CHAPTER – VIII

URBAN HEAT ISLAND AND CALM WEATHER CONDITIONS

In the large cities high density built-up surface and the urban residential, industrial, transportation and commercial functions generate the heat and induce the temperatures. This phenomenon is scientifically called the urban heat island. The thermo-dynamics of urban heat island intensity plays a crucial role in modifying the other variables of the urban micro climate. In a complex, yet integrated process the temperature rise induces the rainfall amount and frequency. In a combined effect, it also leads to the changes in the urban wind velocity pattern and the urban humidity scenario. The urban heat island intensity along with urban landscape heterogeneity and the resultant wind velocity reduction promote the occurrence of calm weather conditions.

Calm conditions greatly influence the increase in the dwell period of air pollutants in the city atmosphere particularly the canopy layer. Because the dwell period of air pollutants is extended under calm weather conditions, it tends to aggravate the air pollution in the major cities. These processes together create the phenomenon of smog particularly during the winter season in the large cities. Oke (1987)\(^1\) revealed that an anti-cyclonic calm and clear night is followed by a dense muggy morning as well as with the late night smog. Resultantly, the temperature variation between the city centre and the countryside may sometimes exceed up to 12°C. Akbari et al. (2001)\(^2\) highlighted that the increased summer temperatures in the urban heat island also increase the demand of cooling energy and its use. This anthropogenic energy use increases the calm conditions and formation of urban smog.

Voogt and Oke (2003)\(^3\) emphasized that the summertime urban heat islands are most intense when the sky is clear and the winds are calm. They noted that the summer difference in the daytime surface temperature between a highly developed built-up surface and the surrounding rural areas is 10° - 15°C. The corresponding

nocturnal difference in the surface temperature is generally 5° - 10° C. Devi (2005) during a survey conducted at Visakhapatnam city observed that heat islands of higher intensities can be developed only during winter season under calm conditions.

Roth et al. (1989) identified that the atmospheric urban heat islands are most expressed under calm and clear conditions at night whereas surface urban heat island intensities are greater during daytimes. According to United States Environmental Protection Agency the rural – urban temperature differential in the megacities can be as much as 12°C under calm and clear nights. It has been observed that urban heat islands are more emphatically formed during periods of calm weather and clear skies.

I. Calm Weather and Urban Heat Island in Ahmedabad

Mean monthly and seasonal pattern of number of calm days has been enquired in order to estimate their impact on the urban heat island intensity. The mean monthly and seasonal transition of the calm weather conditions has also been evaluated in order to ascertain its impact on the temporal change in urban heat island intensity over a long period of time. Mean monthly and seasonal calm weather changes have been evaluated in relation to average monthly number of calm days and the average seasonal number of calm days.

The study illustrates the growth in the number of morning calm days and the growth in the number of evening calm days. It also examines if there is any relationship between the existing average number of calm days and the extant of change in the number of calm days which could explain the aggravating intensity of urban heat island. Whether there is a linear relationship between the existing number of calm days and the changing number of calm days or there is an inverse relationship between the two.

Average Number of Morning Calm Days in Ahmedabad

Figure 8.1 demonstrates the mean monthly and mean seasonal number of calm days.

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6 Reducing Urban Heat Islands: Compendium of Strategies, Climate Protection Partnership Division, United States Environmental Protection Agency.
Ahmedabad: Mean Monthly and Annual Morning Calm Days (1961-2007)

Source: Computed and Cartographed by the Researcher from IMD Data, Pune.
calm days for the enquiry period of 47 years spanning over 1961-2007. The figure represents the number of morning calm days recorded at 8:30 hours. The monthly number of morning calm days were invariably higher than the number of evening calm days in Ahmedabad. This depicts that the calm weather conditions are more pronounced in the morning as compared to the evening. The largest number of 11.1 calm days was recorded in the month of October while the smallest number of 1.7 calm days was recorded in May. The annual number of calm days was 69.1 on an average.

