CHAPTER - V

RAINFALL TRANSITION IN THE MEGACITIES

There is considerable evidence on the relationship between the urban heat island and the changing pattern of rainfall in different urban habitats. There exists a consensus on the role of urban layout, nature of urban land use, built-up density and the aerosols in the city atmosphere influencing the occurrence of rainfall. The rural-urban rainfall differential is closely associated with the urban heat island and its atmospheric pressure.

Large cities have a high built-up density of heat absorbing materials like concrete, steel, glass and asphalt. At times, temperatures in large cities may be 6°C to 8°C higher than sub-urban landscapes and rural surroundings. This increased temperature may provide a source of unstable air. As the air over a city is warmer than the air in the surroundings, the warmer city air tends to rise. As the warmer city air rises, it cools and forms rain-bearing clouds, which induce more rainfall in the large cities than the corresponding countryside. City environments have induced processes of rainfall as compared to the countryside.

The tall buildings in the large cities lead to the lifting of warm, moist, surface air into cooler air. This process tends to develop induced rains. The thermodynamic environment of the urban heat island tends to produce rising air, which forms more rain clouds over the large cities during the rainy season. Hence, the city landscape has a definite impact on the rains.

I  Global Evidence of City Rains

The following studies highlight the influence of urban heat island on the city rains:

Tom Bell¹ (2004) the climate scientist of NASA’s Goddard Space Flight Center explains the impact of urban pollution on rain. He clarifies that the city

pollution may affect the cloud formation and rainfall. Water vapour to condense into rain clouds needs dirt or aerosol nuclei for rainfall.

He further explains that in the natural world, cloud forming aerosols are derived from sea salt, dust and pollen which are large particles but the pollution aerosols over the urban atmosphere are usually smaller and more numerous to produce more rainfall than the natural aerosols. With lots of urban pollutants, the water vapour coalesces into many tiny droplets instead of larger size raindrops.

Bell further says that the impact of rain varies depending on where the clouds form. He also shows the exception that in some cases, urban aerosols suppress rain but in most cases, they tend to increase it.

Atmospheric scientists are still working on the question of what causes the rainfall difference between the urban areas and rural surroundings.

Bell and others believe that the temperature difference between the air near the ground and the atmosphere above may be one key difference. Bubbles of hot air are formed over the land and rise like the ones in the boiling water. The rising air cools, and many tiny droplets form around urban aerosols. These small drops are not large enough to fall, so the storms do not tend to produce rain every time.

More rain can occur when the heated air forms over a very warm area. The bubble of heated air rises faster and climbs higher in the atmosphere.

Bell says that because of urban pollution, droplets that would normally fall out at a lower elevation are smaller and go higher. When high in the atmosphere, the tiny water droplets turn into ice. For the transition state to happen from liquid to solid, the water molecules have to release heat. The added heat kicks in an afterburner, and the bubbles of air are pushed up higher and faster.

He explains that the extra boost makes the storm act like a vacuum cleaner. Something needs to replace the rising air, so more moist air is sucked up. Hence, this vacuum cleaner effect allows the storm to pull in more material to work with than it would have without the urban aerosols, resulting in more rainfall. He further adds that

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2 Ibid
3 Ibid
4 Ibid
the effect only happens when fast-rising air would form a thunderstorm and when the air near the surface is moist.

The key to discerning how aerosols, city structures, city heat and weather systems interact, may very well be understood with NASA’s fleet of Earth-Observing Satellites, which are providing unprecedented information about land use, cloud structure, rainfall and aerosols that can then be integrated into models to sort out the intricacies of urban rain. There is a need for integrated observing systems like Aqua, CALIPSO, Cloudsat, TRMM and the Global Precipitation Measurement Mission along with models to answer these integrated questions.\(^5\)

Shepherd et al. \(^6\) (2002) noticed the apparent urban rain anomaly in the first place from the Tropical Rainfall Measuring Mission (TRMM) satellite, which carries the world’s only space-based precipitation radar. TRMM’s Precipitation Radar bounces radio waves through the atmosphere to measure rainfall. TRMM radar has an edge over the other radar systems in a way that the other radar systems are ground-based, and thus, have a limited range. Whereas, TRMM can observe everywhere between about 40 degrees north and south latitudes. The rain data analysis can be extended to even higher latitudes when combined with GOES weather satellite and rain gauge data. TRMM’s estimates are more pioneering because they can be compared from the estimates in one city to another city, which is not easy to do with two different ground-based systems.

Shepherd et al. \(^7\) (2002) focused on five cities in the south-central and southeastern United States and tried to isolate the concept that the urban environment was the only thing affecting the circulation. He found that the amount of rain that fell per hour was as much as 20 per cent greater in grids that were downwind of cities than it was in grids upwind of the city. He further verified that urban rainfall was real and TRMM could detect it.

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\(^7\) Ibid
Steve Burian \(^8\) (2003) a hydrologist at the University of Utah, says that the appreciable work that Marshall did with TRMM satellite data to analyze the signature of urban areas started a lot of people to think in different ways that they can relate space-borne rainfall data to different urban signatures.

Along the coast of Texas, a sea breeze carries moist air inland in the afternoons and summer rain forms when the moist air piles up along the curves in the coastline carved out by various inlets. Thus, Shepherd\(^9\) (2003), concludes that, “the sea breeze interacts with the urban circulation to create an anomaly.”

Burian and Shepherd \(^10\) (2005) used the historical gauge data to confirm that the per cent occurrence of rainfall around Houston had increased in the post-urban Houston as compared to pre-urban Houston. Hence, they revealed that the city of Houston might have shifted the time of likely occurrence of storm until later in the afternoon. The rainfall had increased downwind of the city. The pre-urban rain-gauge data shows a spread in rainfall over a greater part of the day. Whereas, the post-urban rain-gauge data revealed that more of the day’s rain was concentrated in a narrower time window that peaked at around 4:00 p.m.

Shepherd\(^11\) (2005) detected an increased rainfall downwind of Phoenix, a rapidly growing city in arid Arizona. Rising air from Phoenix’s urban heat island may be interacting with nearby mountains to influence the summer monsoon.

Shepherd\(^12\) (2006) suggested that smaller cities have a different effect than larger cities. With a 2025 projected surface area of Houston, a much larger heat island is generated and as much of that bifurcated flow over the city is not seen. Cloud and

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9 Ibid.


rainfall concentrate over the urban areas as opposed to the downwind area as proposed by Shepherd\textsuperscript{13} (2006).

According to the United Nations Population Division \textsuperscript{14}(2005), the percentage of people living in cities is expected to increase from 48.8 per cent to 59.9 per cent between 2005 and 2030. On these lines, Shepherd \textsuperscript{15} continues that “aggregating this to every city in the world, it certainly has to have an effect on the overall global climate”.

There are implications definitely for agriculture, urban planning, water resource management, as well as for weather and climate forecasting. Jim and Shepherd \textsuperscript{16}(2005) assert that the weather forecast models should include urban land surfaces into consideration.

By understanding the phenomena of urban rain, weather forecast for heavily populated regions could be improved. Moreover, accurate warming of potentially flood-producing rains could save human life and property.

Shepherd\textsuperscript{17} (2006) emphasizes that cities impact rainfall and they can create their own rain and storms. He explains that in big cities along the U.S. Gulf Coast, during the summer, weather tends to be generated by local processes: hot, humid air piles up along the face of a mountain, triggering a thunderstorm, cool moist air blows off a lake collides with hot air over land, and rain clouds are formed.

\begin{flushleft}
\textsuperscript{13} Ibid.
\textsuperscript{16} Ibid.
\end{flushleft}
Shepherd\textsuperscript{18} (2005) explains the need of three basic ingredients for the formation of clouds and rainfall. Firstly, air should be unstable, which happens when the air is warmer than the air that surrounds it. Secondly, a source of lift is required such as sea breeze, or a mountain or a cold front or even a city. Lastly, if there is enough moisture in the rising, cooling air, the water vapour will condense into clouds and eventually rainfall will occur.

Burian and Shepherd\textsuperscript{19} (2005) examined the effect of urbanization on the diurnal rainfall pattern in Houston, U.S.A. They made a temporal analysis of changing rainfall pattern from 1940 to 1958 and from 1984 to 1999. The former rainfall pattern was evaluated when Houston was a small city and did not have a note-worthy urban heat island effect. The latter rainfall analysis was made during 1984-1999 when Houston was a burgeoning city with cognizable urban heat island intensity. The results indicated that the diurnal rainfall pattern in the later phase of metropolitan Houston was much different than that found in the pre-urbanization phase.

In the first phase, the downwind rainfall was 59 per cent greater from noon to midnight but the upwind rainfall was only 30 per cent greater from noon to midnight. The overall urban area had approximately 80 per cent more rainfall from noon to midnight during the warm season than the surrounding countryside. Ever since the induced urban heat island effect, the rainfall increase in the urban area is significantly higher in the afternoon time. The average rainfall during the warm season increased by 25 per cent from the pre-urban to post-urban period. The amount of rainfall decreased by 8 per cent in the upwind region.

Evaluation of urban heat island induced changes in the rainfall pattern play an important role in the weather prediction flood forecasting and water management. There is a need for further studies on the urban influences on rainfall pattern.


Shepherd et al.\textsuperscript{20} (2002) performed a unique analysis of rainfall rates measured by the precipitation radar (PR) aboard the satellite Tropical Rainfall Measuring Mission (TRMM) for a number of cities such as Atlanta, Montgomery, Dallas, Waco and San Antonio. This study found that there was an average 28 per cent increase in mean rainfall in the urban impact zone in comparison to an upwind control area. Bornstein and Lin\textsuperscript{21}, (2000), Thielen et al.\textsuperscript{22}(2000), Adegoke et al.\textsuperscript{23}(2001), and Rozoff et al.,\textsuperscript{24}(2003) in their recent numerical modeling studies have also shown the influence of urban heat island on the enhanced daytime thunderstorm formation.

Chagnon\textsuperscript{25} (1979) noted an increased precipitation within the city downtown as well as 50-75 km downwind to the city.

Ramanathan et al.\textsuperscript{26}(2001) had argued contradictory relationship between the urban heat island and the rainfall pattern. They noted that in the urban areas, there is a reduced rainfall due to cloud microphysics.

Rosenfeld\textsuperscript{27} (1999) suggested that the cloud microphysics in response to increased urban aerosols might reduce the amount of rainfall. However, Shepherd et


al. 28(2002) emphasized that the local dynamics and thermodynamics in the urban heat island induced convergence zone along with a destabilized boundary layer may enhance the urban rainfall.

On an average, the urban areas receive higher daily rainfall during the afternoon and early evening in comparison to upwind and downwind areas.

II Changing Monsoon Behavior in the Megacities

Monsoon is globally the most powerful rain-bearing phenomenon. It is a distinctly powerful atmospheric feature of seasonal rainfall pattern. The monsoon behavior, however, gets fairly moderated in the extensive urban environments. Large cities considerably affect the amount and occurrence of rainfall in their ambit. Urban rain is induced by combustion source and air condition exhausts, which lead to the humidity rise in the city atmosphere. Relatively higher temperatures induce the thermal convection. Increased concentration of aerosols and condensation nuclei improve the dwell period of clouds and the resultant rains. Indian Monsoon has a duration of 120 days from June to September. However, there are recent evidences of behavioral changes in the monsoon. There is a new trend of delayed onset of monsoon in the interior of the sub-continent. On the other hand, the behavior of monsoon peak seems to shift onwards. October rains have an increased tendency. Monsoon behavior is characterised with increased rainfall variability.

The monsoon behavior in the three megacities of Ahmedabad, Hyderabad and Bangalore has a variable character. Ahmedabad experiences a strictly defined rainy season with a comparatively lowest number of rainy days from the southwestern monsoon of the Arabian Sea. Hyderabad further south in the peninsula has higher number of rainy days than Ahmedabad. Rains in Hyderabad are the result of Bay of Bengal branch of monsoon. Bangalore is the southern most megacity of peninsular India. As Bangalore is located on the dissected plateau of Karnataka, it is oriented to


both the advancing and the retreating monsoons of Bay of Bengal. Bangalore experiences double maxima of rains.

Enquiring the monsoon behavior over the large cities is of tremendous application in the water resource management. The landscape and heterogeneous surface of large cities greatly influences the behavior of pre-monsoon rains from January to May, southwest monsoon from June to September and post monsoon rains from October to December.

A changing rainfall pattern and its impact on surface water resources is a crucial climatic problem of hydrological planning that cities are facing (Dikpal and Prasad, 2014). In the large cities, there are intra-city variations in the occurrence and amount of rainfall. Vyas et al., 2012 have also noted a strong indication of rainfall changes at regional and local level in response to city meteorology. Most of the rainfall of central peninsular India is confined to the advancing southwest monsoon.

### III Mean Annual and Monthly Rainfall Transition in Ahmedabad

Mean annual and monthly frequency and transition of rainfall in Ahmedabad has been probed for the period 1961-2007. The mean annual rainfall occurrence is 792 mm in this city. Ahmedabad experiences comparatively the shortest rainy season, which is sharply confined to four months from June to September. As the annual rainfall distribution has high variability, a linear regression analysis was not performed to monitor any reliable changing trend in its occurrence. Under this constraint, figure 5.1 depicts the mean annual rainfall frequency for a period of 47 years. The mean annual rainfall has been calculated as 792 mm.

