5.1 Introduction

Rainfall is considered as the foremost hydrological phenomenon among all other events. It is a climate parameter that shapes the way and manner man lives. Further it controls every aspect of the ecological system, flora and fauna inclusive (Obot et al., 2010). Regime, amount and variability of rainfall are dominant natural factors that affect basically the life and economy of the people (Gadgil, 2002). Therefore, rainfall has always attracted the greatest attention of natural philosophers and meteorologists as it is one of the most important and conspicuous of all atmospheric processes and it has direct relevance to the very survival of all sorts of life (Pant and Rupa Kumar, 1997).

In a variety of climatic patterns of the world, ‘monsoon’ is very peculiar. Monsoons are observed in different parts of the world, but Indian southwest monsoon stands out amongst all of them. It is an important component of the earth’s total climate system and has connections with the global atmospheric circulation (Kelkar, 2009). The monsoon rainfall of India is not uniform in time as well as its amount and distribution is grossly uneven. The variability in monsoon rainfall strongly linked with the society and economy of monsoon countries (Sajani et al., 2007). In view of Kelkar (2009), the Indian monsoon is indeed ‘the monsoon’.

Various studies on Indian monsoon rainfall have been made worldwide including India to understand different facets of Indian monsoon rainfall. These studies mostly are carried out on the administrative areas such as the whole nation, state or at the district level. In comparison of the investigations of the rainfall at nation level, the similar scientific studies at natural regions such as river basins are very limited. A natural region, for instance a river basin can certainly reveal great variations in the distribution of rainfall on spatial and temporal scales. In addition to this, the large variations in the total rainfall from one year to another may also be observed at a basin level. Therefore, the study of rainfall on river basin scale is,
indeed, more practical for water resource management within the basin. Kamaraju and Subrahmanyam (1984) stated that a detailed knowledge of the seasonal and annual distribution of precipitation over the basin is highly essential for any analytical work on water balance and utilization.

Forming a part of the tropical monsoonal lands, the Tapi Basin situated in the central-western India displays all the significant characteristics of monsoon rainfall. The regimes of rainfall have strong influence on the natural and cultural environment of an area. Therefore, the preset work is an endeavor to identify characteristics of rainfall over the Tapi Basin. In the study an attempt has been made to reveal the regime characteristics and spatio-temporal aspects of rainfall. In addition, analyses have been carried out to recognize the rainfall trends and properties of the long-term fluctuations in the rainfall over the basin. Summarizing the exercises done in the previous chapters this chapter presents the major results to unveil the rainfall characteristics of the Tapi Basin.

5.2 Regime characteristics of rainfall

Among the dominant natural factors which strongly influence the life and economy of the people, the regime of rainfall is important (Gadgil, 2002). Beckinsale (1969) defined the regime of a rainfall as the variations in its amount. The importance of the study of rainfall regime lies in its significance to recognize the variations in total amount of rainfall at different places of a region and to understand the general pattern of rainfall within it. Regime characteristics of rainfall represent the general picture of the rainfall of a place or a region and can be used for various hydrological purposes.

The rainfall in the Tapi Basin shows significant variations in space and time. The rainfall regime in different parts of the basin is not identical. Specifically, distinct rainfall regime can be observed in the hilly regions and the plains in the basin. Therefore, the Western Ghats to the west, Satpura Ranges to the north, Ajanta Ranges to the south and Gawilgad Range and Betul Plateau to the east present differential rainfall regime than the plains of the Tapi River and its tributaries. Therefore, the
principal rainfall regime characteristics of the basin have been investigated in chapter 2 and the major conclusions are summarized below.

The average annual rainfall of the Tapi Basin is 814 mm comprising large spatio-temporal variation. Chikhaldara is the rainiest place in the basin, receives 1596 mm average annual rainfall, which is almost double than the average annual rainfall of the Tapi Basin. Whereas, Sakri is the lowest rainfall receiving station having average annual rainfall just 511 mm. The rainfall in the Tapi Basin shows the supremacy of south-west monsoon season. The basin receives nearly 87% of its total rainfall in monsoon season (June to September) and remaining 13% in non-monsoon season (October to May). July is the rainiest month in the basin, contributes about 29% of the annual rainfall. Whereas, April is the driest month in the basin obtains negligible amount of rainfall. High rainfall stations obtain substantial proportion of annual rainfall in monsoonal months and less in non-monsoon season. For example, Chikhaldara, Dharani, and Surat obtain more than 90% of their annual rainfall in monsoon season and non-monsoon season contributes less than 10% of the annual total. Whereas, at low rainfall stations, such as Malegaon, Satana and Sakri, monsoon season contribute about 80% of annual rainfall and non-monsoon season also receives about 20% of annual rainfall of the station. The average annual rainy days of the basin are 44 per year with high variation from one station to another. The number of rainy days at various stations of the basin varies between 30 and 70. The numbers of rainy days of the various stations in the basin are strongly associated with their annual rainfall totals, showing positive correlations. Moreover, the pattern of rainy days in the basin follows the pattern of annual rainfall that is, high rainfall stations (low rainfall stations) have high number (less number) of rainy days. Chikhaldara, the heaviest rainfall station of the basin has highest number of rainy days (71) in the basin while Sakri, the lowest rainfall station has lowest number of rainy days (31) all over the basin. On the basin scale, July comprises highest number of rainy days (12) in the year followed by August (11 rainy days).