The winter season average number of calm days has been 31.2 days for the period December to March. This is the largest number of calm days in any season. The intra-seasonal variation in the number of calm days ranged from 8.7 calm days in January to 7.1 calm days in March. The early summer number of calm days for April and May were recorded 4.8 days. The number of morning calm days for the monsoon season was recorded 13.6 days during June to September. The intra-monsoonal number of calm days variation ranged from 2.3 days in June to 4.8 days in September. The average number of calm days in the retreating monsoon months of October to November was 19.5 days.

Growing Number of Morning Calm Days in Ahmedabad

Figure 8.2 reveals the transition or growth in the number of morning calm days over a period of 47 years encompassing 1961-2007. It depicts a considerable monthly variation in the rise of number of morning calm days. The largest 4.922 increase in the number of morning calm days was recorded in October while the smallest 1.334 calm days increase was reported in February. The annual number of morning calm days grew to 32.614 days in Ahmedabad over the enquiry period.

The average number of winter season morning calm days recorded an increase of 10.856 days during December to March. This was the largest seasonal growth for any season. One could identify a linear relationship between the largest number of winter morning calm days as well as the largest growth in the number of morning calm days in winter. The intra-seasonal variation in the rise of number of calm days ranged from 4.002 days in January to 1.334 calm days in February.
Ahmedabad: Transition in Mean Monthly and Annual Morning Calm Days
(1961-2007)

Source: Computed and Cartographed by the Researcher from IMD Data, Pune.
The early summer increase in the number of morning calm days has been recorded 4.048 days during April and May. The average number of monsoon season morning calm days recorded a growth of 9.974 days from June to September. This has rendered the monsoon season increasingly sultry in Ahmedabad. The intra-monsoonal variation in the growth of morning calm days ranged from 1.61 days in June to 4.416 days in September.

Here, it is once again significant to note that the month of September, which is already hot and sultry reveals a further tendency of enhanced sultry conditions by virtue of considerable increase in the number of calm days. The average increase in the number of morning calm days recorded a growth of 7.728 days from October to November.

Average Number of Evening Calm Days in Ahmedabad

Figure 8.3 depicts the mean monthly and mean seasonal number of evening calm days for the enquiry period of 47 years spanning over 1961-2007. The figure represents the number of evening calm days recorded at 17:30 hrs. The monthly number of evening calm days was invariably smaller than the number of morning calm days in Ahmedabad. It shows that the calm weather conditions are less pronounced in the evening in comparison to the morning weather.

The largest number of 8.6 evening calm days was recorded in the month of October. While the smallest number of 0.6 calm days were recorded in May. The annual number of evening calm days has been 42.4 days on an average. The winter season average number of evening calm days has been 11.3 days for the period December to March. Winter is the season of a large number of evening calm days. This is in continuity of the largest number of morning calm days as well the winter season.

The intra-seasonal winter variation in the number of evening calm days ranged from 5.8 calm days in December to 1.4 calm days in February. The early summer number of calm days for April and May were recorded 2.1 days. The number of evening calm days for the monsoon season was recorded 12.2 days during June to September. The intra-monsoonal number of calm days variation ranged from 1.3 calm
Ahmedabad: Mean Monthly and Annual Evening Calm Days
(1961-2007)

Source: Computed and Cartographed by the Researcher from IMD Data, Pune.
days in June to 4.8 calm days in September. The average number of evening calm days in the retreating monsoon months of October to November was 16.9 days.

**Growing Number of Evening Calm Days in Ahmedabad**

Figure 8.4 indicates the transition in the number of evening calm days over a period of 47 years extending from 1961-2007. It depicts a considerable monthly variation in the rise of evening calm days. The largest 5.658 increase in the number of calm days was recorded in October while the smallest 0.414 calm days increase was reported in May. The annual number of evening calm days grew into 36.018 days in Ahmedabad over 47 years. The average number of winter season evening calm days recorded an increase of 12.374 days during December to March. This was a large seasonal growth among all the seasons. One can examine a considerable linear relationship between the number of evening calm days in winter and the number of days of corresponding transition.