Greater rainfall variability shows more number of years with below normal rainfall and less number of years with above normal rainfall. In view of this situation, it would be significant to examine whether the amount of rainfall and the number of rainy days have increased or decreased in Ahmedabad. It would depict crucial changes in rainfall pattern. The lowest annual rainfall was recorded 284 mm in 1968 while the highest rainfall was experienced as 1306 mm in 1997. The year 1997 experienced much above normal rainfall in all the rainy months with an exceptionally
Ahmedabad: Mean Annual Rainfall Frequency and Trends
(1961 - 2007)

Sources: Computed and Cartographed by the Researcher from DIB Data, Pune.

Fig. 5.1
high rainfall in the first rainy month of June. The absolute range between the lowest
and the highest rainfall depicted 4.6 times variation. A five-year moving averages
were taken to ascertain the pattern of rainfall homogeneity and regularity. A compact
monsoon season of 4 months in Ahmedabad experienced 752.84 mm or 95 per cent of
the mean annual rainfall. The moving averages identified the lowest homogeneity in
the annual rainfall pattern. This occurrence of rainfall has a great bearing on the water
resource management in the city.

Figure 5.2 illustrates the mean monthly rainfall frequency for the first month
i.e. monsoon onset month of June for the period 1961-2007. June being the month of
the onset of monsoon is likely to have highest rainfall variability. This is because the
monsoon does not stabilize in the take-off month. The mean seasonal rainfall has been
calculated as 752 mm. Greater rainfall variability in this monsoon onset month reveals
a much higher number of below normal rainfall years and lesser number of above
normal rainfall years. In response to this situation, it would be crucial to examine
whether the amount of rainfall and the number of rainy days have increased or
decreased in the month of June. It would reveal significant changes in the rainfall
pattern. The average monthly rainfall of June has been 119.5 mm, which is only 15.87
per cent of the four-month rainy season. This occurrence of rainfall is of considerable
consequence on the water resource management in the city of Ahmedabad.

Figure 5.3 demonstrates the mean monthly rainfall frequency for well inside
the monsoon month of July for the period 1961-2007. As July happened to be the core
month of monsoon rains, it is likely to have a comparatively lesser rainfall variability.
This is because the monsoon comes in to swing and is stabilized in this month.
Drought uncertainty, however, looms large at any time and at every place in the
monsoon regime. A lesser rainfall variability in the core monsoon month of July can
be seen because of an almost equal number of above normal rainfall years in
comparison to below normal rainfall years.

In view of this condition, it would be important to assess whether the amount
of rainfall and the number of rainy days have increased or decreased or remained
almost static in the month of July. This situation would highlight the changing pattern
of rainfall, if any. The average monthly rainfall of July has been recorded 280.93 mm
out of the mean seasonal rainfall of 752.84 mm. This accounts to the highest 37.31 per
Fig. 5.2
Fig. 5.3

Ahmedabad: Mean Monthly July Rainfall Frequency and Trends (1961-2007)
cent rain in July. Hence, July is the rainiest month with highest rainfall reliability. July 1987 recorded the extreme lowest of 35.8 mm rainfall, which was only 12.74 per cent of its monthly average. On the other hand, July 1977 recorded the extreme highest of 646 mm i.e. 230.12 per cent of the monthly average. This rainfall behavior has a significant bearing on the water availability and water resource management in the megacity of Ahmedabad.

Figure 5.4 represents the mean monthly rainfall frequency for the core monsoon month of August for the period 1961-2007. As August also happens to be the well-established month of monsoon season, it is also likely to have a comparatively lesser rainfall variability. This is because the monsoon has come into its swing and has got established by this month. As drought is the most characteristic feature of seasonal monsoon regime, drought likelihood remains moderately high even in this high rainfall month. A lesser rainfall variability in this core monsoon month of August is a fair possibility despite lesser number of above normal rainfall years than the below normal rainfall years.

In this situation, it would be significant to estimate whether the amount of rainfall and the number of rainy days have undergone any perceptible change in this month. This condition would demonstrate the changing pattern of rainfall under the influence of urban heat island. The average monthly rainfall of August has been recorded 241.83 mm out of the mean seasonal rainfall of 752.84 mm. This amounts to the second highest percentage of 32.12 in August. Further, August 1999 recorded the lowest extreme of 35.7 mm rainfall, which was as low as 14.76 per cent of its monthly average. August 1990, on the other hand, recorded highest extreme of 609.8 mm rainfall. This was 252.16 per cent of its monthly average. This rainfall pattern carries a crucial bearing on the water availability and the water resource management in the megacity.

Figure 5.5 shows the mean monthly rainfall frequency of September which is the last rainy month of retreating monsoon. It depicts the rainfall frequency for the period 1966-2007. September being the month of retreating monsoon has every likelihood of inherently high rainfall variability. This is because the monsoon regime is dissipating and phasing out in its last month. Drought likelihood is very high in this month in case of early and abrupt withdrawal of monsoon. The greater rainfall
Ahmedabad: Mean Monthly August Rainfall Frequency and Trends
(1961 - 2007)

Fig. 5.4
Ahmedabad: Mean Monthly September Rainfall Frequency and Trends (1961-2007)

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

Fig. 5.5
variability in this retreating monsoon month is due to the fact that, the number of below average rainfall years in September are much higher than the number of above normal rainfall. In response to this situation, it would be quite revealing to enquire whether the amount of rainfall and the number of rainy days have increased or decreased in this month of retreating monsoon. It may also reveal the crucial changes in the rainfall pattern.

The average monthly rainfall of September is 110.58 mm, which is the lowest rainfall month of the season. The amount of rainfall in the retreating monsoon month of September is lower than the monsoon onset month of June. The mean seasonal rainfall is 752.84 mm and the September rainfall is the lowest 14.68 per cent of the four-month rainy season. The figure reveals that there were at least four years when the minimum September rainfall was zero mm. These were obviously the years of severe droughts with the earliest retreat of monsoon. On the other hand, September of 1975 experienced the highest rainfall of 485.3 mm, which was 438.51 per cent of its monthly average. Even this small occurrence of rainfall is of considerable significance on the water availability and water resource management in the megacity.

An analysis of the recent trends of above normal rainfall years and the below normal rainfall years under the influence of urban heat island is of considerable importance in this enquiry. Table 5.1 depicts the more recent changes that have occurred in the number of above normal rainfall years as well as the number of below normal rainfall years in Ahmedabad. This is an analysis of meteorological data of last 18 years during 1990-2007. In the annual trend, out of 18 years, a total of 9 years were of above normal rainfall and another 9 years recorded below normal rainfall. The normal annual rainfall was 792 mm. The above normal rainfall of 9 years received 64 per cent of the total 18 years of rainfall. On the other hand, another 9 years of below normal rainfall recorded only 36 per cent of the total rainfall. In the equal number of years, the above normal rainfall was almost two-thirds of the cumulative rainfall.

In June, the first month of rainy season there was an average rainfall of 119 mm and out of 18 years only 6 years recorded above normal rainfall. These one-third of the years scored 70 per cent of the total rainfall of all the years for the month of June. On the other hand, a bulk of 12 years received 30 per cent of the total rainfall.
### TABLE 5.1

Ahmedabad: Recent Trends in Above and Below Normal Rainfall Years (1990 – 2007)

<table>
<thead>
<tr>
<th>Rainy Months</th>
<th>Average Monthly &amp; Annual Rainfall (mm)</th>
<th>Years of Above Normal Rainfall</th>
<th>Total Rainfall in Above Normal Rainfall Years (mm)</th>
<th>Percentage of Above Normal Rainfall</th>
<th>Years of Below Normal Rainfall</th>
<th>Total Rainfall in Below Normal Rainfall Years (mm)</th>
<th>Percentage of Below Normal Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
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<td>119</td>
<td>6</td>
<td>1,632</td>
<td>70</td>
<td>12</td>
<td>686</td>
<td>30</td>
</tr>
<tr>
<td>July</td>
<td>281</td>
<td>11</td>
<td>4,359</td>
<td>77</td>
<td>7</td>
<td>1,281</td>
<td>23</td>
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<tr>
<td>August</td>
<td>242</td>
<td>8</td>
<td>3,548</td>
<td>74</td>
<td>10</td>
<td>1,225</td>
<td>26</td>
</tr>
<tr>
<td>September</td>
<td>110</td>
<td>6</td>
<td>1,515</td>
<td>74</td>
<td>12</td>
<td>535</td>
<td>26</td>
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<td><strong>792</strong></td>
<td><strong>9</strong></td>
<td><strong>9,678</strong></td>
<td><strong>64</strong></td>
<td><strong>9</strong></td>
<td><strong>5,408</strong></td>
<td><strong>36</strong></td>
</tr>
</tbody>
</table>

Source: Computed on the Basis of Meteorological Data.
Two-thirds of the below normal rainfall years record less than one-third of the total rainfall. Increasingly higher amount of rainfall in less number of rainy years reveals the growing intensity of rainfall.

July which is the rainiest month of the season, has an average monthly rainfall of 281 mm. Out of the total 18 years of secondary investigation, 11 years were found to be of above normal rainfall while only 7 years were witnessed with below normal rains. This depicts that in the megacity of Ahmedabad rainy years have grown. These 11 rainy Julys’ have recorded 77 per cent of the total July rainfall of 18 years while the remaining 7 Julys’ of below normal rainfall have recorded only 23 per cent of the rainfall. Hence, the number of rainy days as well as the rainfall intensity in July has considerably increased.

August is the inner monsoon month in Ahmedabad with the second highest rainfall of 242 mm. Out of a total 18 years, only 8 years recorded above normal rainfall in August and 10 years recorded below normal rainfall in August. These above normal 8 rainfall years recorded 74 per cent of the total rainfall of 18 years and the remaining 10 Augusts recorded 26 per cent of the total rains. This clearly indicates that the rainfall intensity in August is much higher with 74 per cent rains in 8 years in comparison to July with 77 per cent rains in 11 years.

September is the month of retreating monsoon in Ahmedabad with the lowest monthly rainfall of 110 mm in the season. Out of a total 18 years under analysis, only 6 years recorded above normal rainfall in September while 12 years recorded below normal rainfall in September. The above normal 6 rainfall years recorded 74 per cent of the total rainfall of 18 years while the remaining 12 Septembers recorded only 26 per cent of the total rains. This clearly indicates that the rainfall intensity in September is still higher with 74 per cent rains in only 6 years in comparison to August, which also received 74 per cent of the rains, but in 8 years. Hence, September the month of receding monsoon experiences the highest rainfall intensity among all the rainy months. This scenario reveals that in Ahmedabad all the months have shown an enhanced intensity of rainfall. Now, it remains to be verified whether this rainfall intensity has some relationship with the changing nature of number of rainy days in each month.
A temporal analysis of the recent trends of above normal number of rainy days as well as below normal number of rainy days under the influence of urban heat island is also of considerable importance in order to validate the changing trends of above and below normal rainfall years. Table 5.2 reveals the recent trends in the years of above and below normal rainy days in different months of the rainy season in Ahmedabad city. This is an analysis of the meteorological findings of last 18 years during 1990-2007. The annual trend of number of rainy days shows that there are an average yearly 34 rainy days in Ahmedabad city. During the years of analysis, 9 years witnessed above normal number of rainy days i.e. more than 34 days. At the rate of an average 34 days per year, the total number of rainy days in 9 years should have been 306 rainy days. However, during these 9 years of above normal rainy days the actual number of recorded above normal rainy days were 366 days. Hence, above normal rainy days were in excess of 60 days in the period of analysis.

On the other hand, in the face of a total number of 306 average rainy days in this period the actual number of below normal rainy days were only 227 days. Hence, the number of below normal rainy days were in deficit of 79 days during the period of analysis. This clearly reveals that despite a large number of 79 deficit rainfall days there has also been an excess rainfall by 2549 mm during 9 years of above normal rainfall. This surplus urban rainfall has increased at the rate of 283 mm per year during the above normal rainfall years. As against this, there has been a deficit rainfall by a total of 1721 mm during 9 years of below normal rainfall. This urban rainfall in Ahmedabad records a deficit of 191 mm per year during the 9 years of below normal rainfall. This equation makes it abundantly clear that not only the city rainfall has increased in Ahmedabad but its intensity has also considerably increased.

The June trend of number of rainy days shows that there are averages of only 4 rainy days in Ahmedabad city. During the years of analysis, 11 Junes recorded above normal number of rainy days that is more than 4 rainy days. At the rate of an average 4 rainy days per June, the total number of rainy days in 11 years should have been 44 rainy days. Instead, during these 11 years of above normal rainy days the actual number of recorded above normal rainy days were 67 days. Hence, above normal rainy days were in excess of 23 days in the period of analysis. This shows that both the amount of rainfall and the number of rainy days have increased in the month
TABLE 5.2
Ahmedabad : Recent Trends in Above and Below Normal Number of Rainy Days
(1990 – 2007)

<table>
<thead>
<tr>
<th>Rainy Months</th>
<th>Average Rainy Days</th>
<th>Years of Above Normal Rainy Days</th>
<th>Total Rainy Days in Above Normal Rainy Years</th>
<th>Percentage of Above Normal Rainy Days</th>
<th>Years of Below Normal Rainy Days</th>
<th>Total Rainy Days in Below Normal Rainy Years</th>
<th>Percentage of Below Normal Rainy Days</th>
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</thead>
<tbody>
<tr>
<td>June</td>
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<td>84</td>
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<td>151</td>
<td>77</td>
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<td>366</td>
<td>62</td>
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</tbody>
</table>

Source: Computed on the Basis of Meteorological Data.
of June. As against 11 above normal rainy Junes, there were 7 below normal rainy Junes during the study period. Below normal number of 7 rainy days was more than the average number of 4 rainy days. In the month of June, the above normal rainy days were 67 and below normal rainy days were 13. This represented 84 per cent above normal rainy days and 16 per cent below normal rainy days. This indicates that the percentage of below normal rainy days has decreased in June.