A distinct feature of Indian monsoon rainfall is infrequent heaviness of the fall in short period of time. Considering the average annual rainfall of the Tapi Basin (814 mm) and its average annual rainy days (44), on an average, there is about 20 mm
rainfall per rainy day in the basin. However, many heavy to very heavy rainfall spells are on record at various locations in the basin. The 600.6 mm 24 hr rainfall at Amalner on July 30, 1992 is the highest one-day rainfall on record in the basin. The investigation of the highest 24 hr rainfall events in the basin reveals that in general, the heavi ness of such events owes to their locations either in the hilly tracts or nearness to sea. Extreme rainfall events, as well as their contribution in the seasonal rainfall (JJAS) over the Tapi Basin are increasing. The study revealed that the average annual rainy days are decreasing, however, average annual rainfall of the basin is neither increasing nor decreasing. The study, therefore, supports the general thought of climate change and subsequently signifies an increase in disaster potential in the basin. Recurrence interval of one-day rainfall up to 200 mm, which is about one-fourth of the basin’s average annual rainfall is quiet common in the basin and almost each year experiences 24 hr rainfall events equal to 200 mm. The possibility of 24 hr rainfall over 300 mm (nearly 40% of average annual rainfall of the basin) is in 4 to 5 years. Though a few in number, one-day rainfall about half (400 mm) of the average annual rainfall of the basin is not unusual and shows recurrence interval of 10 to 12 years. The exceptional one-day rainfalls equal or more than 600 mm contributing 70 to 75% of average annual rainfall of the basin are very rare and shows recurrence interval of about 100 years. Therefore, the possibility of such phenomenal rainfall events to happen in the basin is once in a century.

5.3 Spatial-temporal aspects of rainfall

Although the monsoons are a regular phenomenon, there are fluctuations in their intensity and spatial extent on time scales ranging from days to centuries (Pant and Rupa Kumar, 1997). In addition, it exhibits a wide spectrum of variability on daily, sub-seasonal, inter-annual, decadal and centennial time scales (Rajeevan et al. 2010). The variability in the monsoon rainfall occasionally leads to the extreme hydrological events such as droughts and floods which affects the huge population and national economy (Kripalani et al. 2003). Hence, the variability in the Indian monsoon especially in the global warming scenario is a topic of intense scientific
debate. Several studies are carried out on the variable nature of monsoon rainfall of the country on both space and time scales.

Being a part of an inherent monsoonal region, the Tapi Basin reflects all typical features of the monsoon rainfall. The Tapi Basin receives rainfall predominantly during the southwest monsoon period and a small fraction of it is associated with rest period of the year. The rainfall over the region is, therefore, highly seasonal. Nevertheless, there is variability in the rainfall on both space and time scales. Therefore, a comprehensive analysis of rainfall based on the available data can present temporal fluctuations and spatial patterns of the basin rainfall. Variability, both over time and space is an important attribute of rainfall in the Tapi Basin which impinges on its resource value and utilization. Therefore, following the discussion on the regime characteristics of rainfall in the chapter 2, variability in rainfall with respect to space and time has been discussed in chapter 3. The principal aim to analyze the annual rainfall data was to understand spatio-temporal variability in the basin. The major results of the study are as under.

