47	8.63	10.37	8.27
31.0-31.9	8.80	10.05	9.57	9.68	8.94	2.90	1.18	2.27	4.82	3.24	5.28	7.97	6.24
32.0-32.9	4.35	6.87	10.91	8.48	6.81	0.91	0.08	0.45	1.94	0.74	0.78	3.12	3.80
33.0-33.9	0.66	1.71	3.96	3.41	1.72	0.56	0.00	0.01	0.42	0.11	0.00	0.59	1.10
34.0-34.9	0.16	0.37	0.64	0.51	0.07	0.08	0.00	0.01	0.00	0.03	0.00	0.04	0.16
35.0-35.9	0.00	0.07	0.07	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
36.0-36.9	0.00	0.00	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
37.0-37.9	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 10

Percentage frequency of resident time of temperature for Thiruvananthapuram during 2009-12

2009-2012	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
19.0-19.9	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.02
20.0-20.9	0.86	0.11	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.09
21.0-21.9	2.48	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.34	0.32
22.0-22.9	4.82	2.63	0.37	0.03	0.00	0.24	0.67	0.34	0.21	0.54	1.32	1.41	1.04
23.0-23.9	8.40	6.05	1.58	0.10	0.30	2.68	6.05	2.59	2.61	2.39	6.49	5.54	3.72
24.0-24.9	13.40	8.60	4.44	2.96	1.88	12.58	15.36	16.83	10.65	13.05	18.89	14.38	11.09
25.0-25.9	11.71	11.69	8.54	8.07	7.39	17.41	20.90	22.92	22.58	19.86	16.49	18.31	15.51
26.0-26.9	10.09	12.09	13.96	12.00	12.60	15.77	16.57	14.92	18.62	16.18	13.51	12.67	14.09
27.0-27.9	9.37	9.90	12.34	15.76	18.35	15.32	13.24	13.00	11.80	11.63	10.63	10.32	12.65
28.0-28.9	8.61	10.18	11.34	13.47	15.52	11.54	9.95	10.48	11.03	10.05	10.03	10.38	11.05
29.0-29.9	7.44	8.71	10.73	11.86	13.07	10.88	9.27	10.11	9.81	8.63	8.33	8.67	9.80
30.0-30.9	11.29	8.20	8.95	12.00	12.77	9.66	6.38	7.73	8.66	7.96	6.74	9.81	9.18
31.0-31.9	8.20	10.80	9.22	8.73	9.98	2.88	1.51	1.04	3.65	6.07	6.22	6.18	6.19
32.0-32.9	2.69	7.81	10.90	8.98	4.70	0.80	0.10	0.03	0.31	3.30	0.90	1.78	3.51
33.0-33.9	0.48	2.16	5.45	4.73	2.55	0.24	0.00	0.00	0.07	0.34	0.03	0.10	1.34
34.0-34.9	0.03	0.36	1.78	1.08	0.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
35.0-35.9	0.00	0.04	0.37	0.17	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
36.0-36.9	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
37.0-37.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 11

Percentage frequency of resident time of temperature for Minicoy during 1969-78

1969-1978	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
20.0-20.9	0.28	0.06	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.03
21.0-21.9	1.53	0.42	0.07	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.59	0.24
22.0-22.9	4.05	2.46	0.47	0.00	0.08	0.00	0.00	0.01	0.03	0.16	1.45	1.99	0.88
23.0-23.9	7.34	4.85	1.78	0.04	0.31	0.10	0.42	0.79	0.68	0.79	3.15	5.07	2.09
24.0-24.9	9.55	8.26	5.60	0.90	1.46	2.24	3.03	5.04	4.19	4.62	9.75	10.22	5.39
25.0-25.9	14.26	12.63	10.36	5.01	4.57	5.36	7.20	11.10	9.27	13.47	15.64	15.95	10.39
26.0-26.9	15.02	17.65	13.78	9.88	9.53	10.40	14.36	18.48	21.40	24.61	18.41	16.57	15.84
27.0-27.9	12.08	15.09	16.41	12.97	15.80	20.21	30.10	29.91	29.00	21.84	15.09	14.24	19.45
28.0-28.9	15.55	12.84	14.62	20.12	21.78	27.42	23.11	17.28	16.45	14.09	12.60	11.33	17.28
29.0-29.9	15.26	18.27	14.16	18.54	20.97	18.37	15.40	13.08	13.51	13.44	13.73	13.99	15.71
30.0-30.9	3.62	6.62	17.57	16.57	13.32	11.12	5.31	3.36	4.35	5.77	7.78	7.90	8.61
31.0-31.9	1.13	0.76	4.80	13.33	9.65	3.25	0.84	0.94	0.93	1.16	1.84	1.88	3.38
32.0-32.9	0.33	0.09	0.34	2.56	1.98	1.33	0.18	0.00	0.19	0.05	0.31	0.24	0.63
33.0-33.9	0.00	0.00	0.03	0.07	0.54	0.21	0.05	0.00	0.00	0.00	0.00	0.00	0.08
34.0-34.9	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
35.0-35.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
36.0-36.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 12