The month of July, which is the rainfall month with highest amount of rainfall, has an average number of 11 rainy days. This is the largest number of rainy days in any month. Out of 18 years of analysis, as many as 11 years recorded above normal rainy days. At the rate of an average 11 rainy days in every July with a total number 11 above normal rainy years, there should have been 121 rainy days. But, during these 11 years the actual number of above normal rainy days in July were 151. Hence, the above normal rainy days in July were in excess of 30 days. In the month of July the above normal rainy days were 151 days out of 11 above normal rainy years. On the other hand, the below normal rainy days were 46 out of 7 years of below normal rainy days. This represented an overall 77 per cent above normal rainy days and 23 per cent below normal rainy days. The percentage above normal rainy days has remained high.

The month of August which has recorded the second highest amount of rainfall, has an average number of 10 rainy days. This is also the second highest number of rainy days. Out of 18 years of rainy days analysis, as many as 10 years recorded above normal rainy days. At the rate of an average 10 rainy days for August with a total number of 10 above normal rainy years, there should have been 100 rainy days. However, during these 10 years the actual number of above normal rainy days were 135. Hence, the above normal rainy days in August were in excess of 35 days. As compared to July’s excess number of 30 days, August recorded 35 excess days in above normal rainy day category. On the other hand, the below normal rainy years in August were 8. There were an overall 75 per cent above normal rainy days and 25 per cent below normal rainy days in August. The percentage above normal rainy days has remained high in August also.

September which is the month of receding rainfall in Ahmedabad has an average number of 5 rainy days. Out of 18 years of rainy days analysis, the lowest 8 years have recorded above normal rainy days. At the rate of an average 5 rainy days
in September with a total number of 8 above normal rainy years, there should have been a total 40 rainy days. However, during these 8 years the actual number of above normal rainy days was recorded 77. Hence, the above normal rainy days in September were in excess of 37 days. This indicates a shift in the monsoon intensity towards its closure.

As compared to the excess above normal rainy days of 30 in July and 35 in August, there were 37 excess days of above normal rainfall in September. As against this, the below normal rainfall years were 10 in September. There were an overall 76 per cent above normal rainy days and 24 per cent below normal rainy days in September. The percentage above normal rainy days has remained high in all the monsoon months in Ahmedabad.

Figure 5.6 illustrates the mean annual rainfall regression on the meteorological data for the period 1961-2007. As the mean annual rainfall variability is higher than the mean monthly rainfall, the regression analysis does not show a close-fit incidence of rainfall in different years. The individual rainfall observations are obviously not near the regression slope line. The linear regression analysis shows a positive slope. It indicates a trend of increasing rainfall. The gross regression of annual rainfall shows an increase of 148.488 mm rainfall over a period of 47 years.

Figure 5.7 shows the mean monthly rainfall transition of Ahmedabad over a period of 1961-2007. The transition values of different regression diagrams of four separate months have been plotted here in one diagram. The first monsoon month of the onset of monsoon rains is June. It has recorded a rainfall increase of 61.686 mm over the period of enquiry. July which is the month of highest rainfall in Ahmedabad, has recorded a rainfall increase of 55.568 mm. August is also a month of very high rainfall. It has recorded a rainfall increase of 108.882 mm. September, which is the month of retreating monsoon has the lowest average rainfall during the rainy season.

September has an average rainfall lower than that of June. September, however, has a negative regression trend. The rainfall has decreased by 71.622 mm over a span of 47 years. Ultimately, the annual regression values depicted a positive rainfall transition of 148.488 mm. Ahmedabad has recorded 18.7 per cent in the annual rainfall in the last 50 years.
Ahmedabad: Mean Annual Rainfall Regression Trend
(1961 - 2007)

Source: Computed and Cartographed by the Researcher from IMD Data, Pune.
Ahmedabad: Transition in Mean Monthly Rainfall
(1961-2007)

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

Fig. 5.7
Transition in Mean Monthly Number of Rainy Days: Ahmedabad

Figure 5.8 is the result of the regression analysis of the mean monthly and mean annual data for the number of rainy days in Ahmedabad during 1961-2007. The regression analysis reveals the transition in the number of rainy days during a compact monsoon season encompassing June, July, August and September. The monthly transition values reveal that June being the most uncertain month of rainfall has depicted a trend of increasing number of rainy days. This is a very insignificant increase of 0.138 rainy days. July has depicted a considerable decrease of 0.736 rainy days. August has revealed a negligible positive transition of 0.092 rainy days. Finally, September has revealed a highest negative transition of 1.656 rainy days. Ultimately, the annual transition values revealed a sizeable negative transition of 2.3 rainy days. This crucial value signifies that in Ahmedabad city the average number of 34 rainy days have experienced an alarming reduction of 2.3 days. It means that Ahmedabad is heading towards lesser than 32 average rainy days. Here, it is significant to correlate that on the one hand the amount of rainfall in increasing in Ahmedabad. Simultaneously, the average number of rainy days are decreasing. This clearly indicates in increasing rainfall intensity in Ahmedabad.

IV Mean Annual and Monthly Rainfall Transition in Hyderabad

Mean annual and monthly frequency and transition rainfall in Hyderabad has been probed for the period 1961-2010 due to regular and larger period data availability. The mean annual rainfall occurrence is 832 mm in this city. Hyderabad experiences slightly longer period of rainfall with five monsoon months from June to October. The annual rainfall in Hyderabad is comparatively more sporadic than in Ahmedabad. The monsoon rains of five months, record only 85 per cent of the mean annual rainfall in Hyderabad as compared to 95 per cent rainfall in four rainy months of Ahmedabad. As the annual rainfall distribution has fairly high variability, a linear regression analysis was not performed to monitor any reliable changing trends in its occurrence. Due to this limitation, figure 5.9 illustrates the mean annual rainfall frequency for a period of 50 years. A large rainfall variability depicts less number of
Ahmedabad: Transition in Mean Number of Rainy Days (1961-2007)

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

Fig. 5.8
Hyderabad: Mean Annual Rainfall Frequency and Trends (1961-2010)

Fig. 5.9
years with above normal rainfall and more number of years with below normal rainfall.

Under this situation, it is significant to examine whether the amount of rainfall and the number of rainy days have increased or decreased in Hyderabad. In either case, it would depict crucial changes in rainfall pattern.

The highest annual rainfall was recorded 1383 mm in 1975 while the lowest annual rainfall was recorded 373 mm in 1985. The year 1975 experienced exceptionally above normal rainfall, not because the advancing monsoon was strong. In fact, June and July in 1975 remained below normal rainfall months. Even August recorded a slightly above normal rainfall. It was because of the strongest retreating monsoon which recorded highest rainfall in 1975. September 1975 was a month of exceptionally above normal rainfall. It was closely followed by high rains in October 1975. Such rainfall trends have an important bearing upon the water availability and water resource management in the megacities.

The rainfall pattern in the monsoons is most uncertain of all the atmospheric phenomena. Hence, a contingent plan should always be ready at hand to meet out different degrees of eventualities for every monsoon month for a sustained water resource management. The absolute range between the highest and lowest rainfall depicted 3.7 times variation in Hyderabad which was smaller than Ahmedabad’s 4.6 times variation. A five-yearly moving averages were taken to ascertain the pattern of rainfall regularity. These five yearly moving averages of Hyderabad rains depicted a more homogeneous and regular pattern than was the case of annual rains in Ahmedabad.

Figure 5.10 illustrates the mean monthly rainfall frequency of June, which is the month of onset of monsoon for the period 1961-2010. June being the first month of monsoon, it is likely to have a high rainfall variability. This is because the monsoon does not get stabilized in the take-off month. The mean rainy season rainfall of Hyderabad is 705 mm which is 85 per cent of the mean annual 832 mm rainfall of the city. A large rainfall variability depicts less number of years with above normal rainfall and more number of years with below normal rainfall. In view of this situation, it is crucial to examine whether the amount of rainfall and the number of
Hyderabad: Mean Monthly June Rainfall Frequency and Trends (1961 - 2010)

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

Fig. 5.10
rainy days have increased or decreased in Hyderabad. In any case, it would depict significant changes in rainfall pattern.

The mean monthly rainfall of June in Hyderabad is 102 mm which is less than the mean June rainfall of 119 mm in Ahmedabad. The highest June rainfall was recorded 225.1 mm in the year 2001 while the lowest June rainfall in Hyderabad was 25.3 mm in 2004. The absolute range between the highest and lowest rainfall in June showed 8.9 times variation. The average monthly rainfall of June represents only 14.46 per cent of the total monsoon rainfall spreading over five months in Hyderabad. To estimate the rainfall regularity pattern in June, five-years moving averages were taken. These moving average of rains depict a more homogenous and regular pattern than that of Ahmedabad.

Figure 5.11 demonstrates the mean monthly rainfall frequency of July, which recorded 163 mm, the second highest rainfall in Hyderabad. In the megacity of Hyderabad, July receives lesser rainfall than the July of Ahmedabad which is the highest rainfall month in that city. July due to the second highest rainfall month, has a high rainfall variability. July rains have a large rainfall variability. A large rainfall variability depicts less number of years with above normal rainfall in comparison to more number of years with below average rainfall. In this prevailing condition, it is crucial to examine whether the amount of rainfall and the number of rainy days have increased or decreased in July.

In either case, it would reveal significant changes in the rainfall pattern of the month. The mean monthly rainfall of July in Hyderabad is 163 mm. The maximum July rainfall was recorded 422.1 mm in 1989 as against the minimum July rainfall of 31.3 mm in 1974. The absolute range between the maximum and minimum rainfall in July depicted a 13.5 times variation. The average monthly rainfall of July was 23.12 per cent of the total monsoon rainfall in the city. The estimated rainfall regularity pattern through five-years moving averages showed a less homogeneous rainfall pattern in July.

Figure 5.12 illustrates the mean monthly rainfall frequency of August, which has recorded the highest monthly rainfall of 189 mm amongst all the five rainy months of Hyderabad. The highest August rainfall of Hyderabad is even less than the second highest August rainfall of 242 mm for Ahmedabad by a considerable margin.
Hyderabad: Mean Monthly July Rainfall Frequency and Trends (1961 - 2010)

Fig. 5.11
Hyderabad: Mean Monthly August Rainfall Frequency and Trends
(1961-2010)

Fig. 5.12
The maximum August rainfall was recorded 469 mm in the year 2000 whereas the minimum August rainfall of 20.5 mm was recorded in 1968. The absolute range between the maximum and minimum rainfall of August depicted a 22.9 times variation. The average monthly rainfall of August was 26.8 per cent of the total monsoon rainfall in the city. August because of its highest monthly rainfall, has a low rainfall variability.

A relatively lower rainfall variability in August is the result of large number of years with above normal rainfall in comparison to slightly larger number of years with below average rainfall. There appears a closest equilibrium between the above and below normal rainfall years in August. In view of this situation, it is crucial to examine whether the amount of rainfall and the number of rainy days have increased or decreased in August. In either case, it would reveal significant changes in the rainfall pattern of the month. The estimated rainfall regularity pattern through the five-year moving averages depicts a relatively more homogeneous rainfall pattern in August.

Figure 5.13 depicts the mean monthly rainfall frequency of September. It has recorded a monthly average of 155 mm rainfall. The decreasing rainfall of September depicts a pattern of receding monsoon. September rainfall in Hyderabad is higher than the corresponding rainfall in Ahmedabad. The maximum September rainfall was recorded 483.9 mm in 1975 while the minimum September rainfall was noted 14.3 mm in 1977. The absolute range between the maximum and minimum rainfall of September revealed a 33.8 times variation.

The average monthly rainfall of September was 21.98 per cent of the total monsoon rainfall in Hyderabad. September because of its low rainfall has a high rainfall variability. A relatively higher rainfall variability in September is because of a large difference between the number of above normal rainfall years and the below normal rainfall years.

In view of this situation, it is crucial to examine whether the amount of rainfall and the number of rainy days have increased or decreased. In any case, it would reveal significant changes in the rainfall pattern of the month. The estimated rainfall regularity pattern through the five-yearly moving averages depicts a relatively more homogeneous rainfall trend with a pattern of decreasing rainfall.

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Hyderabad: Mean Monthly September Rainfall Frequency and Trends (1961-2010)

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

Legend:
- September
- Average
- Moving Averages

Fig. 5.13
Figure 5.14 illustrates the mean monthly rainfall frequency of October. It has recorded a lowest monthly average of 96 mm rainfall. The lowest rainfall of October indicates a pattern of retreating monsoon. October is the secondary receding month of monsoon after September. October rainfall is lower than the June rainfall. The maximum October rainfall was recorded 324.5 mm in 1995 whereas minimum of this month was noted 0 mm in 1965. The absolute range between the maximum and minimum rainfall of this month revealed a 324.5 times variation. The average monthly rainfall of October was calculated only 13.61 per cent of the total monsoon rainfall in Hyderabad.

October because of its lowest rainfall has the highest rainfall variability. The highest rainfall variability in October has also been validated by the largest difference between the number of above normal rainfall years and the below normal rainfall years. In response to this situation, it is crucial to examine whether the amount of rainfall and the number of rainy days have increased or decreased. In either case, it would reveal significant changes in the rainfall pattern of the month. The estimated rainfall regularity pattern through the five-yearly moving average depicts the least homogenous rainfall pattern.