The Tapi Basin illustrates a significant spatially diversified rainfall. Particularly, the eastern and western marginal areas of the basin show strongly non-uniform amount of rainfall than the rest of the area. With reference to the average annual rainfall of the basin and its standard deviation, the whole basin can be divided into three main zones- high rainfall zone, medium rainfall zone and low rainfall zone. The north-eastern part covered by the rugged relief of the Gawilgad Range and the extreme western area of the basin receiving reasonably high rainfall, lie in the first zone. The widespread area in the central and south-eastern part of the basin, formed by the river plains receives rainfall close to the basin’s average are categorized into second zone and a small pocket in the south-west of the basin, contiguous to the western high rainfall zone, falls in the third zone. The high rainfall zone of the basin is characterized by great variation in the amount of rainfall in short distance. While, the extensive river plains in the central part of the basin are characterized by almost uniform amount of rainfall. Similarly, the low rainfall zone of the basin in the south-west also obtains uniform amount of rainfall. The high rainfall zone of the basin is characterized by great variation in the amount of rainfall in short distance. Whereas,
the extensive river plains in the central part of the basin are characterized by almost uniform amount of rainfall. Similarly, the low rainfall zone of the basin in the south-west also obtains uniform amount of rainfall. In general, the spatial pattern of rainfall in the Tapi Basin exhibits a decreasing pattern from east to west with abrupt rise in rainfall to the western edge of the basin.

The spatial distribution of rainfall in the basin is orographically controlled. The Western Ghats plays a key role in rainfall diversity in the basin. The continuity and elevation of the Western Ghats and its offshoots acts as a barrier to the south-western monsoon winds and consequentially resulted into heavy rainfall on the windward side and produce a ‘rain-shadow’ area to the leeward side. A low rainfall zone in the south-west of the basin is in fact the ‘rain shadow’ area which is an outcome of orographic effect of the Western Ghats. All six stations viz. Malegaon, Nandgaon, Satana, Dhule, Sakri and Shindkheda from this zone receive remarkable low rainfall, about 25-35% less than the basin’s average rainfall. The lowest rainfall at Sakri is attributed to its specific location. The Galana Range, the east-west trending offshoot of the Western Ghats runs across the path of monsoon winds and is situated in the rain shadow zone of the main rim of the Western Ghats. Therefore, it can be stated that Sakri is located in the ‘secondary rain shadow area’ which is the significant reason for very low rainfall in this region. The effect of orography on the rainfall clearly visible in the north-eastern high rainfall zone of the basin. This part of the basin is covered by the Gawilgad Range. With its considerable length and uniformity in elevation, the area environs the Gawilgad Range gets high orographic rainfall which accounts for more than 1000 mm. Chikhaldara, situated on the crest line of the Gawilgad Range, receives highest rainfall (1596 mm) in the basin which is about two times more than the basin’s average rainfall. An important and most immediately felt aspect of rainfall of the basin is its inter-annual variability. However, the coefficient of variation (Cv) of the Tapi basin as a unit is 30% suggesting that the rainfall of the basin is less variable. The values of coefficient of skewness (Cs) are positive for all the stations in the basin proposing the occurrence of one or two or a few very wet (high rainfall) years during the gauged period.

Two contrasting features of the rainfall can be noticed in two parts of the 20th
century. It is observed that in comparison of the rainfall in the second half of the century, rainfall in the first half of the century was more variable. Nevertheless, the first half of the century is characterized by above-average rainfall. Thereafter less variability in the rainfall is observed. The basin received not only average rainfall but also less variable rainfall in the second half of the 20th century. The rainfall over the basin, in general, varies between -30 and +30% from its mean. However, in some instances the maximum departure of rainfall is observed between -40 to +40% from the mean. It therefore, reveals that the rainfall of the Tapi Basin as a geographical unit is less variable. The seasonal rainfall of the basin for the period 1901-1950 shows an increasing trend, which come down in the period 1951-2004 and does not present any specific trend. The consistency of rainfall in June in the first half of the century turns into an increasing trend in the second half. July and September presents clear opposing rainfall trends in two parts of the century. Whereas, an increasing trend of rainfall in August in the first half of the century stabilized in the second half of it. The rainfall over the Tapi Basin demonstrates alternating sequences of multi-decadal periods having excess and deficient rainfall. This epochal behaviour of rainfall of the basin can be summarized in three periods:

(i) 1901-1930: dry epoch
(ii) 1931-1960: wet epoch and
(iii) 1961-1990: dry epoch.

The epochal pattern of the rainfall of the Tapi Basin is quite similar to that found over the country. The Tapi Basin neither experienced any widespread severe drought nor a severe flood over the period of a century.

5.4 Long-term fluctuations in the monsoon rainfall

A question of prime importance to rainfall studies in India is whether the monsoon rainfall has changed over the last few decades and whether a change is likely to occur in future. Although it is difficult to recognize the likely future trend of rainfall, it is possible to detect the nature of changes that have occurred in the past. Determining the trends or changes in the rainfall are extremely important because
studies of hydro-meteorological conditions caused them is useful to detect climatic changes (Kale, 1999).