Percentage frequency of resident time of temperature for Minicoy during 1979-88

1979-1988	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
20.0-20.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21.0-21.9	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22.0-22.9	1.08	0.17	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.23	0.03	0.09	0.13
23.0-23.9	3.57	2.38	0.02	0.00	0.05	0.05	0.03	0.60	0.11	0.55	0.87	1.31	0.75
24.0-24.9	9.94	6.30	1.77	0.11	0.43	1.15	2.01	2.86	2.13	2.54	3.89	6.20	3.18
25.0-25.9	12.65	11.23	5.67	1.29	2.48	7.53	6.09	7.26	8.41	8.23	13.70	12.66	8.01
26.0-26.9	16.99	18.09	10.92	5.36	5.49	13.00	12.24	15.21	18.34	16.76	18.61	18.44	14.03
27.0-27.9	17.57	19.23	20.05	10.24	11.84	20.29	28.35	32.03	32.80	26.97	23.26	21.02	22.06
28.0-28.9	11.82	13.90	18.77	22.03	16.45	25.40	23.78	19.47	16.81	17.21	14.47	13.67	17.92
29.0-29.9	17.35	16.28	14.09	22.84	25.01	15.62	13.34	14.68	13.96	13.88	12.77	14.62	16.19
30.0-30.9	8.01	10.44	18.49	15.32	14.08	11.41	9.84	6.50	6.23	11.71	10.33	10.17	11.08
31.0-31.9	0.96	1.82	8.43	15.57	14.20	4.43	3.99	1.32	1.14	1.80	2.03	1.78	4.86
32.0-32.9	0.00	0.17	1.67	6.58	7.82	0.99	0.30	0.08	0.06	0.12	0.05	0.03	1.52
33.0-33.9	0.00	0.00	0.12	0.65	2.01	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.25
34.0-34.9	0.00	0.00	0.00	0.02	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
35.0-35.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
36.0-36.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 13

Percentage frequency of resident time of temperature for Minicoy during 1989-98

1989-1998	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
20.0-20.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21.0-21.9	0.10	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.02
22.0-22.9	1.09	0.86	0.00	0.00	0.00	0.00	0.07	0.03	0.00	0.04	0.00	0.16	0.19
23.0-23.9	3.68	2.82	0.29	0.02	0.07	0.06	0.51	0.29	0.15	0.51	0.65	1.79	0.90
24.0-24.9	8.17	6.09	3.05	0.51	0.46	1.85	3.79	3.36	1.75	3.72	4.70	5.90	3.61
25.0-25.9	11.41	9.55	6.80	2.20	2.12	6.22	11.93	9.09	6.64	10.84	12.86	11.81	8.46
26.0-26.9	16.43	15.73	11.96	6.35	6.02	12.98	18.04	15.89	15.83	20.71	18.27	18.12	14.70
27.0-27.9	19.25	19.89	17.63	11.53	10.76	22.82	23.63	26.56	29.57	22.21	22.22	20.24	20.51
28.0-28.9	13.80	13.47	16.98	18.65	18.60	23.18	18.07	18.46	17.57	17.05	14.12	13.66	16.98
29.0-29.9	14.60	14.38	11.84	19.71	21.80	13.46	10.62	11.04	13.00	11.77	12.13	12.20	13.87
30.0-30.9	9.23	14.06	13.34	12.15	13.64	9.97	8.45	11.67	12.61	10.59	12.53	12.11	11.68
31.0-31.9	2.14	2.93	14.07	13.07	11.04	7.24	4.55	3.55	2.77	2.54	2.39	3.69	5.85
32.0-32.9	0.10	0.07	3.81	12.68	10.25	2.10	0.33	0.06	0.11	0.01	0.12	0.27	2.50
33.0-33.9	0.00	0.00	0.24	3.07	4.84	0.12	0.00	0.00	0.00	0.00	0.02	0.00	0.70
34.0-34.9	0.00	0.00	0.00	0.06	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
35.0-35.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
36.0-36.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 14

Percentage frequency of resident time of temperature for Minicoy during 1999-2008

1999-2008	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
20.0-20.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.04	0.00
21.0-21.9	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.01	0.13	0.03
22.0-22.9	0.72	0.34	0.00	0.03	0.00	0.01	0.00	0.06	0.24	0.09	0.25	0.50	0.19
23.0-23.9	2.55	1.77	0.46	0.11	0.00	0.14	0.31	0.46	0.18	0.54	0.88	2.16	0.79
24.0-24.9	5.49	6.07	1.38	0.21	0.38	1.22	2.39	2.00	2.63	2.66	3.32	5.60	2.77
25.0-25.9	10.20	10.00	4.65	1.39	2.66	6.65	7.86	6.10	8.76	10.03	13.43	11.03	7.72
26.0-26.9	17.23	14.10	8.69	4.50	8.57	13.07	12.81	13.45	14.97	19.78	18.91	16.59	13.55
27.0-27.9	20.63	21.32	15.93	11.72	13.01	21.58	26.16	29.12	26.33	25.05	20.17	20.97	20.94
28.0-28.9	13.75	14.76	21.43	18.50	17.54	22.46	22.40	18.88	18.38	14.67	14.70	13.03	17.55
29.0-29.9	12.40	10.45	15.25	21.49	21.62	13.49	11.37	10.88	10.58	10.52	11.76	11.91	13.51
30.0-30.9	13.40	13.82	11.25	14.75	14.31	9.99	10.31	12.15	11.53	11.49	12.04	12.58	12.29
31.0-31.9	3.36	7.11	14.17	12.34	10.25	8.74	5.86	5.90	6.08	4.65	4.13	5.03	7.32
32.0-32.9	0.15	0.27	6.47	12.13	8.50	2.33	0.51	0.94	0.28	0.46	0.40	0.42	2.77
33.0-33.9	0.00	0.00	0.32	2.79	3.03	0.32	0.01	0.04	0.03	0.00	0.00	0.00	0.55
34.0-34.9	0.00	0.00	0.00	0.04	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
35.0-35.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
36.0-36.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 15

