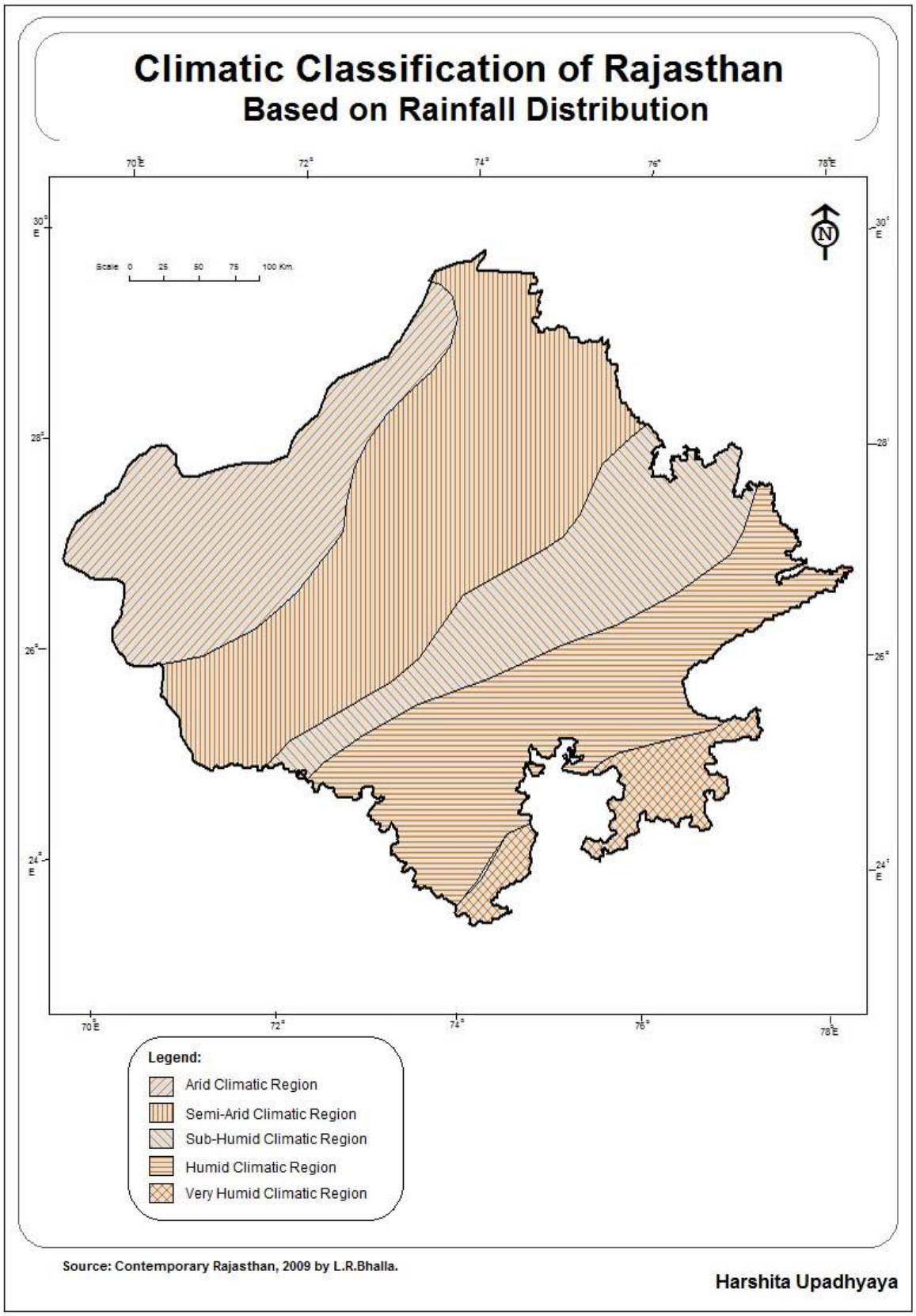
4.1 CLIMATIC REGIONS OF RAJASTHAN

The climate of Rajasthan state has varied contrasts and the presence of Aravallis is the greatest influencing factor. The state can broadly be divided into Arid, Semi-Arid and Sub-Humid Regions, on the basis of rainfall intensities. The Western Rajasthan i.e. in the arid region consist of the districts of Hanumangarh, Jaisalmer, Barmer, Ganganagar, Churu, Jhunjhunu, Sikar, Nagaur, Jodhpur, Pali and Jalore covering an area of nearly 1,43,842 sq.km. The region is characterized by low and highly variable rainfall years creating inhospitable living condition to both human and livestock population. An area of 9,290 sq km in extreme western parts of the state has true desert conditions. With an improvement in rainfall pattern from the west towards the east Rajasthan semi-arid conditions are created in an area of about 66,830 sq km in the districts of Alwar, Jaipur, Bharatpur, Ajmer, Tonk, Sawai Madhopur, Bhilwara, Bundi, Kota, Chittorgarh, Udaipur, Sirohi, Dungarpur and parts of Jhalawar and Banswara.

The distribution of climatic regions of Rajasthan on the basis of rainfall and temperature variations is divided into the following categories: (See Map – 18)

(1) **Arid Region:** The Arid region includes Jaisalmer district, northern parts of Barmer, western of the Phalodi Tehsil of Jodhpur, western parts of Bikaner and southern parts of Ganganagar district. Climate of the region is very severe and arid. Rainfall less than 10 cm in extreme west parts of regions and rest areas record less than 20 cm rainfall. The average temperature during summer is recorded more than 34^{o} C and during winters it ranges in between 12^{o}C to 16^{o}C.

MAP - 18


Climatic Classification of Rajasthan
Based on Rainfall Distribution
70°E
72°
74°
76°
78°E
30° N
28°
26°
24°
Scale 0 25 50 75 100 Km.
Legend:
Arid Climatic Region