There are many studies carried out to detect the rainfall trend on all India or regional scales. However, the studies of rainfall records to determine long-term trends/changes on river basin scale are very limited. In chapter 4, therefore, an attempt has been made to analyze the annual rainfall data of the Tapi Basin in view to obtain the long-term trends/changes over the basin. The principal findings are summarized below.

Significant decreasing trend of rainfall at 0.05 level is observed for Chikhaldara, a highest rainfall receiving station in the basin. Conversely, Sakri, the lowest rainfall receiving station in the basin present significant increasing trend of rainfall at 0.05 level. Therefore, in general it is found that the annual rainfall is decreasing with respect to time at high rainfall stations in the basin. Apposite to it, low rainfall stations in the basin present an increasing trend of rainfall. However, the stations having similar rainfall amount with the basin does not indicate any considerable trend. High rainfall stations (such as Chikhaldara) demonstrate below-average rainfall conditions upto 1930. The middle part of the 20th century i.e. from 1930 to 1960 is featured by above-average rainfall conditions which alter into below-average rainfall conditions after 1960. The low rainfall stations (e.g. Sakri) exhibit below-average rainfall conditions in the early stage of the century, upto 1940. While, the period after 1940 is characterized by continuous above-average rainfall situations. The stations having average rainfall close to the basin’s average (for example, Jamner) display an asymmetrical temporal pattern of rainfall. These stations does not signify any specific direction of change in rainfall amalgamating alternate below and above-average rainfall periods with regular interval.

A composite picture of the long-term fluctuations of rainfall on the basin scale point towards some significant characteristics of the rainfall.

(i) The early period of the 20th century i.e. 1901 to 1930 is associated with the below-average (low) rainfall.
(ii) Above-average (high rainfall) period is observed between 1930 and 1960.

(iii) Below-average (low) rainfall period, in the latter half of the 20th century i.e. after 1960.

Therefore, the analysis of the annual rainfall data of the basin with respect to the deviations in the amount clearly indicates that the major changes in the rainfall occurred around 1930, 1960, and 1990.

The monsoon rainfall in the Tapi Basin is teleconnected with some global parameters. One of the important parameters is El Niño and Southern Oscillation (ENSO). The probability of having high rainfall in the basin is more (44%) during cold ENSO conditions and very less (11%) during warm ENSO conditions and vice versa. It therefore, indicates that during the cold ENSO (warm ENSO) events the magnitude of rainfall will be higher (lower). It is observed that on the basin scale 16% change in the annual rainfall is required in the average rainfall of next 10 years to consider it different than the available rainfall record. Similarly, to determine the significant change in the rainfall of the next 20 and 50 years, the average rainfall should vary by 11 and 8 % respectively than the present mean of the rainfall. Whereas, to declare the average rainfall of the present century (21st century) significantly different than the previous century (20th century), 7% change is required in the long-term mean of the rainfall of the basin.

The application of various techniques to the rainfall data of the basin indicates that the rainfall of the Tapi Basin is highly regular and consistent. Therefore, it is likely to be the same in this as well as in the next century.

5.5 Limitations of the study

Although the present study intended to reveal the characteristics of rainfall over the Tapi Basin, the study is not complete in all respects. Some of the major limitations of the present study have been outlined below.
1. Though the present study is based on the rainfall data extended over 100 years (1901-2004), it is comparatively shorter in duration to draw imperative inferences to validate the rainfall aspects of the widespread geographical region of the basin.

2. Moreover, the data that have been used are monthly and annual rainfall figures. Perhaps, the daily rainfall data would have added a new dimension in results.

3. The basin covers an extensive area of 65145 km² which is nearly 2% of the total geographical area of India. Rainfall data of 56 raingauge stations were available for the study. Rainfall data of a few more stations would have helped for the comprehensive study.

4. The data of Sea Surface Temperature (SST) were available from 1901 to 1983. The SST data for the corresponding rainfall data (1984-2004) could have been more useful for establishing relationship between ENSO and rainfall of the basin in more improved manner.

5. There is general belief that rainfall is controlled by natural as well as cultural vegetation. The effect of natural vegetation and agriculture on the rainfall has not been covered in the present study.