Percentage frequency of resident time of temperature for Minicoy during 2009-12

2009-2012	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
20.0-20.9	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21.0-21.9	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.86	0.08
22.0-22.9	1.96	0.25	0.00	0.07	0.00	0.00	0.00	0.00	0.18	0.14	0.09	1.68	0.35
23.0-23.9	4.10	2.30	0.10	0.31	0.00	0.10	0.20	0.24	1.77	1.42	1.18	4.03	1.23
24.0-24.9	8.23	5.26	0.96	1.02	0.14	2.19	1.71	2.57	4.26	7.17	7.34	6.84	3.74
25.0-25.9	13.05	9.39	4.78	1.67	1.09	5.36	6.79	6.40	9.42	9.91	14.67	11.87	7.53
26.0-26.9	15.22	13.84	9.90	4.20	3.21	12.09	13.78	15.62	16.08	16.58	18.70	15.31	12.54
27.0-27.9	16.77	17.20	11.82	6.83	7.45	22.17	26.68	29.57	26.40	21.74	19.20	16.39	18.33
28.0-28.9	10.98	13.88	20.08	13.22	19.59	23.94	22.92	20.16	15.17	16.35	12.05	17.44	17.34
29.0-29.9	12.95	10.59	16.94	25.79	26.67	17.66	12.60	11.82	12.86	11.00	11.50	13.90	15.64
30.0-30.9	10.71	14.30	11.85	19.19	16.51	9.15	9.81	8.91	10.05	11.05	8.83	7.43	11.66
31.0-31.9	5.13	11.05	12.36	11.71	12.24	5.19	5.48	4.20	3.62	4.16	5.71	3.35	7.25
32.0-32.9	0.65	1.87	9.67	10.18	9.37	2.02	0.03	0.51	0.18	0.50	0.72	0.91	3.27
33.0-33.9	0.00	0.07	1.54	5.64	3.56	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.99
34.0-34.9	0.00	0.00	0.00	0.17	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
35.0-35.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
36.0-36.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Curve fittings of different time period for each station are done and it will serve as a tool for future reference.

2.1. *Resident time*

Total number of hours in which a temperature (with one degree interval) resides is the resident time of that particular temperature for the day and this gives an idea of the temperatures to which we are exposed the most. The frequency table of resident time of each temperature with one degree interval up to the maximum temperature is prepared. As the common period of availability of data for the three stations starts from 1969 the first decadal started with 1969-78, then 1979-88 and so on instead of calendar decade staring from of 1971-1980. The remaining available period also considered together to get the status of recent period. The frequencies are calculated for resident time with respect to each degree of temperature for all months, *viz*., January to December, seasonal and annual. The annual frequencies are converted to percentage frequencies as a standardizing tool for comparing with other decades and stations which are having varying data set due to missing data. This method will rectify the cropping in of errors due to data gaps, if any. The relation between temporal variability in residence time for the temperatures for each station has been worked out for the study as explained below. Contour analysis of resident time has also been performed on the data tables.

2.2. *Mumbai*

Mumbai has two weather monitoring stations, one at Santacruz airport and the other at Colaba towards the southern tip of Mumbai. In this study we have taken Colaba station to represent Mumbai. While considering data as a whole for the station, the lowest minimum is in the range of 14.0-14.9 and highest maximum is in the range of 40.0-40.9. Then sorted the data into decade-wise and frequencies are calculated for resident time with respect to the temperature ranges of 14.0-14.9, 15.0-15.9, 16.0-16.9, …, 40.0-40.9 respectively for all months, *viz*., January to December and also annual. The annual frequencies are converted to percentage frequencies as shown in Tables 1-5.

2.3. *Thiruvananthapuram*

While considering the entire data set for Thiruvananthapuram, the lowest minimum is in the range of 19.0-19.9 and highest maximum is in the range of 37.0-37.9. Then sorted the data into decade-wise and