Semi-Arid Climatic Region
Sub-Humid Climatic Region
Humid Climatic Region
Very Humid Climatic Region
Source: Contemporary Rajasthan, 2009 by L.R.Bhalla.
Harshita Upadhyaya

(2) **Semi-arid Region:** The average temperature during winter season ranges between 10^{o} C and 17^{o} C and the summer season temperature range 32^{o} C to 36^{o} C. As the region has erratic as well as torrential rainfall it brings floods too each time. Rainfall ranges 20 to 40 cm. This region comprises the western parts of Ganganagar, Hanumangarh, Jodhpur and Barmer districts. The winter season is very short and arid in the northern parts of this region.

(3) **Sub-humid Region:** In the semi arid humid region, rainfall is meager and the amount of rainfall is limited to a few monsoon months only. The rainfall is between 40 to 60 cm and the average temperature during summer season ranges from 28^{o} to 34^{o} C whereas it is recorded 12^{o} C in northern parts and 18^{o} C in the southern parts. Alwar, Jaipur, Dausa and Ajmer, eastern parts of Jhunjhunu, Sikar, Pali and Jalore districts, north-western parts of Tonk, Bhilwara and Sirohi districts are included in this category. This region has steppe type of vegetation.

(4) **Humid Region:** this region receives winter rainfall associated with cyclones along with monsoon season rainfall which varies from 60 to 80 cm. Deciduous trees dominate the region. Humid region is found at the districts of Bharatpur, Dholpur, Sawai Madhopur, Bundi, Kota, Barmer and Rajsamand and the north-eastern parts of Udaipur.

(5) **Very Humid Region:** Very Humid Region includes south-east Kota, Baran, Jhalawar, Banswara, south-west Udaipur and adjacent areas of Mt. Abu. Here, the summers are very hot and winters are cold and dry. Rainfall received is between 80 cm to 150 cm, which is mostly during the rainy season. Monsoon savanna type of vegetation is present in the region.