Table 5.3 invokes an analysis of the crucially significant changes that have taken place in the number of above normal rainfall years together with the number of below normal rainfall years in a cause and effect relationship with the urban heat island in Hyderabad. Because the urban growth and the resultant urban heat island intensity has tremendously been accentuated in the last twenty five years in the primate city of Hyderabad in this region, an analysis of changes in the number of above and below normal rainfall has been made for the more recent period from 1989 to 2010.

This is an analysis of recent 22 years over an earlier rainfall frequency analysis for a period of 50 years in this chapter. In the annual trend of the above and below normal rainfall years in Hyderabad, out of 22 years only 9 years recorded above normal rainfall and 13 years experienced below normal rainfall. The normal annual rainfall was 832 mm in Hyderabad. The monsoon season rainfall of 705 mm was 85 per cent of the annual average rainfall in Hyderabad. The 9 years of above
Hyderabad: Mean Monthly October Rainfall Frequency and Trends

(1961 - 2010)

Fig. 5.14
### TABLE 5.3
Hyderabad: Recent Trends in Above and Below Normal Rainfall Years
(1989 – 2010)

<table>
<thead>
<tr>
<th>Rainy Months</th>
<th>Average Monthly &amp; Annual Rainfall (mm)</th>
<th>Years of Above Normal Rainfall</th>
<th>Total Rainfall in Above Normal Rainfall Years (mm)</th>
<th>Percentage of Above Normal Rainfall</th>
<th>Years of Below Normal Rainfall</th>
<th>Total Rainfall in Below Normal Rainfall Years (mm)</th>
<th>Percentage of Below Normal Rainfall</th>
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<td><strong>13</strong></td>
<td><strong>9,577</strong></td>
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</table>

Source: Computed on the Basis of Meteorological Data.
normal rainfall received 49 per cent of the rainfall. On the other hand, 13 years of below normal rainfall recorded 51 per cent of the total rainfall.

The 9 years of above normal rainfall received a total of 9,160 mm rainfall. On the scale of normal or average rainfall, these 9 years should have received a total of only 7,488 mm rainfall. Hence, the above normal rainfall years recorded a surplus of 1672 mm rainfall at an average rate of 186 mm surplus rainfall per year. On the other hand, 13 below normal rainfall years received 9,577 mm total rainfall. Once again, on the scale of normal or average rainfall, these 13 years should have recorded a total of 10,816 mm annual rainfall. It is significant to note that the below normal rainfall years faced a deficit of 1239 mm total rainfall at an average rate of 95 mm deficit rainfall per year.

Hence, it is crucial to note that although 9 above normal rainfall years were too few in numbers against 13 below normal rainfall years, still the above normal rainfall was in a surplus of 1672 mm against a deficit of 1239 mm rainfall. Hence, it is evident that the megacity of Hyderabad has experienced a marginal increase in the amount of rainfall under the influence of urban heat island.

In June which is the first month of monsoon season, the average rainfall was 102 mm. The average June rainfall was 14.46 per cent of the total monsoon rain in Hyderabad. In this month of monsoon onset, out of 22 recent years of analysis only 9 years recorded above normal rainfall. Another 13 years recorded below normal rainfall. Despite this, 9 above normal rainfall years recorded 64 per cent of the rainfall while 13 below normal rainfall years recorded only 36 per cent of the total rainfall. The above normal rainfall 9 years actually received a total of 1407 mm rainfall. On the scale of normal, the total rainfall of June for 9 years should have been only 918 mm.

Hence, the above normal rainfall years recorded a surplus of 489 mm rainfall at an average rate of 54 mm surplus rain per year. On the other hand, 13 below normal rainfall years received a total rainfall of only 798 mm. Yet again, on the scale of normal rainfall, the remaining 13 years should have recorded a total of 1326 mm June rainfall. Here, it is crucial to note that the below normal rainfall years faced a deficit of 528 mm total rainfall at an average deficit rate of 40 mm per year. At this point, it is crucial to note that although 9 above normal rainfall years were too few in numbers
against 13 below normal rainfall years, the above normal rainfall surplus of 489 mm was only slightly smaller than the below normal rainfall deficit of 528 mm. This equation suggests that the megacity of Hyderabad might experience a trend of slight decrease in the rainfall of June.

July is the second month of monsoon rains. It has a monthly average of 163 mm of rains. The average July rainfall has been recorded 23.12 per cent of the total rainfall of the rainy season in Hyderabad. In this month of well inside the monsoon location, out of 22 recent years of rainfall analysis 10 years recorded above normal rainfall. Another 12 years recorded below normal rainfall. Inspite of this, 10 above normal rainfall years recorded 68 per cent of the total rainfall whereas 12 below normal rainfall years received only 32 per cent of the total rainfall. The above normal rainfall 10 years actually received a total of 2,461 mm rainfall. On the scale of normal or average monthly rainfall, the total rainfall of July for 10 years should have been only, 1630 mm.

Hence, the above normal rainfall years received a surplus of 831 mm of rainfall at an average rate of 83 mm surplus rain per year. As against this, 12 below normal rainfall years received a total rainfall of only 1,139 mm. Here also, on the scale of normal rainfall, the remaining 12 years should have potentially recorded a total of 1956 mm July rainfall. Here, it is crucial to note that the below normal rainfall year faced a deficit of 817 mm total rainfall at an average deficit rate of 68 mm per year. At this juncture, it is significant to note that although 10 above normal rainfall years experienced the surplus rain of a total 831 mm and 12 below normal rainfall years experienced a total deficit rain of 817 mm it is only statistically smaller deficit than the surplus. This deceptive, smaller deficit might harness a little decreasing trend in the July rainfall.

August is the core monsoon month. It has the highest monthly average of 189 mm rainfall in the megacity of Hyderabad. The average August rainfall has been calculated 26.8 per cent of the total monsoonal rainfall. An analysis of recent rainfall trends has been made for the period 1989-2010. Out of 22 recent years of rainfall analysis, 14 years recorded above normal rainfall. August rainfall of Hyderabad reported the largest number of above normal rainfall years in the three megacities of Ahmedabad, Hyderabad and Bangalore. The remaining 8 years recorded below
normal rainfall. As a consequence to it, 14 above normal rainfall years recorded 79 per cent of the monthly rainfall while 8 below normal rainfall years recorded only 21 per cent of the total August rainfall. The 14 above normal rainfall years actually received an aggregate 4,063 mm rainfall.

Here, on the scale of normal or average monthly rainfall, the aggregate rainfall of August for 14 years should have been only 2,646 mm. Hence, the above normal rainfall years received a surplus of 1,417 mm of rainfall at an average rate of 101 mm surplus rain per year. On the other hand, 8 below normal rainfall years received an aggregate rainfall of only 1,108 mm. Once again, on the scale of normal rainfall, the remaining 8 years should have potentially recorded a total of 1,512 mm August rainfall. Here, it is significant to note that the below normal rainfall years faced an aggregate deficit of 404 mm rainfall at an average yearly deficit of 50.5 mm. At this point, it is crucial to note surplus rainfall of 14 above normal rainfall years considerably outweighed the deficit rainfall of 8 below normal rainfall years. This indicates a prospect of very high increase in the rainfall of August under the impact of urban heat island intensity in the megacity of Hyderabad.

September is the month of receding monsoon. It has an average monthly rainfall of 155 mm. The average of September is higher than that of June. It is the month of receding monsoon. The average September rainfall has been computed as 21.98 per cent of the total monsoonal rainfall. An analysis of the recent rainfall years has been made for the period 1989-2010.

Out of 22 recent years of rainfall a lowest 6 years recorded above normal rainfall. September rainfall in Hyderabad noted one of the lowest number of above normal rainfall in the three megacities. The remaining bulk of 16 years recorded below normal rainfall. In this equation, 6 above normal rainfall years recorded 42 per cent of the monthly rainfall whereas 16 below normal rainfall year recorded 58 per cent of the total September rainfall. The 6 above normal rainfall years actually received an aggregate 1,184 mm rainfall. On the scale of normal monthly rainfall, the aggregate of September for 6 years should have been only 930 mm. Hence, the above normal rainfall years received a surplus of 254 mm rainfall at an average rate of 42 mm surplus rain per year.
As against this, 16 below normal rainfall years received an aggregate rainfall of 1,640 mm. Here again, on the scale of normal rainfall, these 16 years should have potentially recorded a total of 2,480 mm September rainfall. Here, it is crucial to note that the below normal rainfall years faced an aggregate deficit of 840 mm rainfall at an average yearly deficit of 52.5 mm. Here, it is significant to note that the surplus rainfall of 6 above normal rainfall years was abundantly outweighed by the deficit rainfall of 16 below normal rainfall years. This scenario indicates the prospects of very high decrease in the rainfall of September under the influence of urban heat island intensity in Hyderabad.

October is the month of retreating monsoon. It is the last rainy month of the monsoon season. It has lowest average monthly rainfall of 96 mm. It has an average rainfall lower than that of June. The average October rainfall has been calculated as 13.61 per cent of the total monsoonal rainfall. From an analysis of the recent years of rainfall behavior for the period 1989-2010, it has been noted that out of 22 years of rainfall enquiry 10 years recorded above normal rainfall. Another 12 years recorded below normal rainfall. In this equation, 10 above normal rainfall years recorded 74 per cent of the monthly rainfall while 12 below normal rainfall years recorded only 26 per cent of the total October rainfall.

Infact, 10 above normal rainfall years actually received an aggregate 1,757 mm rainfall. On the basis of normal monthly rainfall, the aggregate rainfall of October for 10 years should have been 960 mm. Hence, the above normal rainfall years received a surplus of 797 mm rainfall at the rate of an average 80 mm per year. On the other hand, 12 below normal rainfall years received an aggregate rainfall of only 605 mm. Once again, on the basis of normal rainfall, these 12 years should have potentially recorded a higher aggregate of 1,152 mm rainfall. Here, it is important to note that the below normal rainfall years faced an aggregate deficit of 547 mm rainfall at an average yearly deficit of 45.6 mm. Here, it is significant to note that the surplus 797 mm rainfall of 10 above normal rainfall years was higher than the deficit 547 mm rainfall of 12 below normal rainfall years. This scenario suggests a slight increase in the October rains in Hyderabad.

A temporal analysis of the recent trends of above and below normal number of rainy days under the influence of urban heat island is of considerable importance in
order to validate a relationship between the number of rainfall years and the number of rainy days. This will also help in examining the changes in the rainfall intensity. Table 5.4 reveals the recent trends in the number of above and below normal rainy days in different months of the rainy season in Hyderabad city. It depicts the number of rainy days of the recent 22 years from 1989 to 2010. The annual trend of number of rainy days shows that Hyderabad has an yearly average of 49 rainy days.

During the 22 years of annual analysis, 9 years witnessed above normal number of rainy days i.e., more than 49 days. The above normal rainy days were 47 per cent of the total. At the rate of an average 49 rainy days per year the total number of rainy days in 9 years should have been 441 rainy days. However, during these 9 years of above normal rainy days, the actually recorded number of rainy days were 503 days. Hence, the above normal rainy days were in excess of 62 days in the period of analysis.

On the other hand, Hyderabad experienced 13 years of below normal number of rainy days. It means that in these 13 years the number of rainy days in each year were less than 49 days. The below normal rainy days represented 53 per cent of the total. At the rate of an average 49 rainy days per year the total number of rainy days in 13 years should have been 637 days. However, during these 13 years of below normal rainy days, the actually recorded number of rainy days were 557 days. Hence, the below normal rainy days were in deficit of 80 days. This clearly reveals that despite a large number of 80 deficit rainfall days during 13 years there has been excess or surplus rainfall by 1672 mm. It is amply evident from this equation that not only the amount of rainfall has increased but the intensity of rain has also increased in the megacity of Hyderabad.

The number of rainy days trend in June shows that there are an average 7 rainy days in Hyderabad city. During 22 years of analysis, 10 Junes recorded above normal rainy days that is more than 7 rainy days. At the rate of an average 7 rainy days per June the aggregate number of rainy days in 10 years should have been 70 rainy days. In fact, during the 10 years of above normal rainy days the actually recorded number of above normal rainy days were 89 rainy days. Hence, the above normal number of rainy days were in surplus of 19 days in the period of analysis. As against 10 years of
TABLE 5.4
Hyderabad: Recent Trends in Above and Below Normal Number of Rainy Days
(1989 – 2010)

<table>
<thead>
<tr>
<th>Rainy Months</th>
<th>Average Rainy Days</th>
<th>Years of Above Normal Rainy Days</th>
<th>Total Rainy Days in Above Normal Rainy Years</th>
<th>Percentage of Above Normal Rainy Days</th>
<th>Years of Below Normal Rainy Days</th>
<th>Total Rainy Days in Below Normal Rainy Years</th>
<th>Percentage of Below Normal Rainy Days</th>
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<td><strong>557</strong></td>
<td><strong>53</strong></td>
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</tbody>
</table>

Source: Computed on the Basis of Meteorological Data.
above normal rainy days in June there were 12 years of below normal rainy days in this month. In the month of June the above normal rainy days were 63 per cent and the below normal rainy days were 37 per cent. This indicates that the percentage of below normal rainy days has increased in June. Hence, there is a likelihood of decreasing trend in rainfall.

July is the second rainiest month in Hyderabad. It has an average number of 10 rainy days. This is one of the largest number of rainy day months. In July there are 10 years of above normal rainy days. There are 12 years of below normal rainy days. At the rate of an average 10 rainy days in every July with a total number of 10 above normal rainy years, there should have been an aggregate 100 rainy days in July. But during these 10 years the actual number of above normal rainy days were 119. Hence, the above normal rainy days in July were in excess of only 19 days. On the other hand, there were 12 years of below normal rainy days which account for a total 120 below normal rainy days.