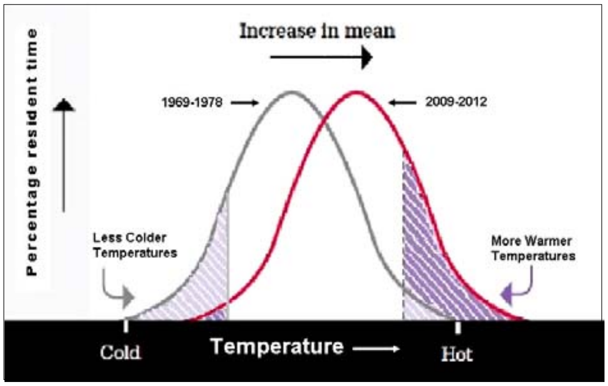

Fig. 1. Expected scenario for a station in view of warming of the climate system

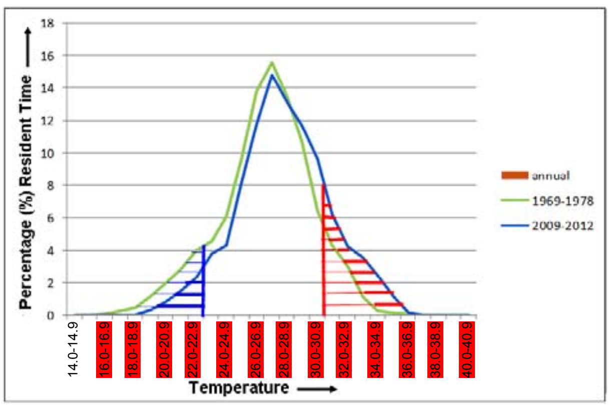

Fig. 2. Percentage resident time of the temperature for Mumbai

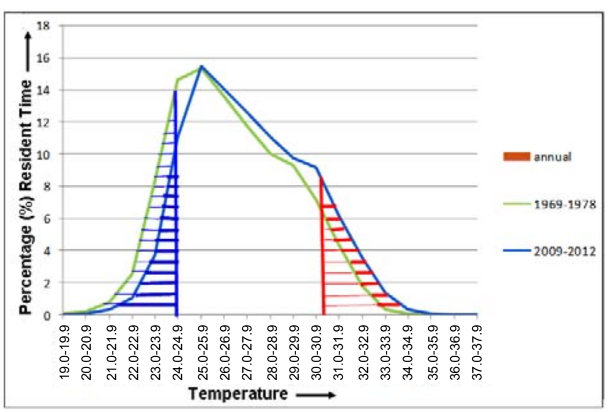

Fig. 3. Percentage resident time of the temperature for Thiruvananthapuram

frequencies of resident time are calculated with respect to the temperature ranges of 19.0-19.9, 20.0-20.9, 21.0-21.9, …, 37.0-37.9 respectively for all the months, *viz.*, January to December and also annual are converted to percentage frequencies as shown in Tables 6-10.

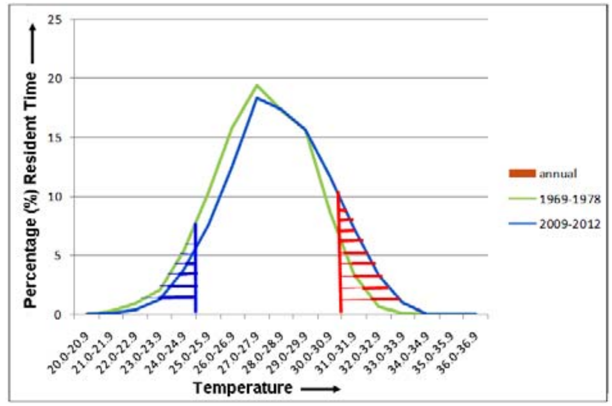

Fig. 4. Percentage resident time of the temperature for Minicoy

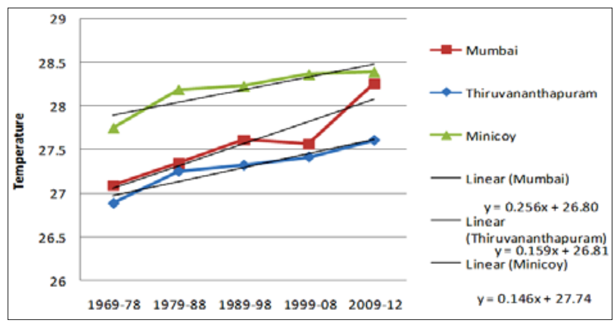

Fig. 5. Linear trend (°C per decade) of decadal mean temperature for Mumbai, Thiruvananthapuram and Minicoy

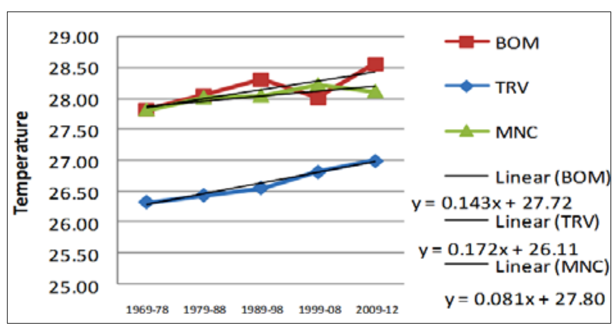

Fig. 6. Decadal linear trends (°C per decade) in seasonal (monsoon) mean temperature for Mumbai, Thiruvananthapuram and Minicoy

2.4. *Minicoy*

For Minicoy, the lowest minimum is in the range of 20.0-20.9 and highest maximum is in the range of 36.0-36.9. Then sorted the data into decade-wise and frequencies are calculated with respect to the temperature ranges of 20.0-20.9, 21.0-21.9, 22.0-22.9, …, 36.0-36.9 respectively for all the months, *viz.*, January to December and also annual are converted to percentage frequencies as shown in Tables 11-15.

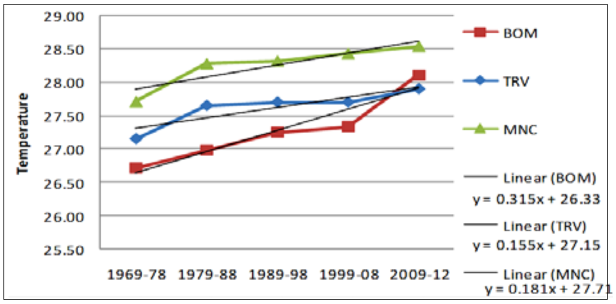

Fig. 7. Decadal linear trends (°C per decade) in non-monsoon season mean temperature for Mumbai, Thiruvananthapuram and Minicoy

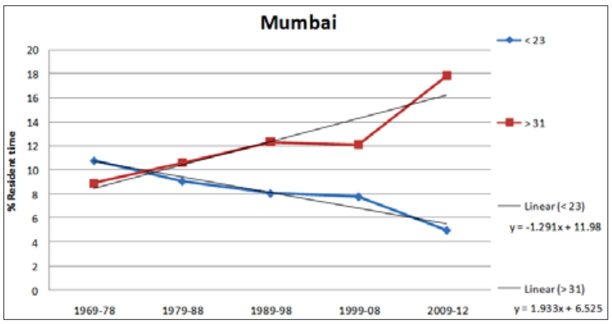

Fig. 8. Decadal linear trend (%) in percentage resident time of the temperature < 23 °C and ≥ 31 °C for Mumbai