The intra-seasonal variation in the rise of calm days ranged from 4.462 days in December to 1.288 days in February. The early summer increase in the number of evening calm days has been recorded 2.76 days during April and May. Monsoon season recorded a growth of 9.66 evening calm days from June to September. This would render the monsoon season evening and nights increasingly sultry in Ahmedabad. The intra-monsoonal variation in the growth of evening calm day ranged from 1.15 days in June to 3.496 days in August and just closely followed by September with 3.45 days. The pattern of intra-monsoonal evening growth in the number of calm days closely resembled with the changing pattern of morning calm days. The increase in the number of evening calm days recorded a growth of 11.27 days during October and November.

**Growing Number of Annual Calm Days in Ahmedabad**

Figure 8.5 depicts a synoptic view of the growth in the average annual number of calm days over a period of 47 years for enquiry. It shows a considerable increase of 32.614 morning calm days on an yearly average. Similarly, the average annual evening calm days showed a still higher growth of 36.018 calm days. The average annual evening growth of calm days is even higher than the morning calm days. It suggests that the evenings and the nights in Ahmedabad would be even more sultry.
Ahmedabad: Transition in Mean Monthly and Annual Evening Calm Days
(1961-2007)

Source: Computed and Cartographed by the Researcher from IMD Data, Pune.

Fig. 8.4
Ahmedabad: Rise in Annual Number of Calm Days
(1961-2007)

Source: Computed and Cartographed by the Researcher from IMD Data/India

Fig. 8.5
and unbearable in the total scenario of urban heat island. This would render an additional adverse effect on the micro urban climate.

II Calm Weather and Urban Heat Island in Hyderabad

In order to examine the changing micro climate of Hyderabad city, mean monthly and seasonal pattern of calm days has been enquired. The mean monthly and seasonal transition of the calm weather conditions has also been evaluated. It is intended to examine whether there is any relationship between the existing number of calm days and the number of changing calm days. It also evaluates whether there is a linear relationship or an inverse relationship between the existing number of calm days and the number of changing calm days.

Average Number of Morning Calm Days in Hyderabad

Figure 8.6 depicts the mean monthly and mean seasonal number of morning calm days for the enquiry period of 50 years spanning over 1961-2010. The figure represents the number of morning calm days recorded at 8:30 hours. The monthly number of morning calm days was invariably higher than the number of evening calm days in Hyderabad. This depicts that the calm weather conditions are more pronounced in the morning as compared to the evening. The largest number of 14.9 calm days was recorded in the month of December. While the smallest number of 0.4 calm days were recorded in June and July.

The annual number of calm days was 76.7 on an average. The winter season average number of calm days has been 45.5 days for the period December to March. This is the largest number of calm days in any season. The intra-seasonal winter variation in the number of calm days ranged from 14.9 calm days in December to 8.2 calm days in March. The early summer number of calm days for April and May were recorded 5.9 days. The number of morning calm days for the monsoon season was recorded 14.9 days during June to October. The intra-monsoonal number of calm days variation ranged from 0.4 days in June to 9.7 days in October. The average number of calm days in the month of November was 10.5 days.

Growing Number of Morning Calm Days in Hyderabad

Figure 8.7 reveals the transition or growth in the number of morning calm
Hyderabad: Mean Monthly and Annual Morning Calm Days
(1961-2010)

Source: Computed and Cartographed by the Researcher from IMD Data, Pune.

Fig. 8.6
Hyderabad: Transition in Mean Monthly and Annual Morning Calm Days (1961-2010)

Number of Days

January: 2.205
February: 3.038
March: 3.234
April: 4.263
May: 1.764
June: 1.029
July: 0.49
August: 2.058
September: 3.92
October: 3.675
November: 2.156
December: 4.312
Annual: 32.695

Source: Computed and Cartographed by the Researcher from IMD Data, Pune.