Koppen's Classification:

Koppen's classification for the World Climatic regions is totally based on the vegetation, as the effects of temperature and rainfall are directly evident and visible it. Here, the three categories are associated with Tropical/Mega-thermal climates, Dry (arid and semiarid) climates and Mild Temperate/Meso-thermal climates respectively. The classification of Rajasthan according to Koppen is as follows (see Map – 19):

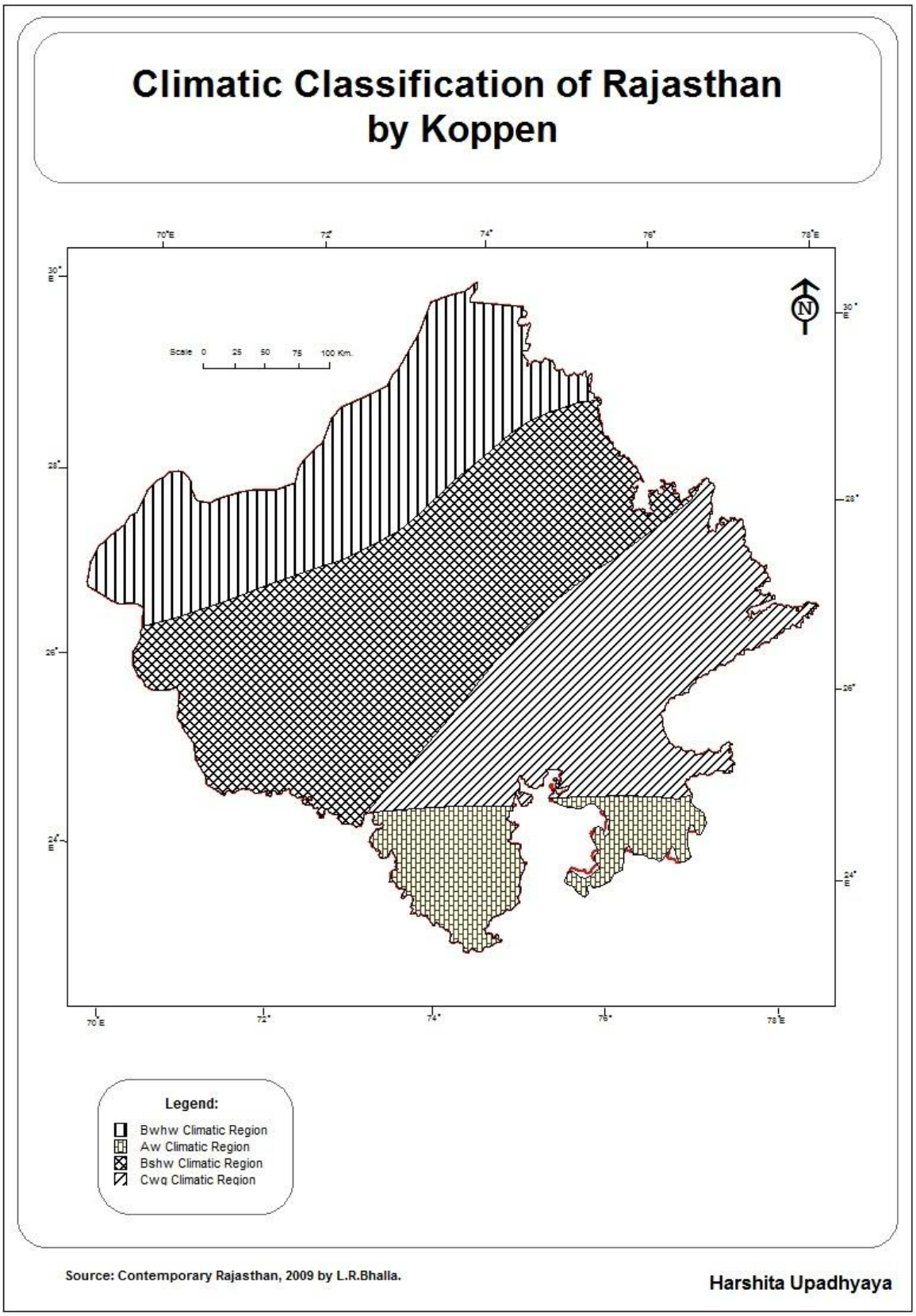
(1) **Aw or Tropical Humid Region:** The southern parts of Dungarpur district and Banswara come under the region. Here, arid tropical grasslands and Savanna like region are found along with deciduous trees of Monsoon type. Winter season is arid and cool whereas summers experience scorching heat. Rainfall also mainly occurs in summer season. The temperature is more than 18^{o} C in the coldest month records.