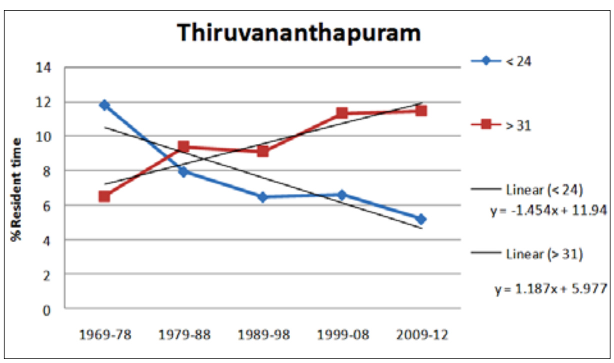

Fig. 9. Decadal linear trend (%) in percentage resident time of the temperature < 24 °C and ≥ 31 °C for Thiruvananthapuram

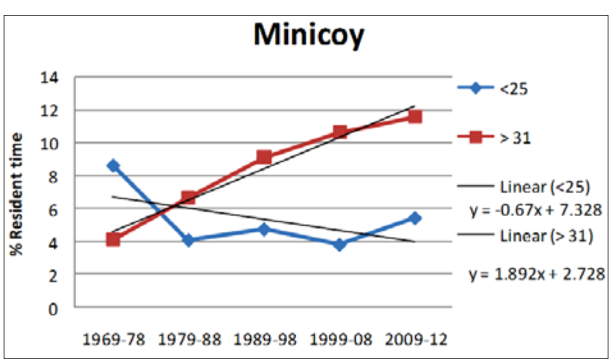

Fig. 10. Decadal linear trend (%) in percentage resident time of the temperature < 25 °C and ≥ 31 °C for Minicoy

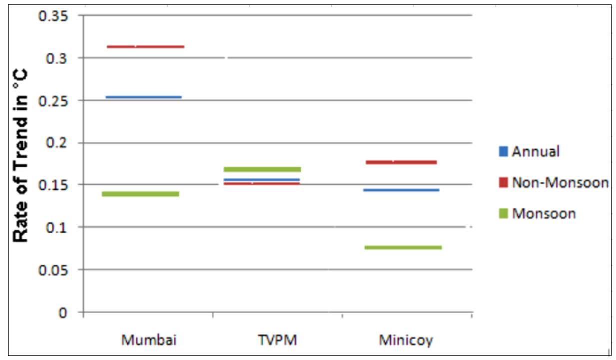

Fig. 11. Decadal rate of trend in temperature (°C) for Mumbai, Thiruvananthapuram and Minicoy for annual, non-monsoon and monsoon period

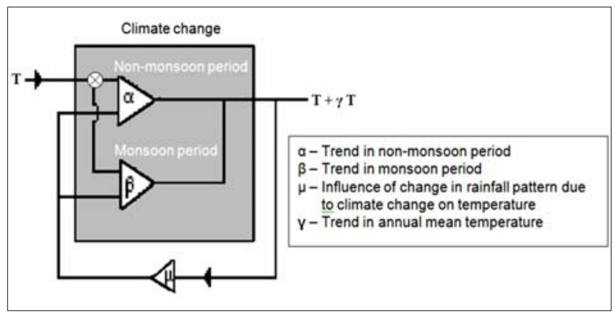

Fig. 12. Embedded system of climate

2.5. *Temperature distribution of head and tail regime*

The resident time of the lower and higher temperature regime which together constitute at least 20 per cent of the resident time of the initial decade and its trend during the subsequent decades were also studied in detail. The expected scenario for any station in view of warming of the climate system which is unequivocal is shown in Fig. 1.

2.5.1. *Mumbai*

As expected, a noticeable shift in the mean and the frequency of resident time of lower and higher end of temperatures (*i.e.*, up to 23 °C and above 31 °C), which is covering around 20% of the total resident time of the first decade happened in Mumbai and is shown in Fig. 2. The resident time of lower temperatures are decreasing and higher temperatures are increasing and the trend is shown in Fig. 8.

2.5.2. *Thiruvananthapuram*

The shift in the mean and the frequency of resident time of lower and higher end of temperatures (*i.e.*, up to

24 °C and above 31 °C), which is covering around 20% of the total resident time of the first decade and is shown in Fig. 3. The resident time of lower temperatures are decreasing and higher temperatures are increasing and the trend is shown in Fig. 9.

2.5.3. *Minicoy*

The shift in the mean and the frequency of resident time of lower and higher end of temperatures (*i.e*., up to 25 °C and above 31 °C), which is covering around 13% of the total resident time of the first decade and is shown in Fig. 4. The resident time of lower temperatures are decreasing and higher temperatures are increasing and the trend is shown in Fig. 10. These types of trends are also visible during monsoon period as well and are given in Table 17.

3. Results and discussion

Attempts are made here not only to study trends but also to quantify the rate of change in temperature during the period 1969-2012. The features associated with the analysis of all the cities are discussed in the following sections.

3.1. *Features associated with Mumbai*

Mumbai is situated on the west coast of India at 18° 54′ N and 72° 49′ E. Mumbai has a tropical wet and dry climate. It has witnessed rapid urbanization in our study period. Increasing trends are revealed in all the earlier referred studies while considering either average or maximum temperatures.

For the decade 1969-1978, out of 86634 hourly temperature data sets, February representing 6697, the least and May represents 7382, the highest among the data sets. In this decade, temperature hit 2 times in the minimum range of 14.0-14.9 in January and once in its maximum range of 38.0-38.9 in March. Range between the maximum and minimum for Mumbai is very high compared to Minicoy and Thiruvananthapuram, even though all the three stations are having maritime effect is common, is because of extra- tropical influence in the winter season. Percentage frequency of resident time in the range 21.0-22.9 was most resided over more than 24% occasions in January. Similarly temperatures in the ranges 23.0-24.9 (>26% occasions), 25.0-26.9 (>27% occasions), 27.0-28.9 (>36% occasions), 28.0-29.9 (>44% occasions), 28.0-29.9 (>41% occasions), 27.0-28.9 (>54% occasions), 26.0-27.9 (>60% occasions), 26.0-27.9 (>48% occasions), 26.0-27.9 (>35% occasions), 26.0-27.9 (>23% occasions), 24.0-25.9 (>22% occasions), 26.0-27.9 (>29% occasions) in February to December and annual respectively. Percentage frequency of resident time is given in Table 1.