The actual number of below normal rainy days were 79 days. The below normal rainy days were 41 less than aggregate average numbers. In the month of July the above normal rainy days were 60 per cent and the below normal rainy days were 40 per cent. This trend also indicates that the percentage of below normal rainy normal rainy days has increased in July. As a result of it, there is a likelihood of decreasing rainfall trend.

August is the rainiest month in Hyderabad. It has an average number of 10 rainy days. This is also one of the largest number of rainy days months. In August there are the largest 16 years of above normal rainy days. As against it, August obviously has the smallest 6 years of below normal rainy days. At the rate of an average 10 rainy days in every August coupled with a total 16 years of above normal rainy days, there should have been an aggregate 160 rainy days in August. As a matter of fact, during these 16 years the actual number of above normal rainy days were recorded 202 days. Hence, the above normal number rainy days in August were in excess of 42 days.

On the other hand, there were only 6 years of below normal rainy days which should account a total 60 below normal rainy days. However, the actual number of below normal rainy days were only 47 days. The below normal rainy days were in a
deficit of 13 days. In August the above normal rainy days were 81 per cent and the below normal rainy days were 19 per cent only. This trend indicates that the percentage of below normal rainy days has decreased. Consequently, there is a likelihood of increasing rainfall trend in August.

September is the receding month of monsoon rains. Hence, it has only 8 average number of rainy days. However, the above normal rainy days in September were for 11 years. Hence, September had an equal 11 number of years with below normal rainy days. At the rate of an average 8 rainy days in every September coupled with 11 years of above normal rainy days, there should have been an aggregate 88 above normal rainy days. But during these 11 years the actual number of above normal rainy days were recorded as many as 109 days. As a result of it, the above normal rainy days were in excess of 21 days. On the other hand, there were 11 years of below normal rainy days, which should account an aggregate 88 below normal rainy days. However, the actual numbers of below normal rainy days were only 55 days. Consequently, the below normal rainy days were 33 days lesser than the expected average number. In September the above normal rainy days were 64 per cent while the below normal rainy days were 36 per cent. This indicates that the percentage of below normal rainy days is a sizeable and growing number. In response to this equation, there is a likelihood of decreasing rainfall trend in September.

October is the last rainy month of the monsoon season. It is a month of retreating monsoon. October has the lowest seasonal rainfall of 96 mm and consequently the smallest number of average five rainy days. Out of 22 years of analysis, October experienced 12 years of above normal rainy days. As against it, October witnessed 10 years of below normal rainy days. At the rate of an average five rainy days in October coupled with 12 years of above normal rainy days, there should have been an aggregate 60 rainy days. But infact, during these 12 years the actual number of above normal rainy days were 97 days. As a result of it, the above normal rainy days were in excess of 37 days. On the other hand, there were 10 years of below normal rainy days which should mean an aggregate 50 below normal rainy days. However, the actual number of below normal rainy days were only 34 days, consequently, the below normal rainy days were 16 days lesser than expected average number. In October the above normal rainy days were 74 per cent whereas the below normal rainy days were 26 per cent. This indicates that the percentage of below
normal rainy days is small and decreasing while the percentage of above normal rainy
days is large and increasing. In response to this equation, there is the likelihood of
increasing rainfall trend in October.

Figure 5.15 illustrates the mean annual rainfall regression of Hyderabad on the
meteorological data for the period 1961-2010. The scatter plot in the diagram depict
that the mean annual rainfall variability is very high. Infact, mean annual rainfall
variability is particularly higher than the mean monthly variability except in the
month of September. Because of the higher rainfall variability the regression trend
does not show a close fit pattern in different years. The annual rainfall observation are
resultantly not near the regression slope line. The linear regression slope shows a
stagnant trend with a very slight positive slope. It indicates a trend of very little
rainfall growth. The gross regression of annual rainfall shows an increase of only
33.663 mm over a period of 50 years.

Figure 5.16 depicts the mean monthly and annual rainfall transition of
Hyderabad over a period of 1961-2010. The transition value of different regression
diagrams of five separate months have been plotted in this histogram. In Hyderabad
also the first month of the onset of monsoon rains is June. It has recorded a rainfall
decrease by 4.06 mm in the last 50 years. July has also recorded a rainfall decrease of
20.58 mm over the study period. August is the month of highest rainfall in
Hyderabad.

This highest rainfall month of lowest rainfall variability recorded the highest
rainfall increase of 141.659 mm over a period of 50 monsoons. September which is
the month of receding monsoon coupled with highest rainfall variability has shown a
negative regression trend. September has recorded the highest rainfall decrease of
90.454 mm over the study period. October is the month of retreating monsoon in
Hyderabad. Because October is the last month of monsoon rains, it recorded the
lowest rainfall with conversely almost highest rainfall variability. Still, however, this
month has recorded a positive regression depicting a rainfall increase of 9.114 mm.
Eventually, the annual regression values of Hyderabad have depicted a modest
positive transition. The annual rainfall in this megacity has increased by 33.663 mm.
It measures a 4 per cent annual rainfall increase in the last 50 years.
Fig. 5.15

Hyderabad: Mean Annual Rainfall Regression Trend (1961-2010)

Source: Computed and Cartographed by the Researcher from Hill Data, Pune.
Hyderabad: Transition in Mean Monthly Rainfall (1961 - 2010)

Fig. 5.16

Source: Computed and Cartographed by the Researchers from IMD Data, Pune.
Transition in Mean Monthly Number of Rainy Days: Hyderabad

Figure 5.17 is the result of the regression analysis of the mean monthly and mean annual data of the number of rainy days in Hyderabad during 1961-2010. The regression analysis reveals a transition in the number of rainy days during an extended monsoon season which encompasses June, July, August, September and October. The monthly transition values reveal that because June has twice the below normal rainy days of 12 in comparison to only 6 above normal rainy days in the recent years, it has depicted a trend of decreasing number of rainy days. June has depicted a very alarming decrease of 2.646 rainy days over its monthly average of only 7 rainy days. It has recorded a 37.8 per cent decrease in its average number of rainy days. This substantial decrease in the number of rainy days in the monsoon onset month indicates that the opening monsoon rain is heading towards higher intensity, increasing uncertainty and a shift of monsoon onset towards July, which means the delayed rains.

July has also depicted a negative transition in the number of rainy days. July has recorded a decrease in the number of rainy days by 2.45 days. This decrease has taken place over an average 10 rainy days in July. Hence, there is a substantial 24.5 per cent decrease in the number of July rainy days. This significant decrease in the number of rainy days indicates a rising uncertainty in the monsoon rain. August which is the core monsoon month of highest monthly rainfall in Hyderabad, has also recorded the largest number of above normal rainy days. As a cumulative effect of these conditions,

August has recorded a significant positive transition in the number of rainy days. August has revealed an increase of 2.205 rainy days. Hence, there is a significant 22 per cent increase in the number of rainy days of August. September has recorded a highest negative transition of 2.842 days in Hyderabad. Significantly, September in Ahmedabad also recorded the highest negative transition in the number of rainy days. This reveals the growing vulnerability of September rains to uncertainties. The number of September rainy days in Hyderabad have shown a decrease by 35.5 per cent over the average number of corresponding rainy days.
Hyderabad: Transition in Mean Number of Rainy Days
(1961 - 2010)

Fig. 5.17
October which is the last month of monsoon rainy days experiences the lowest rainfall. It also has the lowest average number of five rainy days. However, October has witnessed a sizeable number of above normal rainy days in the recent years. Hence, October has recorded only a feeble positive transition. The number of rainy days have increased only by 0.147 days. Eventually, the annual regression values of number of rainy days have a cumulative negative transition of high order. The annual transition recorded a 5.3 days decrease in the number of rainy days. The average number of rainy days in Hyderabad were 49 days. The negative transition has reduced the average annual number of 49 rainy days to now 43.61 average rainy days. This has inflicted a considerable 11 per cent decrease in the annual number of rainy days in Hyderabad. Thus, an increase in the amount of rainfall on the one hand and the decrease in the number of rainy days on the other hand, invokes an increasing rainfall intensity.

V Mean Annual and Monthly Rainfall Transition in Bangalore

In order to measure the changing pattern of rainfall in the megacity of Bangalore under the impact of urban heat island, mean annual and monthly frequency and transition of rainfall has been examined for the period 1961-2010. Bangalore receives the highest 989 mm mean annual rainfall in comparison to 792 mm in Ahmedabad and 832 mm in Hyderabad. Similarly, Bangalore experiences an 8 month protracted rainy period of double maxima of monsoon coupled with the pre-monsoon rains from April to November. As against this, Ahmedabad experiences a sharply defined rainy season of only four months and Hyderabad receive a bit extended 5 months monsoon rains.

The distribution pattern of annual rainfall in Bangalore is more sporadic in comparison to Ahmedabad and Hyderabad. As a result of it, Bangalore does not receive persistent heavily showers. The moderate showers are intermittent with clear skies in 5 out of 8 months of rainy period. It should not be a matter of surprise when the prolonged 8 months rainy period receive 96 per cent of the mean annual rainfall in Bangalore. To evaluate any reliable changing pattern in rainfall occurrence, the linear regression analysis was not performed because of the high rainfall variability than other climate variables.
Figure 5.18 illustrates the mean annual rainfall frequency for a period of 50 years. The rainfall frequency depicts slightly more number of years with above normal rainfall and less number of years with below normal rainfall. In view of this situation, it is crucial to examine whether the amount of rainfall and the number of rainy days have increased or decreased in Bangalore. In either case, it would depict significant changes in the pattern of rainfall occurrence. The highest annual rainfall was recorded 1608.8 mm in 2005 whereas the lowest annual rainfall was recorded 587.2 mm in 1994.

Here, it can be analyzed that because of the longest rainy period, the amplitude of annual rainfall variability in Bangalore is at a lowest 2.74 level. As against this, Ahmedabad with the shortest rainy period has the highest 4.6 times amplitude of annual rainfall variability. Hyderabad has a moderate 3.7 amplitude of annual rainfall variability. Hence, there is an evidently clear inverse relationship between the length of rainy period and amplitude of rainfall variability. The five years moving average were taken to identify the pattern of rainfall regularity. These five years moving averages of Bangalore rains depicted a comparatively most homogeneous and regular rainfall pattern than Hyderabad and Ahmedabad, which has the least homogeneous rainfall pattern.

Figure 5.19 demonstrates the mean monthly rainfall frequency of April for a 50 years period of 1961-2010. April is the first month of cognizable rains. It is a pre-monsoon month in India. In view of its lowest amount of rainfall, April depicts a high rainfall variability. This is also because of the fact April is not apart of any regular rainfall season, a large rainfall variability depicts less number of years with above normal number rainfall and more number of years with below normal rainfall. In view of this situation, it is crucial to examine whether the amount of rainfall and the number of rainy days has increased or decreased in Bangalore. In either case, it would depict significant changes in the rainfall pattern.

The mean monthly rainfall of April is 51 mm in Bangalore. The highest April rainfall was recorded 328.8 mm in 2001 whereas the lowest April rainfall was zero mm in 1983. The absolute range between the highest and lowest rainfall in April showed a 324 times variation. The average monthly rainfall of April represents only
Bangalore: Mean Annual Rainfall Frequency and Trends
(1961 - 2010)

Fig. 5.18
Bangalore: Mean Monthly April Rainfall Frequency and Trends (1961-2010)

Source: Computed and Cartographed by the Researcher from IMD Rainfall Data.
5.39 per cent of the total rainfall of 8 rainy months. This is the lowest monthly percentage of the rainy period. To estimate the rainfall regularity pattern in April, a five-yearly moving averages were taken. These moving averages also depict the least homogenous and regular pattern of rains in April.

Figure 5.20 illustrates the mean monthly rainfall frequency of May for a 50 years period of 1961-2010. May is the month of fairly noticeable rainfall. The mean monthly May rainfall is 112 mm. This is also the month of pre-monsoon rains in the region. Because of the occurrence of non-rainy season rains in May, the rainfall variability is considerably high. A large rainfall variability depict less number of years with above normal rainfall and more number of years with below normal rainfall. Under this situation, it is significant to assess whether the amount of rainfall and the number of rainy days have increased or decreased in May. In any case, it would signify crucial changes in the rainfall pattern.

The highest May rainfall was recorded 207.9 mm in 2004, whereas the lowest May rainfall was 1.3 mm in 2003. The average monthly rainfall of May was more than double the average of April. It is perhaps because of this, the yearly variation of rainfall was less extreme in May than in the month of April. However, both the months depicted considerable rainfall variability. The absolute range between the highest and lowest rainfall in May showed 160 times variation. The average monthly rainfall of May represent 11.84 per cent of the total rainfall of 8 rainy months. May also receives higher rainfall than June, July and November. In order to estimate the rainfall regularity pattern in May, five-yearly moving averages were plotted. The moving averages depict relatively non-homogenous and regular pattern of rainfall in comparison to April.

Figure 5.21 depicts the mean monthly rainfall frequency of June for the period 1961-2010. June is the month of monsoon onset in most parts of southern and eastern India. However, monsoon in June is quite evasive in Bangalore. This megacity in June experiences the rain-shadow characteristics. The mean monthly June rainfall in Bangalore is 95 mm. Because of the rain-shadow characteristics, the rainfall variability is considerably high in June. A large rainfall depicts less number of years with above normal rainfall and more number of years with below normal rainfall. In
Bangalore: Mean Monthly May Rainfall Frequency and Trends (1961 - 2010)

Fig. 5.20
Bangalore: Mean Monthly June Rainfall Frequency and Trends
(1961 - 2010)

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

Fig. 5.21
view of this condition, it is crucial to examine whether the rainfall and the number of rainy days have increased or decreased in June.