Fig. 8.7

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days over a period of 50 years encompassing 1961-2010. It depicts a considerable monthly variation in the rise of number of morning calm days. The largest 4.312 increase in the number of morning calm days was recorded in December while the smallest 0.49 calm days increase was reported in July. The annual number of morning calm days grew to 32.095 days in Hyderabad over the enquiry period.

The average number of winter season morning calm days recorded an increase of 12.789 days during December to March. This was the largest seasonal growth for any season. One could identify a linear relationship between the largest number of winter morning calm days and the largest growth in the number of morning calm days in winter. The intra-seasonal variation in the rise of number of calm days ranged from 4.312 days in December to 2.205 calm days in January.

The early summer increase in the number of morning calm days has been recorded 6.027 days during April and May. The average number of monsoon season morning calm days recorded a growth of 11.172 days from June to October. This has rendered the monsoon season increasingly sultry in Hyderabad. The intra-monsoonal variation in the growth of morning calm days ranged from 0.49 days in July to 3.92 days in September. Here, it is once again significant to note that the month of September which is already hot and sultry reveals a further tendency of enhanced sultry conditions by virtue of considerable increase in the number of calm days. The average increase in the number of morning calm days recorded a growth of 2.156 days for November.

**Average Number of Evening Calm Days in Hyderabad**

Figure 8.8 depicts the mean monthly and mean seasonal number of evening calm days for the enquiry period of 50 years spanning over 1961-2010. The figure represents the number of evening calm days recorded at 17:30 hours. The monthly number of evening calm days was invariably smaller than the number of morning calm days in Hyderabad. It shows that the calm weather conditions are less pronounced in the evening in comparison to the morning weather. The largest number of 2.8 evening calm days was recorded in the month of April. While the smallest number of 0.7 calm days were recorded in July. The annual number of evening calm days has been 19.3 days on an average.
Fig. 8.8

Hyderabad: Mean Monthly and Annual Evening Calm Days
(1961-2010)

Source: Computed and Cartographed by the Researcher from IMD Data, Pune.
The winter season average number of evening calm days has been 5.9 days for the period of December to March. Winter is the season of a large number of evening calm days. This is in continuity of the largest number of morning calm days also during the winter season. The intra-seasonal winter variation in the number of evening calm days ranged from 1.2 calm days in December to 2.0 calm days in March.

The early summer number of calm days for April and May were recorded 4.7 days. The number of evening calm days for the monsoon season was recorded 7.4 days during June to October. The intra-monsoonal number of calm days variation ranged from 0.7 calm days in July to 2.1 calm days in September. The average number of evening calm days in the month of November was 1.2 days.

**Growing Number of Evening Calm Days in Hyderabad**

Figure 8.9 indicates the transition in the number of evening days over a period of 50 years extending from 1961-2010. It depicts a considerable monthly variation in the rise of evening calm days. The largest increase of 4.361 calm days was recorded in May while the smallest increase of 1.617 calm days was reported in July. The annual number of evening calm days grew into 34.594 days in Hyderabad over 50 years. The average number of winter season evening calm days recorded an increase of 10.535 days during December to March. This was a large seasonal growth among all the seasons. One can examine a considerable linear relationship between the number of evening calm days in winter and the number of days of corresponding transition.

The intra-seasonal variation in the rise of calm days ranged from 3.43 days in December to 2.009 days in February. The early summer increase in the number of evening calm days has been recorded 7.546 days during April to May. The number of monsoon season evening calm recorded a growth of 12.936 days from June to October. This would render the monsoon season evening and nights increasingly sultry in Hyderabad. The intra-monsoonal variation in the growth of evening calm days ranged from 1.617 days in July to 3.822 days in September. The pattern of intra-monsoonal evening growth in the number of calm days closely resembled with the changing pattern of morning calm days. The increase in the number of evening calm days recorded a growth of 3.626 in the month of November.
Hyderabad: Transition in Mean Monthly and Annual Evening Calm Days
(1961-2010)

Source: Computed and Cartographed by the Researcher from IMD Data, Pune.