For the decade 1979-1988, Mumbai having total 87229 hourly temperature data sets. Out of this, February representing 6782, the least and October representing 7440, the highest among the data sets. In this decade, temperature hit 2 times in the minimum range of 14.0-14.9 in December and 2 times in its maximum range of 40.0-40.9 in March. Percentage frequency of resident time is given in Table 2.

For the decade 1989-1998, Mumbai having total 74396 hourly temperature data sets. Out of this, September representing 5039, the least and August representing 6696, the highest among the data sets. In this decade, temperature hits once in the minimum range of 14.0-14.9 in January and once in its maximum range of 38.0-38.9 in April. Percentage frequency of resident time is given in Table 3.

For the decade 1999-2008, Mumbai having total 85978 hourly temperature data sets. Out of this, April representing 6672, the least and January, March, July, August and October are representing 7440, the highest among the data sets. In this decade, temperature hit 2 times in the minimum range of 14.0-14.9 in February and once in its maximum range of 39.0-39.9 in December. Percentage frequency of resident time is given in Table 4.

For the remaining period 2009-2012, Mumbai having total 13836 hourly temperature data sets. Out of this, November representing 718, the least and January, March, July are representing 1488, the highest among the data sets. In this decade, temperature hits once in the minimum range of 17.0-17.9 in December and once in its maximum range of 37.0-37.9 in May. Percentage frequency of resident time is given in Table 5.

The decadal mean temperature $\left(\bar{t}\right)$ is calculated using the formula

$$\bar{t} = \frac{\sum f_i t_i}{\sum f_i} \qquad \text{(A)}$$

where, f_i is the percentage frequency of resident time and t_i is the middle value temperature of the i^{th} frequency class. Linear trend (°C per decade) of decadal mean temperature for Mumbai is shown in the Fig. 5. The equation for linear trend of decadal mean temperature will be the characteristic equation for Mumbai. That is $y = 0.256\ x + 26.80$ projecting the next decadal mean temperature as 28.34 °C.

The same way, non-linear characteristic equation for Mumbai is $y = 0.04\ x^2 + 0.011\ x + 27.08$, which is projecting the next decadal mean temperature as 28.59 °C.

$\frac{dy}{dx} = 0.08x + 0.11$ and $\frac{d^2y}{dx^2} = 0.08$, which is positive and shows accelerated change from the previous decade.

Decadal linear trend (°C per decade) in seasonal (monsoon) mean temperature for Mumbai is shown in the Fig. 6. The rate of increase of mean temperature in this period is 0.143 °C per decade. Decadal linear trends (°C per decade) in mean temperature during non-monsoon season for Mumbai are given in Fig. 7. The rate of increase of mean temperature for Mumbai in this period is 0.315 °C per decade, is much high than the annual mean trend of 0.256 °C. Rainfall activity in monsoon period seems to be the correction factor for the increasing trend in the annual mean temperature. These observed changes in temperatures are due to changes in land use pattern, increase in automobile registration, construction activities, urbanization and increase in population. Most of the trends show positive change in temperature with different rates in various seasons.

The changes taken places in the lower and higher temperature ranges are significant in any climate change study. For that reason, 1969-78 taken as a reference decade with resident hours having temperatures up to 23 °C and above 31 °C, which is covering around 20% of the total resident time for Mumbai. Details are given in the Table 16 and linear trends are shown in the Fig. 8. The resident time of lower temperatures are decreasing at the rate of 1.291% per decade and if the same linear trend continues up to the next five decades, then there will not be significant resident time of temperatures below 23 °C. However lower temperature can break the extremes or some percentage of resident time would still be there for temperatures below 23 °C, if suitable synoptic situations arise or if we consider non-linearity in the trend. The resident time of higher temperatures are increasing at the rate of 1.933% per decade and if the same scenario continues up to the next fifty decades, then the temperatures will be above 31 °C only. Percentage frequency of resident time for the lower and higher temperature regime for Mumbai during monsoon period is given in Table 17.

3.2. *Features associated with Thiruvananthapuram*

Thiruvananthapuram is situated on the west coast of India at 8° 29′ N and 76° 57′ E and has a tropical wet and dry climate. For the decade 1969-1978, Thiruvananthapuram having total 82577 hourly temperature data sets. Out of this, April representing 6449, the least and May representing 7405, the highest among the data sets. In this decade, temperature hit 27 times in the minimum range of 19.0-19.9 during December to February and 2 times each in its maximum range of 35.0-35.9 in March and May. Percentage frequency of resident time is given in Table 6.

For the decade 1979-1988, Thiruvananthapuram having a total 85945 hourly temperature data sets. Out of this, February representing 6774, the least and October representing 7362, the highest among the data sets. In this decade, temperature hit 37 times in the minimum range of 20.0-20.9 during December to February and 4 times in its maximum range of 36.0-36.9 in March. Percentage frequency of resident time is given in Table 7.

For the decade 1989-1998, Thiruvananthapuram having a total 78606 hourly temperature data sets. Out of this, February representing 6044, the least and March is representing 6696, the highest among the data sets. In this decade, temperature hit 20 times in the minimum range of 20.0-20.9 during December to February and 15 times in its maximum range of 35.0-35.9 in March to April. Percentage frequency of resident time is given in Table 8.