In either case, it would depict significant changes in the rainfall pattern. The highest June rainfall was recorded 228 mm in 1996 while the lowest June rainfall was 16.9 mm in 1981. The absolute range between the highest and lowest rainfall in June showed a 13.5 times variation. The yearly rainfall variation in June is considerably higher than April and May. The average monthly rainfall of June represents 10.04 per cent of the total rainfall of the eight rainy months. In order to estimate the rainfall regularity pattern in June, five-yearly moving averages were plotted. The moving averages depict a relatively less homogeneous and less regular pattern of rainfall in comparison to May.

Figure 5.22 demonstrates the mean monthly rainfall frequency of July for a fifty-years period of 1961-2010. July is a monsoon month all over India. Still, however, Bangalore or the Karnataka plateau comes under the rain-shadow region during the advancing monsoon. The mean monthly July rainfall in Bangalore is 111 mm. Because of the rain-shadow characteristics, the rainfall variability is considerably high in July. A large rainfall variability depicts less number of years with above normal rainfall and more number of years with below normal rainfall. In this situation, it is significant to evaluate whether the amount of rainfall and number of rainy days have increased or decreased in July.

In any case, it would reveal crucial changes in the rainfall pattern. The highest July rainfall was recorded 285.6 mm in 1994 whereas the lowest July rainfall was 18.2 mm in 2009. The absolute range between the highest and lowest rainfall showed a 15.7 times variation. The yearly rainfall variation in July has also been as high as in June. The average monthly rainfall of July represents 11.62 per cent of the total rainfall of the eight month rainy period. In order to estimate the rainfall regularity pattern in July, five-yearly moving averages were plotted. The moving averages of July also depict a relatively less homogenous and less regular rainfall pattern similar to June.

Figure 5.23 illustrates the mean monthly rainfall frequency of August for the period 1961-2010. August is the core monsoon month all over India including the remote desert districts of Barmer, Bikaner and Jaisalmer. This is generally the rainiest
Bangalore: Mean Monthly July Rainfall Frequency and Trends
(1961 - 2010)

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

Fig. 5.22
Fig. 5.23

Bangalore: Mean Monthly August Rainfall Frequency and Trends (1961 - 2010)
month in most parts of India. Still, however, August in Bangalore experiences mild rain shadow conditions. The mean monthly August rainfall in Bangalore is 142 mm because of the rain shadow characteristics; the rainfall variability is considerably high in August also. A large rainfall variability depicts less number of above normal rainfall years and more number below normal rainfall years. In view of this scenario, it is crucial to examine whether the amount of rainfall and the number of rainy days have increased or decreased in August. In either case, it would reveal significant changes in rainfall pattern.

The highest rainfall in August was recorded 387.1mm in 1998 while the lowest August rainfall was 45mm in 1984. The absolute range between the highest and lowest rainfall showed 8.6 times variation. The yearly rainfall variation in August seems to be higher than June and July. The average monthly rainfall of August represents 15.01 per cent of the total rainfall of eight month rainy period. To estimate the rainfall regularity pattern in August, five-yearly moving average were plotted. These moving averages also depict a less homogeneous or more heterogeneous rainfall pattern.

Figure 5.24 demonstrates the mean monthly rainfall frequency of September for the period 1961-2010. September in most parts of India is generally a month of receding rains. Hence, September receives one of the lowest rainfalls of the rainy season. Contrary to it, Bangalore receives the highest rainfall in September. This is despite the fact that September is the month of retreating monsoon. In fact the retreating N.E. monsoon is stronger than the advancing S.W. monsoon over Bangalore. The mean monthly September rainfall in Bangalore is 211mm. Because of the highest rainfall in September, there is moderate rainfall variability. The moderate rainfall variability depicts very less difference between the number of above normal rainfall years vis-a-vis number of below normal rainfall years.

Still, however, the number of above normal rainfall years are less than the number of below normal rainfall years. In this situation, it is significant to assess whether the amount of rainfall and the number of rainy days have increased or decreased in September. In any case, it would reveal significant changes in the rainfall pattern. The highest September rainfall was recorded 516.6mm in 1986 whereas the lowest September rainfall was 44.1mm in 2003. The absolute range between the
Bangalore: Mean Monthly September Rainfall Frequency and Trends (1961 - 2010)

Source: Computed and Graphed by the Researcher from IMD Data files.

Fig. 5.24
highest and lowest rainfall showed 12 times variation. The yearly rainfall variation in September is less than corresponding variation in August. The average monthly rainfall of September represents 22.3 per cent of the total rainfall. To depict the rainfall regularity pattern, the five-yearly moving averages showed moderately homogeneous rainfall pattern.

Figure 5.25 illustrates the mean monthly rainfall frequency of October for the period 1961-2010. October is the second month of the retreating monsoon. Yet October records a fairly high rainfall. In fact, the second highest due to rain forced monsoon in this region. The mean monthly October rainfall in Bangalore is 164 mm. The rainfall variability is low in October. The low rainfall variability is evident from again very less difference between the number of above normal and below normal rainfall years. In this equation, the number of above normal rainfall years are slightly less than the number of below normal years. In view of this scenario, it is crucial to evaluate whether the amount of rainfall and the number of rainy days have increased and decreased in October. In either case, it would reveal significant changes in the rainfall pattern. The highest October rainfall was recorded 605.6 mm in 2005 while the lowest October rainfall was only 3.2 mm in 1965. The absolute range between highest and lowest rainfall showed 189 times variation. The average monthly rainfall was 17.34 per cent of the total rainy period. To estimate the rainfall regularity pattern in October, the five-yearly moving averages were plotted. These moving averages depict a highly homogeneous and regular rainfall pattern.

Figure 5.26 depicts the mean monthly rainfall frequency of November for the period 1961-2010. November is the last rainy month in Bangalore. November receives one of the lowest 61 mm rainfall. The rainfall variability in this month is very high. The very high rainfall variability is evident from a very large difference between the number of above normal and below normal rainfall years. In this equation the number of above normal rainfall years are far lesser than the number of below normal rainfall years. In view of this situation, it is significant to examine whether the amount of rainfall and the number of rainy days have increased or decreased in November. In any case, it would reveal significant changes in the rainfall pattern. The highest November rainfall was recorded 235.7 mm in 1966 whereas as the lowest November rainfall was only 1.2 mm in 1966. The absolute range between the highest and lowest
Bangalore: Mean Monthly November Rainfall Frequency and Trends
(1961 - 2010)

Fig. 5.26
rainfall showed 196 times variation the averages monthly rainfall of November was 6.45 per cent of the total rainfall of 8 rainy months. To estimate the rainfall regularity pattern in November, the five-yearly moving averages were plotted. These moving averages revealed a highly heterogeneous and irregular rainfall pattern.

Table 5.5 depicts the significant changes in the number of above and below normal rainfall years in response to urban heat island in Bangalore. As the urban growth and the resultant urban heat island intensity has rapidly accentuated in the last two decades in Bangalore, an analysis of changes in the number of above and below normal rainfall has been made for the more recent period from 1991-2010. This is the focused analysis of the recent 20 years in comparison to an earlier rainfall frequency analysis for a period of 50 years. In the annual trend of the above and below normal rainfall years in Bangalore, out of 20 years as many as 15 years have recorded above normal and the remaining 5 years received below normal rainfall. The normal annual rainfall was 989 mm in Bangalore. The average rainfall of the 8 rainy months was 946 mm or 96 per cent of the average annual rainfall of Bangalore. The 15 years of above normal rainfall recorded it 83 per cent of the total rainfall. On the other hand 5 below normal rainfall received only 17 per cent of the total rainfall.

The 15 years of above normal rainfall receive an aggregate of 17,870 mm rainfall. On the basis of normal, for average rainfall these 15 years should have recorded a total of only 14,835 mm rainfall. Hence, the above normal rainfall years recorded an excess of 3035 mm rainfall at an average rate of 202 mm surplus rainfall per year. On the other hand, five below normal rainfall years received an aggregate 3549 mm rainfall. Once again, on the scale of normal or average rainfall, these 5 years should be recorded an aggregate 4,945 annual rainfall.

It is significant to note that the below normal rainfall years received a deficit of 1396 mm total rainfall at an average rate of 279 mm deficit rainfall per year. Here it is significant to note that 15 above normal rainfall years were too many against 5 below normal rainfall years. As the result of it, the above normal rainfall years were in an abundant surplus of 3035 mm rainfall against a deficit of 1396 mm in below normal rainfall years. Hence, it is evident that the megacity of Bangalore has experienced a substantial increase in the amount of rainfall under the impact of urban heat island.
### TABLE 5.5
Bangalore: Recent Trends in Above and Below Normal Rainfall Years

<table>
<thead>
<tr>
<th>Rainy Months</th>
<th>Average Monthly &amp; Annual Rainfall (mm)</th>
<th>Years of Above Normal Rainfall</th>
<th>Total Rainfall in Above Normal Rainfall Years (mm)</th>
<th>Percentage of Above Normal Rainfall</th>
<th>Years of Below Normal Rainfall</th>
<th>Total Rainfall in Below Normal Rainfall Years (mm)</th>
<th>Percentage of Below Normal Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>51</td>
<td>11</td>
<td>1,095</td>
<td>82</td>
<td>9</td>
<td>243</td>
<td>18</td>
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<tr>
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<td>10</td>
<td>1,660</td>
<td>68</td>
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<tr>
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<td>1,481</td>
<td>64</td>
<td>12</td>
<td>849</td>
<td>36</td>
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<td>68</td>
<td>11</td>
<td>1,038</td>
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<tr>
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<td>2,391</td>
<td>61</td>
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<td>1,499</td>
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<tr>
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<td>77</td>
<td>8</td>
<td>925</td>
<td>23</td>
</tr>
<tr>
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<td>8</td>
<td>814</td>
<td>71</td>
<td>12</td>
<td>330</td>
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<td>83</td>
<td>5</td>
<td>3,549</td>
<td>17</td>
</tr>
</tbody>
</table>

Source: Computed on the Basis of Meteorological Data.
April is the first month of considerable rains much before the monsoon season. The average monthly rainfall in April was 51 mm. This average rainfall is 5.39 per cent of the total 8 rainy months. In April out of 20 recent years of rainfall analysis, 11 years recorded above normal rainfall. Another 9 years received below normal rainfall. The 11 above normal rainfall years recorded 82 per cent of the aggregate rainfall while remaining 9 below normal rainfall years recorded only 18 per cent of the total rainfall. The above normal rainfall 11 years actually received an aggregate 1095 mm rainfall.

On the scale of average April rainfall 11 years should have received only 561 mm rainfall. Hence, the above normal rainfall years recorded an excess of 534 mm rainfall at an average rate of 48.54 mm surplus rain per year. On the other hand, 9 below normal rainfall years receive a total rainfall of 243 mm. Once again, on the scale of normal rainfall the remaining 9 years should have received an aggregate 459 mm rainfall. Hence, it is crucial to note that the below normal rainfall years faced a deficit of 216 mm at an average deficit rate of 24 mm per year. At this point, it is crucial to note that the 11 surplus above normal rainfall years surplus 534 mm was considerably large than 9 below normal rainfall years deficit of 216 mm. This equation suggests that April in the megacity of Bangalore might experience a trend of reasonable increase in the rainfall.

May is the month of pre-monsoon rains. It received an average monthly rainfall of 112 mm. This monthly rainfall is 11.84 per cent of total 8 rainy months. In May out of 20 recent years of rainfall analysis, 10 years recorded above normal rainfall and another 10 years receive below normal rainfall. The 10 above normal rainfall years recorded 68 per cent of the aggregate rainfall whereas the 10 equal number of below normal rainfall years recorded a one third or 32 per cent of the total rainfall. This suggests a trend of raising rainfall to May in the city. The 10 above normal rainfall years actually recorded an aggregate 1660 mm rainfall. On the scale of average may rainfall, 10 years should have received 1120 mm rainfall. Hence, the above normal rainfall years recorded an excess of 540 mm rainfall at an average rate of 54 mm surplus rain per year.

On the other hand, 10 below normal rainfall years receive a total of 768 mm. Here on the scale of normal rainfall the equal number of 10 years should have
received an aggregate 1120 mm rainfall. Here, it is crucial to note that the below normal rainfall years found a deficit of 352 mm at an average deficit rate of 32.5 mm per year. At this point it is crucial to note that the 10 surplus years above normal rainfall surplus or 540 mm was considerably larger than 10 below normal rainfall years deficit of 352 mm. This equation suggests that May in the megacity of Bangalore may also experience a trend of some increase in the rainfall.

June is the first month of monsoon rains as it receives an average monthly rainfall of 95 mm. It is surprising to note that this first month of monsoon receives lesser rainfall than 112 mm pre-monsoon month of May. The June monthly rainfall is 10.04 per cent of 8 monthly rainy period. In June, out of 20 recent years rainfall analysis, 12 years recorded above normal rainfall and 8 years received below normal rainfall. The 12 above normal rainfall years received 78 per cent of the aggregate rainfall while 8 below normal rainfall years recorded only 32 per cent of the total rainfall. This suggests a trend of rising rainfall in June. The 12 above normal rainfall years actually recorded an aggregate 1851 mm rainfall.