Fig. 8.9

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Growing Number of Annual Calm Days in Hyderabad

Figure 8.10 depicts a synoptic view of growth in the average annual number of calm days over a period of 50 years of enquiry period. It shows a considerable increase of 32.095 morning calm days on an yearly average. Similarly, the average annual evening calm days showed a still higher growth of 34.594 calm days. The average annual evening growth of calm days is even higher than the morning calm days. It suggests that the evenings and the nights in Hyderabad would be even more sultry and unbearable in the total scenario of urban heat island. This would have an additional adverse effect on the micro urban climate.

III Calm Weather and Urban Heat Island in Bangalore

In order to examine the changing micro climate of Bangalore city, mean monthly and seasonal pattern of calm days has been enquired. The mean monthly and seasonal transition of the calm weather conditions has also been evaluated. It is intended to examine whether there is any relationship between the existing number of calm days and the extant of change in the number of calm days. It also evaluates whether there is a linear relationship or an inverse relationship between the existing number of calm days and the number of changing calm days.

Average Number of Morning Calm Days in Bangalore

Figure 8.11 depicts the mean monthly and mean seasonal number of calm days for the enquiry period of 52 years spanning over 1961-2012. The figure represents the number of morning calm days recorded at 8:30 hours. The monthly number of morning calm days was invariably higher than the number of evening calm days in Bangalore. This depicts that the calm weather conditions are more pronounced in the morning as compared to the evening.

The largest number of 7.3 calm days was recorded in the month of March. While the smallest number of 0.4 calm days were recorded in June. The annual number of calm days was 45.4 on an average. The winter season average number of calm days has been 18.3 days of the period December to March. This is the largest number of calm days in any season.
Fig. 8.10
Bangalore: Mean Monthly and Annual Morning Calm Days (1961-2012)

Source: Computed and Cartographed by the Researcher from IMD Data, Pune.

Fig. 8.11
The intra-seasonal variation in the number of calm days ranged from 2.6 days in December to 7.3 days in March. The early rainy period number of calm days for April and May were recorded 9.6 days. The number of morning calm days for the advancing monsoon period was recorded 2.2 days during June to August.

The intra-seasonal number of calm days summer variation ranged 0.4 days in June to 1.2 days in August. The average number of morning calm days for the retreating monsoon period was recorded 15.3 days during September to November. The intra-seasonal number of calm days variation ranged from 3.5 days in September to 6.8 days in October.

**Growing Number of Morning Calm Days in Bangalore**

Figure 8.12 reveals the transition or growth in the number of morning calm days over a period of 52 years encompassing 1961-2012. It depicts a considerable monthly variation in the rise of number of morning calm days. The largest increase in the number of morning calm days 7.395 was recorded in March while the smallest increase of 0.561 calm days was reported in May. The annual number of morning calm days grew to 33.711 days in Bangalore over the enquiry period.

The average number of winter season morning calm days recorded an increase of 17.289 days during December to March. This was the largest seasonal growth for any season. One could identify a linear causal relationship between the largest number of winter morning calm days and the largest growth in the number of morning calm days in winter.

The intra-seasonal winter variation in the rise of number of calm days ranged from 2.856 days increase in January to 7.395 calm days in March. The early rainy period increase in the number of morning calm days has been recorded 1.938 days during April and May. The average number of advancing monsoon period morning calm days recorded a growth of 3.57 days from June to August.