(2) **Bshw Climatic Region:** This climatic region is semi-arid, where winters are dry and even in summers there is no sufficient amount of rainfall. Vegetation is of steppe type, characterized with thorny bushes and grasses. This region comprises the districts of Barmer, Jalore, Jodhpur, Nagaur, Churu, Sikar, Jhunjhunu and Hanumangarh.

(3) **Bwhw Climatic Region:** The region has arid-hot desert climate with very scanty rainfall. On the contrary the process of evaporation is very active. Thus, these areas are known as desert region, limited to western parts of Thar Desert. North-western Jodhpur, Jaisalmer, western Bikaner and western parts of Ganganagar district are included in this category.

(4) **Cwg Climatic Region:** The south-eastern areas of Aravalli are the part of the region. Rains are limited to few monsoon months only. Seasonal winds do not bring rains to this region during winters.

MAP - 19


Climatic Classification of Rajasthan
by Koppen
70°E
72°
74°
76°
78°E
30° N
28°
26°
24°
Scale 0 25 50 75 100 Km.
N
Legend:
Bwhw Climatic Region
Aw Climatic Region
Bshw Climatic Region
Cwg Climatic Region
Source: Contemporary Rajasthan, 2009 by L.R.Bhalla.
Harshita Upadhyaya

Thorntwaite's Classification

The base of this classification Thornthwaite took into account the amount of rainfall and evaporation along with seasonal and monthly distribution of temperature and rainfall which made it popular and widely accepted. Rajasthan may broadly be divided into the following four regions (see Map – 20):

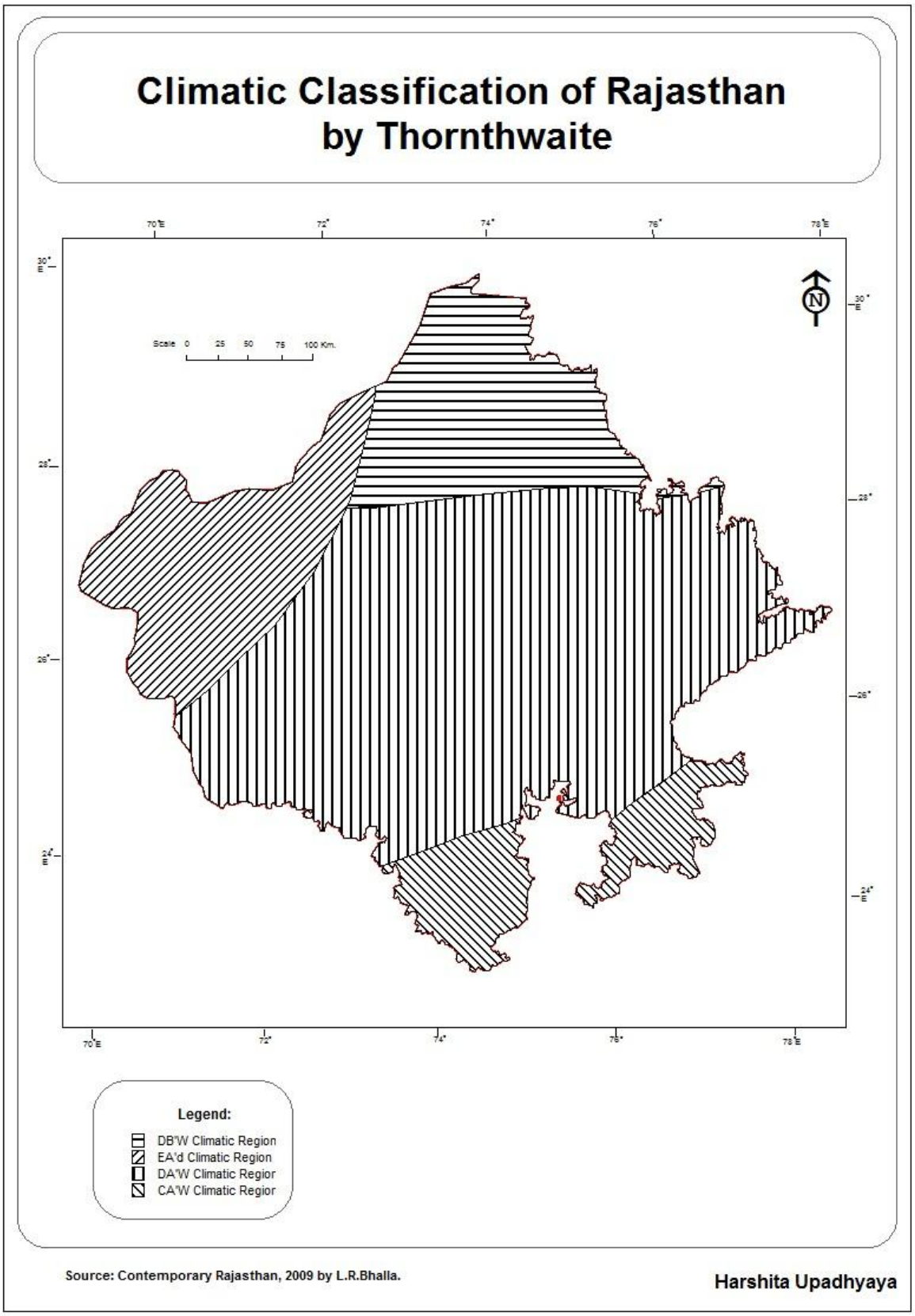
(1) **CA'w Climatic Region:** this region is characterized by wet summers and dry winters. Savanna and Monsoon type of vegetation are found here. This region includes south-eastern parts of Udaipur and districts of Banswara, Dungarpur, Kota, and Jhalawar.