On the scale of average June rainfall, 12 years should have recorded an aggregate 1140 mm rainfall. Hence, the above normal rainfall years recorded an excess of 711 mm rainfall also average rate of 59.25 mm surplus rains per years. On the other hand, 8 below normal rainfall years received an aggregate of 529 mm rainfall. Here again, on the scale of normal rainfall, 8 below normal rainfall years should have received an aggregate 760 mm of rainfall. Here, it is significant to note that the below normal rainfall years faced a deficit of 231 mm at an average deficit rate of 28.87 mm per years. At this point, it is significant to note that 12 surplus years of above normal rainfall had an aggregate surplus of 711 mm which is much higher than 352 mm aggregate deficit of 8 below normal rainfall years. This equation suggests that June would also experience a higher trend in the increase of rainfall.

July is normally a well inside monsoon month except in the rain shadow Bangalore. It receives an average monthly rainfall of only 110 mm. Surprisingly, July also receives a lesser rainfall than the pre-monsoon month of May. The July monthly rainfall is 11.62 per cent of the 8 monthly rainy period. In July, out of 20 recent years of rainfall analysis, only 8 years recorded above normal rainfall and 12 years receive below normal rainfall. The 8 above normal rainfall years received 64 per cent of the
rainfall whereas 12 below normal rainfall years recorded 36 per cent of the total rainfall. This suggests a trend of rising rainfall in July. The 8 above normal rainfall years actually recorded an aggregate 1481 mm rainfall.

On the scale of average July rainfall, these 8 years should have recorded an aggregate 880 mm rainfall. Hence, the above normal rainfall years recorded an excess of 601 mm rainfall at an average 75.12 mm surplus rains per year. On the other hand, 12 below normal rainfall years received an aggregate of 849 mm rainfall. Once again, on the scale of normal rainfall, 12 below normal rainfall years should have received an aggregate of 1320 mm rainfall. Hence, it is crucial to note that these below normal rainfall years faced a deficit of 471 mm rainfall at an average deficit of 39.25 mm per year. At this point, it is crucial to note that only 8 above normal rainfall years recorded a higher surplus of 601 mm rainfall than 471 mm deficit for 12 below normal rainfall years. This suggests that July would also experience a trend of some increase in the rainfall.

August is normally the rainiest month except in this rain shadow region where the city of Bangalore is located. It receives an average monthly rainfall of 142 mm. The August monthly rainfall is 15.01 per cent of the eight monthly rainy period. In August, out of 20 recent years of rainfall analysis, 9 years recorded above normal rainfall and 11 years received below normal rainfall. The 9 above normal rainfall years received 68 per cent of the rainfall while 11 below normal rainfall years recorded 32 per cent of the total rainfall. This also suggests a trend of rising rainfall in August. The 9 above normal rainfall years actually recorded an aggregate 2208 mm rainfall.

On the scale of average August rainfall these 9 years should have recorded an aggregate 1278 mm rainfall. Hence, the above normal rainfall years recorded an excess of 930 mm rainfall at an average rate of 103.33 mm surplus rain per year. On the other hand, 11 below normal rainfall years received an aggregate of 1038 mm rainfall. Here again, on the scale of normal August rainfall, 11 below normal rainfall years should have received an aggregate 1562 mm rainfall. Here it is significant to note that these below normal rainfall years faced a deficit of 524 mm rainfall at an average deficit rate a 47.63 mm per year. At this point, it is crucial note that a lesser 9 above normal rainfall years recorded a higher surplus of 930 mm than a smaller
deficit of 524 mm in more numerous 11 below normal rainfall years. This suggests that August would also experience a trend of rising rainfall.

September is the month of retreating N.E. monsoon and reducing rainfall all over India. However, N.E. monsoon winds orient themselves as the advancing monsoon over Bangalore in the Karnataka plateau. As a result, September is the month of highest 211 mm rainfall on an average. The September monthly rainfall is 22.3 per cent of the 8 monthly rainy period. In September out of 20 recent year of rainfall analysis, 9 years recorded above normal rainfall and 11 years received below normal rainfall. The 9 normal above normal rainfall years received 61 per cent of the rainfall whereas 11 below normal rainfall years recorded a significantly high 39 per cent of the total rainfall. This does not suggest a clear verdict of rising trend in September rains.

The above normal rainfall 9 years actually recorded an aggregate 2391 mm rainfall. On the scale of normal September rainfall, these 9 should have recorded an aggregate 1899 mm rainfall. Hence the above normal rainfall years recorded and excess of only 492 mm rainfall at an average rate of 54.66 mm surplus rain per year. On the other hand, 11 below normal rainfall years received and aggregate of 1499 mm rainfall. On the scale of normal September rainfall, these 11 below normal rainfall years should have received an aggregate 2321 mm rainfall. Here, it is significant to note that this below normal rainfall years faced a massive deficit of 822 mm rainfall at an average deficit of 74.72 mm per year. At this point, it is crucial to note that the yearly rainfall deficit is much greater than the yearly surplus rainfall. This gives a clear indication of decreasing rainfall trends in September.

October is the month of end of the monsoon in most parts of India. However, the retreating monsoon is never a retreating monsoon in Bangalore and Chennai. As a result, October received a substantial second highest rainfall of 164 mm on an average. The October monthly rainfall is 17.34 per cent of the 8 monthly rainy period. In October, out of 20 recent years of rainfall analysis, 12 years recorded above normal rainfall and 8 years received below normal rainfall. The above normal rainfall 12 years received 77 per cent of the rainfall while 8 below normal rainfall years recorded only 23 per cent of the total rainfall. This equation suggests a trend of increasing rainfall in October.
The 12 above normal rainfall years actually recorded an aggregate 3032 mm rainfall. On the scale of normal October rainfall, these 12 years should have recorded an aggregate of only 1968 mm rainfall. Hence, the above normal rainfall years recorded and excess of 1064 mm rainfall at an average rate of 88.66 mm surplus rain per year. On the other hand, 8 below normal rainfall years receive an aggregate of 925 mm rainfall. On the scale of normal October rainfall, these 8 below normal rainfall years should have received an aggregate 1312 mm rainfall. Here, it is crucial to note that these below normal rainfall years faced a deficit of 387 mm at an average deficit of 48.37 mm per year. At this point, it is significant to note that the yearly rainfall surplus is much greater than the yearly rainfall deficit. This scenario suggests a trend of increasing rainfall in October.

November is the last rainy month outside the monsoon region in most part of India. However, it does provide a cognizable amount of rainfall. November receives the second lowest rainfall of 61 mm in Bangalore. The November monthly rainfall is 6.45 per cent of the 8 monthly rainy period. In November, out of 20 recent years of rainfall analysis, only 8 years recorded above normal rainfall and 12 years received below normal rainfall. The 8 above normal rainfall years received 71 per cent of the rainfall whereas 12 below normal rainfall years recorded 29 per cent of the total rainfall. The 8 above normal rainfall years actually recorded an aggregate 814 mm rainfall.

On the scale of normal November rainfall, these 8 years should have recorded an aggregate of only 488 mm rainfall. Hence, the normal rainfall years recorded a modest excess of 326 mm rainfall at an average rate of 40.75 mm surplus rain per year. On the other hand, 12 below normal rainfall years have received an aggregate of 330 mm rainfall. On the scale of normal November rainfall, these 12 below rainfall years should have received an aggregate 732 mm rainfall. Here, it is significant to note that these below normal rainfall years faced a deficit of 402 mm at an average deficit of 33.5 mm per year. At this point, it is crucial note that the total deficit of 12 below normal rainfall years amounting to 402 mm was more than the total surplus of 8 above normal rainfall years amounting to only 326 mm. This scenario suggests a trend of decreasing rainfall in November.
A temporal analysis of the recent changes in the above and below number of rainy days as a consequence of urban heat island would hold a great significance in verifying the relationship between the number of rainfall years and the number of rainy days. This may considerably help in examining the changes in the rainfall intensity as well. Table 5.6 reveals the trends in the number of above and below normal rainy days in all months of rainy period in the megacity of Bangalore. It illustrates that the number of rainy days of the recent 20 years from 1991-2010. The annual trend of number of rainy days shows that Bangalore has a yearly average of 58 rainy days over and above an 8 monthly long rainy period.

During the 20 years of annual analysis 14 years witnessed above normal number of rainy days i.e., more than 58 days. The above normal rainy days were 76 per cent of the aggregate rainy days. In 14 years of above normal rainy days, the aggregate number of normal rainy days were actually 933 days whereas at the rate of an average 58 rainy days per year the total number of rainy days in 14 years should have been 812 days. Hence, the above normal rainy days were in excess of 121 days during the period of analysis.

On the other hand, Bangalore experienced only 6 years of below normal number of rainy days. In these 6 years the number of rainy days in each year were less than 58 rainy days. The below normal rainy days were 24 per cent of the total rainy days. In 6 years of below normal rainy days the aggregate number of below normal rainy days were actually 290 days while at the rate of an average 58 rainy days per year the total number of rainy days in 6 years should have been 348 days. Hence, the actual below normal rainy days were in a deficit of 58 days during the period of analysis. By equation of surplus-rain 121 days vis-a-vis deficit-rain of 58 days, suggests a trend of increase in the number of rainy days.

In April there are an average number of three rainy days in the megacity of Bangalore. During 20 years of rainy days analysis in April as many as 15 years recorded above normal rainy days. The above normal rainy days were 91 per cent of the aggregate rainy days. In 15 years of above normal rainy days, the aggregate number of above normal rainy days were actually 71 days whereas at the rate of an average 3 rainy days per year the total number of rainy days in 15 years should have been 45 days. Hence, the above normal rainy days were in excess of 26 days during
TABLE 5.6
Bangalore: Recent Trends in Above and Below Normal Number of Rainy Days

<table>
<thead>
<tr>
<th>Rainy Months</th>
<th>Average Rainy Days</th>
<th>Years of Above Normal Rainy Days</th>
<th>Total Rainy Days in Above Normal Rainy Years</th>
<th>Percentage of Above Normal Rainy Days</th>
<th>Years of Below Normal Rainy Days</th>
<th>Total Rainy Days in Below Normal Rainy Years</th>
<th>Percentage of Below Normal Rainy Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>3</td>
<td>15</td>
<td>71</td>
<td>91</td>
<td>5</td>
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<td>9</td>
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<td>7</td>
<td>14</td>
<td>123</td>
<td>82</td>
<td>6</td>
<td>27</td>
<td>18</td>
</tr>
<tr>
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<td>14</td>
<td>109</td>
<td>81</td>
<td>6</td>
<td>25</td>
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<td>11</td>
<td>107</td>
<td>72</td>
<td>9</td>
<td>41</td>
<td>28</td>
</tr>
<tr>
<td>August</td>
<td>10</td>
<td>12</td>
<td>141</td>
<td>72</td>
<td>8</td>
<td>56</td>
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<td>86</td>
<td>7</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
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<td><strong>14</strong></td>
<td><strong>933</strong></td>
<td><strong>76</strong></td>
<td><strong>6</strong></td>
<td><strong>290</strong></td>
<td><strong>24</strong></td>
</tr>
</tbody>
</table>

Source: Computed on the Basis of Meteorological Data.
the period of analysis. On the other hand, April experienced only 5 years of below normal number of rainy days. The below normal rainy days were only 9 per cent of the total rainy days. In 5 years of below normal rainy days, the aggregate number of below normal rainy days were actually 7 days whereas at the rate of an average 3 rainy days in April the total number of rainy days in April should have been 15 rainy days. Here, the actual below normal rainy days were in a deficit of 8 rainy days during the period of analysis. The equation of 26 surplus of rainy days vis-a-vis 8 deficit rainy days suggest a trend of considerable increase in the number of rainy days.

May in Bangalore has an average number of 7 rainy days. During 20 years of rainy days analysis of May, as many as 14 years recorded above normal rainy days. The above normal rainy days were 82 per cent of the aggregate rainy days. In 14 years of above normal rainy days, the aggregate number of above normal rainy days were actually 123 days while at the rate of an average 7 rainy days per year the total number of rainy days in 14 years should have been 98 days. Hence, the above normal rainy days were in excess of 25 days during the period of analysis.

On the other hand, May experience only 6 years of below normal at number of rainy days. The below normal rainy days were only 18 per cent of the total rainy days. In 6 years of below normal rainy days the aggregate number of below normal rainy days were actually 27 days whereas at the rate of an average rainy days in May the total number of rainy days should have been 42 days. Hence, the actual below normal rainy days were in deficit of 15 rainy days during the period of analysis. The equation of 25 surplus rainy days vis-a-vis 15 deficit rainy days suggest a trend of considerable increase in the number of rainy days.

June in Bangalore has an average number of 6 rainy days only. During 20 years of rainy days analysis of June as many as 14 years recorded above normal rainy days. The above normal rainy days were 81 per cent of the aggregate rainy days. In 14 years of above normal rainy days the aggregate number of above normal rainy days were actually 109 days, while at the rate of an average 6 rainy days per year the total number of rainy days in 14 years should have been 84 days. Hence, the above normal number rainy days were in surplus of 25 days during the period of analysis. On the other hand, June experienced only 6 years of below normal number of rainy days.
The below normal rainy days were only 19 per cent of the total rainy days. In 6 years of below normal rainy days the aggregate number of below normal rainy days were actually 25 days whereas at the rate of an average 6 rainy days in June the total number of below normal rainy days should have been 36 days. Hence, the actual below normal rainy days were in deficit of 11 days during the period of analysis. The equation of 25 surplus rainy days vis-à-vis 11 deficit rainy days also suggest a trend of considerable increase in the number of rainy days.