6. Besides rainfall, the other forms of precipitation have not been studied in the study.

7. The results of the present study could have been supported using some additional statistical techniques.

5.6 Major findings of the study

In spite of a few limitations, the present study attempted to bring out the cohesive characteristics of rainfall of the Tapi Basin with respect to the objectives of the study. The major observations that have emerged from this study are as follows;

1. The average annual rainfall of the Tapi Basin is 814 mm, comprising large spatio-temporal variation. Chikhaldara is the rainiest place in the basin, receives 1596 mm average annual rainfall, which is almost double than the average annual rainfall of the Tapi Basin. Whereas, Sakri is the lowest rainfall receiving station having average annual rainfall just 511 mm. The rainfall in the Tapi Basin shows
the supremacy of south-west monsoon season. The basin receives nearly 87% of its total rainfall in monsoon season (June to September) and remaining 13% in non-monsoon season (October to May). July is the rainiest month in the basin.

2. The average annual rainy days of the basin are 44 per year with high variation from one station to another. The number of rainy days at various stations of the basin varies between 30 and 70.

3. The 600.6 mm 24 hr rainfall at Amalner on July 30, 1992 is the highest one-day rainfall on record in the basin. Extreme rainfall events, as well as their contribution in the seasonal rainfall (JJAS) over the Tapi Basin are increasing. Average annual rainy days are decreasing, however, average annual rainfall of the basin is neither increasing nor decreasing. The study, therefore, supports the general thought of climate change and subsequently signifies an increase in disaster potential in the basin.

4. The Tapi Basin illustrates a significant spatially diversified rainfall. Particularly, the eastern and western marginal areas of the basin show strongly non-uniform amount of rainfall than the rest of the area. The north-eastern part covered by the rugged relief of the Gawilgad Range and the extreme western area of the basin receives reasonably high rainfall. The widespread area in the central and south-eastern part of the basin, formed by the river plains receives rainfall close to the basin’s average rainfall and a small pocket in the south-west of the basin, obtains low rainfall. In general, the spatial pattern of rainfall in the Tapi Basin exhibits a decreasing pattern from east to west with abrupt rise in rainfall to the western edge of the basin.

5. The spatial distribution of rainfall in the basin is orographically controlled. The Western Ghats and its offshoots and the Gawilgad Range play a key role in rainfall diversity in the basin.

6. The rainfall over the Tapi Basin demonstrates alternating sequences of multi-decadal periods having excess and deficient rainfall. This epochal behaviour of rainfall of the basin can be summarized in three periods: (i) 1901-1930: dry epoch (ii) 1931-1960: wet epoch and (iii) 1961-1990: dry epoch. The epochal pattern of the rainfall of the Tapi Basin is quite similar to that found over the country. The
Tapi Basin neither experienced any widespread severe drought nor a severe flood over the period of a century.

7. A composite picture of the long-term fluctuations of the rainfall on the basin scale point towards some common characteristics of the rainfall.
   (i) The early period of the 20th century i.e. 1901 to 1930 is associated with the below-average (low) rainfall.
   (ii) Above-average (high) rainfall period is observed between 1930 and 1960.
   (iii) Below-average (low) rainfall period is observed in the latter half of the 20th century i.e. after 1960.

The deviation in the amount of the rainfall clearly indicates that the major changes in the basin rainfall occurred around 1930, 1960, and 1990.

8. The monsoon rainfall in the Tapi Basin is teleconnected with some global parameters. One of the important parameters is El Niño and Southern Oscillation (ENSO). The probability of having high rainfall in the basin is more (44%) during cold ENSO conditions and very less (11%) during warm ENSO conditions and vice versa. It indicates that during the cold ENSO (warm ENSO) events the magnitude of rainfall will be higher (lower).

9. It is observed that on the basin scale 16% change in the annual rainfall is required in the average rainfall of next 10 years to consider it different than the available rainfall record. Similarly, to determine the significant change in the rainfall of the next 20 and 50 years, the average rainfall should vary by 11 and 8% respectively than the present mean of the rainfall. Whereas, to declare the average rainfall of the present century (21st century) significantly different than the previous century (20th century), 7% change is required in the long-term mean of the rainfall of the basin.

10. The application of various techniques to the rainfall data of the basin indicates that the monsoonal rainfall of the Tapi Basin is highly regular and consistent. Therefore, it is likely to be the same in this as well as in the next century.

The inferences regarding the rainfall characteristics arrived in the present study have been discussed for a medium sized river basin. However, because the
topography, climate and geographical location within the monsoonal/tropical region are diverse, the inferences cannot be applied directly to all other natural regions within the monsoonal region. Nevertheless, such studies are beginning to provide a database and discuss the importance of rainfall studies in monsoonal environments. Hence, concluding the discussion it can be stated that in spite of a few limitations, the present study attempted to bring out the cohesive characteristics of rainfall of the Tapi Basin pertaining to the objectives of the study. This work, therefore, certainly opens an avenue to the further research in the rainfall study.