For the decade 1999-2008, Thiruvananthapuram having a total 86660 hourly temperature data sets. Out of this, August representing 6688, the least and May representing 7440, the highest among the data sets. In this decade, temperature hits 33 times in the minimum range of 20.0-20.9 during December, January and March and once each in its maximum range of 37.0-37.9 during September and February. Percentage frequency of resident time is given in Table 9.

For the remaining period 2009-2012, Thiruvananthapuram having total 35032 hourly temperature data sets. Out of this, February representing 2779, the least and May, July, August and December are representing 2976, the highest among the data sets. In this decade, temperature hit 7 times in the minimum range of 19.0-19.9 in December and January and once in its maximum range of 36.0-36.9 in March. Percentage frequency of resident time is given in Table 10.

The decadal mean is calculated using the formula (A). Linear trend (°C per decade) of decadal mean temperature for Thiruvananthapuram is shown in the Fig. 5. The equation for linear trend of decadal mean temperature will be the characteristic equation for Thiruvananthapuram. That is, $y = 0.159x + 26.81$ projecting the next decadal mean temperature as 27.76 °C.

The non-linear characteristic equation of Thiruvananthapuram is $y = -0.023x^2 + 0.3x + 26.65$, which is projecting the next decadal mean temperature as 27.62 °C only.

$\frac{dy}{dx} = -0.046x + 0.3$ and $\frac{d^2y}{dx^2} = -0.046$, which is negative and shows a reduced rate from the previous decade.

Decadal linear trend (°C per decade) in seasonal (monsoon) mean temperature for Thiruvananthapuram is shown in the Fig. 6. The rate of increase of mean temperature in this period is 0.172 °C per decade. Decadal linear trends (°C per decade) in mean temperature during non-monsoon season are given in Fig. 7. The rate of increase in mean temperature during this period is 0.155 °C per decade, is slightly less than the annual mean trend of 0.159 °C. This may be due to decreasing trend in the rainy days and rain intensity during monsoon season. It is also to mention that the annual trend is suppressed, which may be due to changes in rainfall pattern during non-monsoon period, may require further investigation with rainfall data.

Details regarding the changes taken place in the lower and higher temperature ranges are given in the table 16 and linear trends are shown in the Fig. 9. The resident time of lower temperatures are decreasing at the rate of 1.454% per decade and if the same linear trend continues up to the next four decades, then there will not be significant resident time of temperatures below 24 °C. The resident time of higher temperatures are increasing at the rate of 1.187% per decade and if the same scenario continues up to the next eighty decades, then the temperatures will be above 31 °C only. Percentage frequency of resident time for the lower and higher temperature regime for Thiruvananthapuram during monsoon period is given in Table 17.

3.3. *Features associated with Minicoy*

Minicoy observatory situated at 08° 18' N and 73° 00' E. For the decade 1969-1978, Minicoy having a total 87326 hourly temperature data sets. Out of this, February representing 6840, the least and August and October representing 7440, the highest among the data sets. In this decade, Minicoy temperature hit 29 times in the minimum range of 20.0-20.9 during November to March and once in its maximum range of 34.0-34.9 in May. Percentage frequency of resident time is given in Table 11.

For the decade 1979-1988, out of a total 75799 hourly temperature data sets, February representing 5289, the least and May representing 6570, the highest. In this decade, temperature hit 3 times in the minimum range of 21.0-21.9 during January and 10 times in its maximum range of 34.0-34.9 in April to May. Percentage frequency of resident time is given in Table 12.

For the decade 1989-1998, out of a total 78561 hourly temperature data sets, February representing 6072, the least and July, October and December are representing 6696, the highest among the data sets. In this decade, temperature hit 19 times in the minimum range of 21.0-21.9 during December to February and 29 times in its maximum range of 34.0-34.9 in April to May. Percentage frequency of resident time is given in Table 13.

For the decade 1999-2008, out of a total 86668 hourly temperature data sets, August representing 6690, the least and July representing 7439, the highest among the data sets. In this decade, temperature hit 4 times in the minimum range of 20.0-20.9 during October and December and once in its maximum range of 36.0-36.9 during September. Percentage frequency of resident time is given in Table 14.

For the remaining period 2009-2012, Minicoy having total 32187 hourly temperature data sets. Out of this, October representing 2190, the least and July is representing 2976, the highest among the data sets. In this decade, temperature hits once in the minimum range of 20.0-20.9 in January and 10 times in its maximum range of 34.0-34.9 in April and May. Percentage frequency of resident time is given in Table 15.

The decadal mean is calculated using the formula (A). Linear trend (°C per decade) of decadal mean temperature for Minicoy is shown in the Fig. 5. The equation for linear trend of decadal mean temperature will be the characteristic equation for Minicoy. That is, $y = 0.146x + 27.74$ projecting the next decadal mean temperature as 28.62 °C.

The non-linear characteristic equation of Minicoy is $y = -0.052x^2 + 0.463x + 27.37$, which is projecting the next decadal mean temperature as 28.28 °C.

$\frac{dy}{dx} = -0.102x + 0.463$ and $\frac{d^2y}{dx^2} = -0.102$, which is negative and shows a reduced rate from the previous decade.

Decadal linear trend (°C per decade) in seasonal (monsoon) mean temperature for Minicoy is shown in the Fig. 6. The rate of increase of mean temperature in this period is 0.081 °C per decade. Rainfall activity in monsoon period seems to be the correction factor for the increasing trend in the annual mean temperature. Decadal linear trends (°C per decade) in mean temperature during non-monsoon season are given in Fig. 7. The rate of increase of mean temperature in this period is 0.181 °C per decade.