July in Bangalore has an average number of 7 rainy days. During 20 recent years of rainy days analysis of July 11 years recorded above normal rainy days. The above normal rainy days were 72 per cent of the aggregate rainy days. In 11 years of above normal rainy days, the aggregate number of above normal rainy days were actually 107 days, whereas at an average 7 rainy days per years the total number of rainy days in 11 years should have been 77 days. Hence, the above normal rainy days were in surplus of 30 days during the period of analysis. On the other hand, July experienced 9 years of below normal rainy days. The below normal rainy days were 28 per cent of the total rainy days. In 9 years of below normal days the aggregate number of below normal rainy days were actually 41 days while at the rate of an average 7 rainy days in July the total number of below normal rainy days should have been 63 days. Hence, the actual below normal rainy days were in deficit of 22 days during the period of analysis. The equation of 30 surplus rainy days vis-à-vis by deficit rainy days suggests a trend of marginal increase in the number of rainy days.

August is the month of widespread rain all over India. However, in Bangalore it is not a month of robust rainfall. But as monsoon is prevalent here with less vigorous showers the number of rainy days are not less. August has an average number of 10 days. During 20 recent years of rainy days analysis for August, 12 years recorded above normal rainy days. The above normal rainy days were 72 per cent of the aggregate rainy days. In 12 years of above normal rainy days, the aggregate number of above normal rainy days were actually 141 days, whereas at the rate of an average 10 rainy days per year the total number of rainy days in 12 years should have
been 120 days. Hence, the above normal rainy days were in surplus of 21 days during the period of analysis.

On the other hand, August experienced 8 years of below normal number of rainy days. The below normal rainy days were 28 per cent of the aggregate rainy days. In 8 years of below normal rainy days, the aggregate number of below normal rainy days were actually 56 days, while at the rate of an average 10 rainy days in August the total number of below normal rainy days should have been 80 days. Hence, the actual number of below normal rainy days were in deficit of 24 days during the period of analysis. The equation of 21 surplus rainy days vis-a-vis 24 deficit rainy days suggest a trend of negligible of negative growth in the number of rainy days.

Although September is the month of retreating monsoon all over India, but in Bangalore monsoon is in its full swing in this month. Hence, September has highest rainfall and an average largest number of 10 rainy days. During 20 recent years of rainy days analysis for September only 8 years recorded above normal number of rainy days, the above normal rainy days were only 56 per cent of the aggregate rainy days. In 8 years of above normal rainy days, the aggregate number of above normal rainy days were actually 105 days. Whereas at the rate of an average 10 rainy days per year the total number of rainy days in 8 years should have been 80 days.

Hence, the above normal rainy days were in surplus of 25 days during the period of analysis. On the other hand, September experienced 12 years of below normal number of rainy days. The below normal rainy days were at an exceptionally high 44 per cent of aggregate rainy days. In 12 years of below normal rainy days, the aggregate number of below normal rainy days were actually 82 days, while at the rate of an average 10 rainy days in September the total number of below normal rainy days should have been 120 days. Hence, the actual number of below normal rainy days were in deficit of 38 days during the period of analysis. The equation of 25 surplus rainy days vis-a-vis 38 deficit rainy days suggest a likely trend of decreasing number of rainy days.

October is also a month of fairly high rainfall in Bangalore. It has an average number of 8 rainy days. During 20 recent years of rainy days analysis for October, 17 highest number of years recorded above normal number of rainy days. In these 17 years, the above normal rainy days were also the highest 92 per cent of the aggregate
rainy days. In 17 years above normal rainy days, the aggregate number of above
normal rainy days were also the highest 175 days, whereas at the rate of an average 8
rainy days per October the total number of rainy days in 17 years should have been
136 days. Hence, the above normal rainy days were in surplus of 39 days during the
period of analysis.

On the other hand, October experienced a paltry 3 years of below normal
number of rainy days. The below normal rainy days had a dismally low 8 per cent of
the aggregate rainy days. In 3 years of below normal rainy days the aggregate number
of below normal rainy days were actually 16 days, whereas at the rate of an average 8
rainy days in October the total number of below normal rainy days should have bee
only 24 days. Hence, the actual number of below normal rainy days were in deficit of
8 days during the period of analysis. The equation of 39 surplus rainy days vis-à-vis 8
deficit rainy days suggest a likely trend of considerable increase in the number of
rainy days.

November is the last rainy month of the extended rainy period in Bangalore. It
has an average number of 4 rainy days. During 20 recent years of rainy days analysis
for November, 13 years recorded above normal number of rainy days. In this 13
years, the above normal rainy days were 86 per cent of the aggregate rainy days. In 13
years of above normal rainy days, the aggregate number of above normal rainy days
were actually 72 days, whereas at the rate of an average 4 rainy days per November
the total number of rainy days in 13 years should have been 52 days. Hence, the above
normal rainy days were in surplus of 20 days during the period of analysis.

On the other hand, November experienced only 7 years of below normal
number of rainy days. The below normal rainy days were 14 per cent of the aggregate
rainy days. In 7 years of below normal rainy days the aggregate number of below
normal rainy days were actually 12 days, while at the rate of an average 4 days in
November the total number of below normal rainy days should have been only 28
days. Hence, the actual number of below normal rainy days were in deficit of 16 days
during the period of analysis. The equation of 20 surplus rainy days vis-à-vis 16
deficit rainy days suggest a trend of only a marginal increase in the number of rainy
days.
Figure 5.27 illustrates the mean annual rainfall regression of Bangalore on the meteorological data for the period 1961-2010. The scatter plot in the diagram depicts that the mean annual rainfall variability is moderate in comparison to very high variability in Ahmedabad. In Bangalore the mean annual rainfall variability is comparatively lower than several rainy months like May, June and September. Because of the moderate annual rainfall variability the regression trend has shown a better close fit pattern for many years.

As a result of it, the annual rainfall observation are near the regression slope line. The linear regression slope depicts a fairly steep gradient. Interestingly, the regression slope is positive it indicates a trend of high rainfall growth. The rainfall regression slope of the longest rainy season Bangalore is identical to the rainfall regression slope of the shortest rainy season Ahmedabad. The gross regression of annual rainfall shows a high increase of 148.813 mm rainfall in Bangalore in the last 50 years.

Figure 5.28 is based on the result of the regression analysis of the mean monthly and mean annual data of the amount of rainfall in Bangalore over a period of 1961-2010. The transition values of the rainfall regression diagrams of different months have been plotted here in this histogram. Bangalore has an extended rainy period spanning over 8 month. In Bangalore, April is the first month of considerable rains. Although April is the month of lowest average rainfall of only 51 mm, still it has recorded a high rainfall growth of 28.2 mm over its small average in the last 50 years. This is a very high increase of 55.3 per cent rainfall in April. May has experienced 18.326 mm rainfall growth, which amount to 16.4 per cent rainfall increase over its monthly average rainfall. June happens to be the first monsoon month of feeble rainfall in Bangalore. It has recorded a highest 55.076 mm rainfall growth. This also amounts to highest 58 per cent rainfall increase over its monthly average rainfall.

July is also a month of mean rainfall in Bangalore. It has recorded 25.872 mm rainfall growth in the last 50 years. This has scored 23.5 per cent increase over it monthly average rainfall. August is the month of moderate rainfall in Bangalore. It has recorded 31.213 mm rainfall increase the last 50 years. This accounts to 22 per cent increase over its monthly average rainfall. September is the month of highest rainfall in Bangalore. It falls in the retreating monsoon regime. September has
Fig. 5.27

Source: Computed and Cartographed by the Researcher from IMD Data, Pune.
Fig. 5.28

Bangalore : Transition in Mean Monthly Rainfall
(1961 - 2010)

Rainfall (mm)

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

Fig. 5.28
experienced a 14.504 mm decrease in its monthly rainfall. This demonstrates 6.9 per cent decrease over its monthly average rainfall.

October is the month of fairly high amount of rainfall in Bangalore. It has recorded a very high 39.935 mm increase in its monthly rainfall, it amounts to 24.3 per cent growth over it monthly average rainfall. November is the last month of another low rainfall. It has also experience a negative growth in its rainfall like the month of September. It has witnessed 23.235 decrease in its monthly rainfall. This reveals a 41.3 per cent decrease over its already low monthly average rainfall. It means the amount of rainfall is rapidly decreasing in the last rainy month. Hence, it indicates a shortening of Bangalore’s long rainy season in the long run. Ultimately, annual regression values of rainfall in Bangalore have depicted a robust positive transition. The amount of annual rainfall in this megacity has increased by 148.813 mm. It has recorded a high 15 per cent increase over its already high annual rainfall.

**Transition in Mean Monthly Number of Rainy Days: Bangalore**

Figure 5.29 is based on the results of the regression analysis of the mean monthly and mean annual data of number of rainy days in Bangalore over a period of 1961-2010. The transition values of rainy days regression of different months have been plotted on a composite histogram. Bangalore city has an extended rainy period of 8 months. This rainy period spans over more than a rainy season. The monthly transitional value of April reveal that, as this month has thrice the above normal rainy years of 15 in comparison to only five below normal rainy years, in the recent years it has depicted trend of increasing number of rainy days.

April has experienced an increase of 1.078 rainy days over its monthly average of only 3 rainy days. It has recorded a 35.9 per cent increase in its average number of rainy days. The largest increase in the number of rainy days in the first rainy month in Bangalore indicates an expansion in the rainy period coupled with a growing amount of April rainfall. The increase of one rainy day in April with a corresponding increase of 28 mm rainfall depicts a rising rainfall intensity as well.

The monthly transitional values of May reveal that, as this month has 14 years of above normal rainy days in comparison to 6 years of below normal rainy days, in
Bangalore: Transition in Mean Number of Rainy Days
(1961 - 2010)

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

Fig. 5.29
the recent years it has also depicted a trend of increasing number of rainy days. May has experienced a highest increase of 1.96 days over its monthly average of 7 rainy days. It has recorded a 28 per cent increase in its average number of rainy days. This large increase in the number of rainy days in May is coupled with increasing amount of rainfall in May. The increase of 1.96 rainy days in May with the corresponding increase of 18.3 mm rainfall depicts an additional rising rainfall intensity of 9.3 mm in one rainy day. The monthly transitional values of June reveal that, despite this month has 14 above normal rainy day years in comparison to 6 below normal rainy day years in the recent years it has not depicted any trend of incoming number of rainy days. This no increase in the number of rainy days in June is coupled with the highest 55 mm increase in the amount of rainfall in June. This equation indicates that June has experienced a highest increase in its rainfall intensity.

The monthly transitional values of July reveal that, as this month has 11 years of above normal rainy days in comparison to 9 years of below rainy days it has also depicted a trend of increasing number of rainy days. July has experienced a slight increase of 0.294 days over its monthly average of 7 rainy days. It has recorded a 4.2 per cent increase in its average number of rainy days. This marginal increase in the number of rainy days in July is coupled with considerable increase in the amount of rainfall. The increase of 0.294 rainy days in July with the corresponding increase of 25.872 mm rainfall depicts an additional rising rainfall intensity in July.

The monthly transitional values of August reveal that, despite this month has 12 years of above normal rainy days in comparison to 8 years of below normal rainy days, it has depicted a trend of decreasing rainy days. August has experienced a decrease of 0.539 days over its monthly average of 10 rainy days. It has recorded a 5.4 per cent decrease in its average number of rainy days. This noticeable decrease in the number of rainy days in August is coupled with considerable increase in the amount of rainfall. The decrease of 0.539 rainy days with a corresponding increase of 31.213 mm rainfall clearly depicts a trend of increasing rainfall intensity in August.

The monthly transitional values of number of rainy days in September reveal that this month has 8 years of above normal rainy days as against 12 years of below normal rainy days. It gives a hint of decreasing rainy days in September. September has also experienced a decrease of 0.392 days over its monthly average of 10 rainy
days. This slight decrease in the number of rainy days in September is coupled with a corresponding decrease in the amount of rainfall. The decrease of 0.392 rainy days along with a corresponding decrease of 14.504 mm rainfall depicts a trend of decreasing rainfall intensity.

The monthly transition values in the number of rainy days in October reveal that this month has the largest 17 years of above normal rainy days as against only three years of below normal rainy days. It suggests a trend of formidable increase in the number of rainy days in October. This month has experienced a visibly high increase of 1.274 days over its monthly average of 8 rainy days. The robust increase in the number of rainy days in October is coupled with a corresponding increase in the amount of rainfall. The increase of 1.274 rainy days along with an increase of 39.935 mm rainfall depicts a higher order positive trend at both the ends. It reveals the fact that October has experienced the biggest rainfall positives followed by April and May.

The monthly transitional values of the number of rainy days in November are associated with pattern of 13 years of above normal rainy days in comparison to 7 years of below normal rainy days. It suggests a trend of reasonable increase in the number of rainy days in November. This month has experienced a cognizable increase of 0.49 days over its monthly average of 4 rainy days. The increase in the number of rainy days is coupled with a considerable decrease in the amount of rainfall. The increase of 0.49 rainy days along with a decrease of 25.235 mm rainfall depicts a decrease in the rainfall intensity in the last raining month of November.

Ultimately, the mean annual transition values of the number of rainy days in Bangalore city have been examined in association with the annual pattern of above and below normal number of rainy days. Out of 20 recent years of annual analysis, Bangalore recorded 14 years of above normal rainy days as against 6 years of below normal rainy days. It suggests an annual trend of considerable increase in the number of rainy days. Bangalore has experienced an appreciable annual increase of 3.773 rainy days over its annual average of 58 rainy days. The increase in the number of annual rainy days is coupled with a very high increase in the annual average rainfall. An equation of annual increase of 3.773 rainy days also with an impressive increase of 148.813 mm annual rainfall in Bangalore reveals a higher order of positive trend at both the complementary ends.