The intra-seasonal number of calm days variation in the growth of morning calm days ranged from 0.918 days in July to 1.581 days in August. The average number of morning calm days for the retreating monsoon period was recorded 10.863 days during September to November. The intra-seasonal number of calm days
Bangalore: Transition in Mean Monthly and Annual Morning Calm Days
(1961-2012)

Source: Computed and Cartographed by the Researcher from IMD Data, Pune.

Fig. 8.12
variation in the growth of morning calm days ranged from 2.295 days in September to 5.202 days in October.

**Average Number of Evening Calm Days in Bangalore**

Figure 8.13 depicts the mean monthly and mean seasonal number of evening calm days for the enquiry period of 52 years spanning over 1961-2012. The figure represents the number of evening calm days recorded at 17:30 hours. The monthly number of evening calm days was invariably smaller than the number of morning calm days in Bangalore. It shows that the calm weather conditions are less pronounced in the evening in comparison to the morning weather. The largest number of 7.5 evening calm days was recorded in the month of October. While the smallest number of 0.9 calm days were recorded in June. The annual number of evening calm days has been 47.0 days on an average. The winter season average number of evening calm days has been 15.2 days for the period December to March. Winter is the season of a large number of evening calm days. This is in continuity of the largest number of morning calm days also during the winter season.

The intra-seasonal variation in the number of evening calm days ranged from 3.5 calm days in December to 4.3 calm days in March. The early rainy period number of calm days for April and May were recorded 9.8 days. The number of evening calm days for the advancing monsoon period was recorded 3.6 days during June to August. The intra-seasonal number of calm days variation ranged from 0.9 days in June to 1.7 days in August. The average number of evening calm days for the retreating monsoon period was recorded 18.4 days during September to November. The intra-seasonal number of calm days variation ranged from 5.1 days in September to 7.5 days in October.

**Growing Number of Evening Calm Days in Bangalore**

Figure 8.14 indicates the transition in the number of evening days over a period of 52 years extending from 1961-2012. It depicts a considerable monthly variation in the rise of evening calm days. The largest increase in the number of calm days was recorded 8.313 in October while the smallest increase of 1.071 calm days was reported in February.
Fig. 8.13

Bangalore: Mean Monthly and Annual Evening Calm Days
(1961-2012)

Source: Computed and Cartographed by the Researcher from IMD Data, Pune.
Bangalore: Transition in Mean Monthly and Annual Evening Calm Days
(1961-2012)

Source: Computed and Cartographed by the Researcher from IMD Data, Pune.

Fig. 8.14

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The annual number of evening calm days grew up to 44.523 days in Bangalore over a period of 52 years. The average number of winter season evening calm days recorded an increase of 10.149 days during December to March. This was a large seasonal growth among all the seasons. One can examine a considerable linear relationship between the number of evening calm days in winter and the number of days of corresponding transition.

The intra-seasonal winter variation in the rise of calm days ranged from 1.071 days in February to 4.08 days in March. The early rainy period increase in the number of evening calm days has been recorded 7.395 days during April to May. The average number of advancing monsoon period evening calm days recorded a growth of 6.579 days from June to August. The intra-seasonal number of calm days variation in the growth of evening calm days ranged from 1.224 days in June to 3.315 days in August. The average number of evening calm days for the retreating monsoon period was recorded 20.4 days during September to November. The intra-seasonal number of calm days variation in the growth of evening calm days ranged from 6.018 days in September to 8.313 days in October.

**Growing Number of Annual Calm Days in Bangalore**

Figure 8.15 depicts a synoptic view of the growth in the average annual number of calm days over an enquiry period of 52 years. It shows a considerable increase of 33.711 morning calm days on an yearly average. Similarly, the average annual evening calm days showed a still higher growth of 44.523 calm days. The average annual evening growth of calm days is even higher than the morning calm days. It suggests that the evening and the nights in Bangalore would be even more sultry and unbearable in the total scenario of urban heat island. This would render an additional adverse effect on the micro urban climate.
Augurago: Rise in Annual Number of Calm Days (1961-2012)

Fig. 8.15