TABLE 16

Percentage frequency of resident time of the temperature of the head and tail regime

Decade	Mumbai		Thiruvananthapuram		Minicoy	
	< 23 °C	> 31 °C	< 24 °C	> 31 °C	< 25 °C	> 31 °C
1969-78	10.77	8.88	11.78	6.49	8.62	4.09
1979-88	9.05	10.57	7.92	9.35	4.06	6.65
1989-98	8.04	12.30	6.46	9.09	4.72	9.08
1999-08	7.76	12.08	6.58	11.32	3.78	10.65
2009-12	4.96	17.79	5.18	11.44	5.41	11.55

TABLE 17

Percentage frequency of resident time of the temperature of the head and tail regime during monsoon period

Decade	Mumbai		Thiruvananthapuram		Minicoy	
	< 26 °C	> 30 °C	< 24 °C	> 30 °C	< 26 °C	> 30 °C
1969-78	13.75	10.93	12.96	5.70	12.39	7.98
1979-88	12.40	16.04	9.63	6.41	9.56	11.60
1989-98	10.61	18.97	6.94	5.17	11.49	15.86
1999-08	11.62	14.63	7.00	10.63	9.78	18.73
2009-12	9.38	24.24	3.86	10.73	9.94	14.89

Details regarding the changes taken places in the lower and higher temperature ranges are given in the Table 16 and linear trends are shown in the Fig. 10. The resident time of lower temperatures are decreasing at the rate of 0.67% per decade and if the same linear trend continues up to the next six decades, then there will not be significant resident time of temperatures below 25 °C. The resident time of higher temperatures are increasing at the rate of 1.892% per decade and if the same scenario continues up to the next fifty decades, then the temperatures will be above 31 °C only. Percentage frequency of resident time for the lower and higher temperature regime for Minicoy during monsoon period is given in Table 17.

3.4. *Embedded system of climate*

Decadal rate of trend in temperature (°C) for Mumbai, Thiruvananthapuram and Minicoy for annual, non-monsoon and monsoon period is shown in Fig. 11. It is observed from the analysis that the trends in mean temperature during non-monsoon and monsoon periods are increasing at different rates and is significantly higher in non-monsoon period. However, the annual trend in the temperature is lower than the trend in non-monsoon period suggests the influence of rainfall activity on temperature. Any significant change in rainy days and its intensity due to climate change will certainly influence the future temperature pattern. Accelerated increase in trend in case of reduction in rainy days or in intensity, retarded increase in trend or even decreasing trend in case of increase in rainy days or in intensity. This feedback mechanism is given in Fig. 12, which is self explanatory. The trend in rainfall pattern due to climate change is in itself work like a feedback mechanism which controls the future trend in temperature and in effect the climate system as a whole.

4. Conclusions

Trends in the resident temperatures show the shifting towards higher sides including Minicoy. This confirms the effect of global warming irrespective of urban effect. There are significant changes in trends in all the stations even during monsoon season for the entire period. The scenario of significant climate change especially global warming is now well documented and the evidence incontrovertible. Projected climate change over India based on various models in IPCC reports suggests steady increase in temperature. This study has given characteristic equations for Mumbai, Thiruvananthapuram and Minicoy which are projecting the next decadal mean annual temperatures as 28.34 °C, 27.76 °C and 28.62 °C respectively. The rate of trend in temperature change is very high for Mumbai than other cities. The trends, both annual and seasonal, showed increasing tendency in temperature during the second half of the last century. The annual mean temperature at each city has increased. The results are summarized as follows.

(*i*) The resident time of lower temperatures in Mumbai are decreasing at the rate of 0.1291% per year and if the same trends continue up to the next five decades, then there will not be significant resident time for temperatures below 23 °C. At the same time, resident time of higher temperatures are increasing at the rate of 1.933% per decade and if the same scenario continues up to the next fifty decades, then the temperatures will be above 31 °C only.

(*ii*) For Thiruvananthapuram, the resident time of lower temperatures are decreasing at the rate of 1.454% per decade and if the same linear trend continues up to the next four decades, then there will not be significant resident time of temperatures below 24 °C. However, the resident time of higher temperatures are increasing at the rate of 1.187% per decade and if the same scenario continues up to the next eighty decades, then the temperatures will be above 31 °C only.

(*iii*) The resident time of lower temperatures for Minicoy are decreasing at the rate of 0.67% per decade and if the same linear trend continues up to the next six decades, then there will not be significant resident time of temperatures below 25 °C. The resident time of higher temperatures are increasing at the rate of 2.623% per decade and if the same scenario continues up to the next fifty decades, then the temperatures will be above 30 °C only.

(*iv*) Decadal linear increasing trends in mean temperature during non-monsoon season for Mumbai, Thiruvananthapuram and Minicoy are 0.315 °C, 0.155 °C and 0.181 °C per decade respectively.

(*v*) The rate of increase of mean temperature for Mumbai and Minicoy during monsoon season is 0.143 °C and 0.081 °C per decade respectively, are significantly less than the decadal trend in annual mean, which suggests that rainfall activity in monsoon period seems to be the correction factor for the increasing trend in the annual mean temperature. However, the rate of increase of mean temperature for Thiruvananthapuram during monsoon seasonal for the study period is 0.172 °C per decade, is slightly higher than the decadal trend in annual mean. This small trend may be due to decreasing trend in the rainy days over Thiruvananthapuram.

However, lower temperatures of the above cities can break their extremes or some percentage of resident time would still be there for lower temperatures, if suitable synoptic situations arise or if we consider non-linearity in the trend.

(*vi*) The trend in rainfall pattern due to climate change itself is a feedback mechanism for the future climate system.

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