(2) **DA'w Climatic Region:** The region comprises south and eastern areas of Rajasthan, covering districts of Sirohi, east Jalor, Pali, Ajmer, Chittorgarh, Bundi, Sawai Madhopur, Tonk, Bhilwara, Bharatpur, Jaipur, Dausa, Alwar, Sikar and Jhunjhunu. Rainfall is meager and Semi-arid vegetation is found. Summers are marked by High temperatures.

(3) **DB'W Climatic Region:** It includes the northern areas of Rajasthan i.e. Ganganagar, Hanumangarh, Churu and Bikaner districts. The region has short and dry winters whereas summers are long and associated with good rains. Thorny bushes and semi-arid vegetation are found here.

(4) **EA'd Tropical Desert Climatic Region:** This region of Marusthali includes Barmer, Jaisalmer, western Jodhpur, south-western Bikaner district. The climate is very hot and arid. Rains are deficient in every season. Only Xerophytic vegetation grown only.

MAP - 20


Climatic Classification of Rajasthan
by Thornthwaite
70°E
72°
74°
76°
78°E
30°N
28°
26°
24°
Scale 0 25 50 75 100 Km.
N
Legend:
DB'W Climatic Region
EA'd Climatic Region
DA'W Climatic Regior
CA'W Climatic Regior
Source: Contemporary Rajasthan, 2009 by L.R.Bhalla.
Harshita Upadhyaya

AGRO- CLIMATIC ZONES

The entire country has been delineated into 126 agro-climatic zones by The Indian Council of Agricultural Research, out of which the state has been divided into 10 agro-climatic zones (see Map– 21). These zones have been classified on the basis of agro-climatic parameters like rainfall, temperature regime, topography, soil characteristics, cropping pattern and irrigation availability. See Annexure – I. The Agro-climatic zones are as follows:

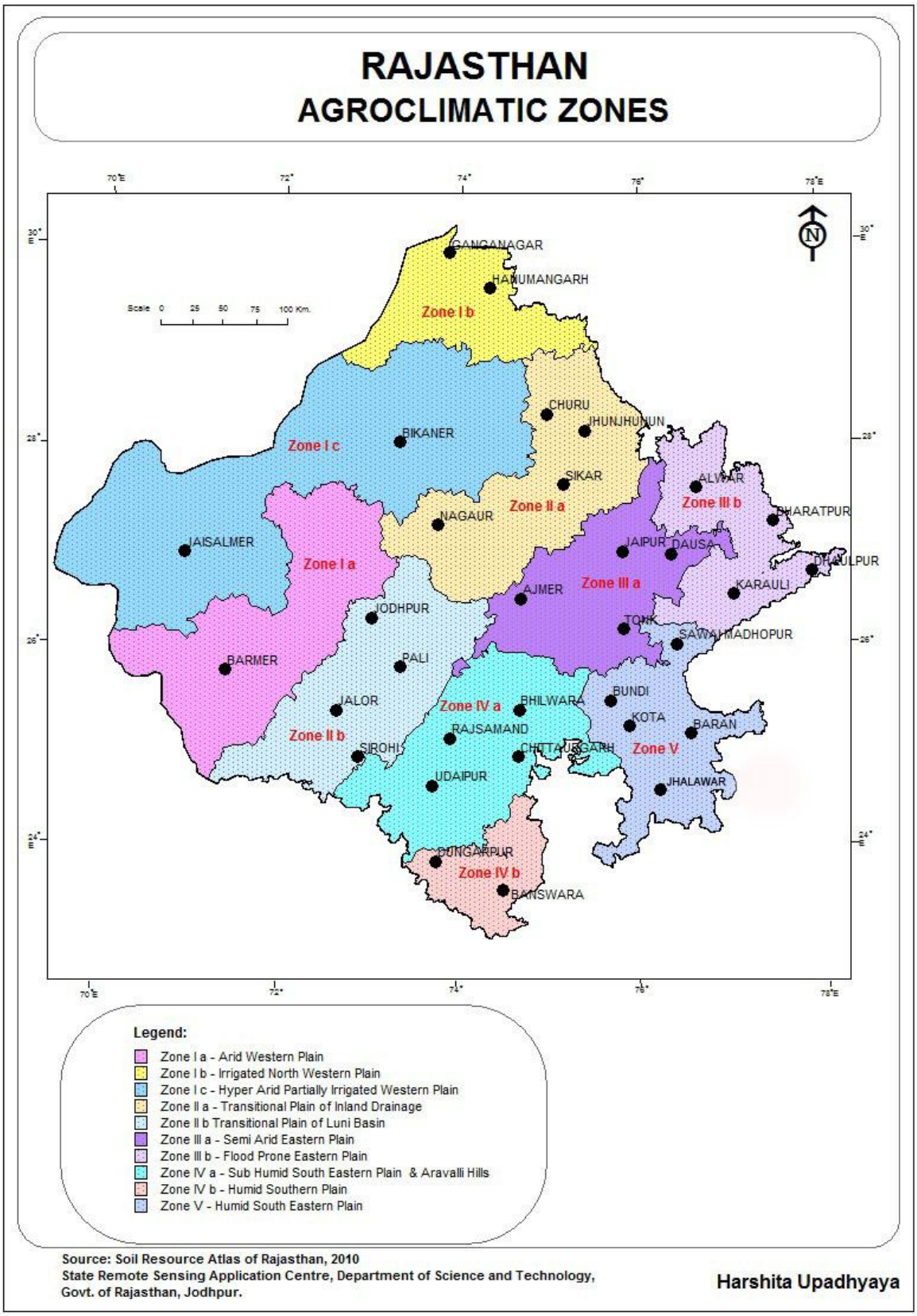
1. Arid North Western Sandy Plain

The plain is characterized by vast sandy plain with sand dunes, sandy plain pediments and palayas present in the region. The vast area covered with sand dunes has coarse textured soil with $CaCO_3$ and gypsum. This physiographic zone is located in the north western part of the state covering Jaisalmer, Barmer, Bikaner and Jodhpur districts. The zone has erratic and uncertain rainfall witnessing frequent droughts. The mean annual rainfall is 100 to 400mm. Groundwater is deep and saline but at few places tube-well water is used for irrigation. Rain-fed agriculture is practiced in some pockets and livelihood is primarily livestock based.

2. Irrigated North Western Plain

This plain extends in the northern part of the state in Ganganagar, Hanumangarh and north western part of Bikaner district. As the zone is irrigated by network of Indira Gandhi Canal, Bhakra and Gang canal, it is intensively cultivated. The plain is dominantly covered by the medium and fine textured deep to very deep soils. The bed of River Ghagghar stretching from Suratgarh to Anupgarh is fine textured and intensively cultivated. In addition, in the southern and eastern part the region there is vast Aeolian plain covered with dunes with small area of deep buried pediments.

MAP - 21


RAJASTHAN
AGROCLIMATIC ZONES
GANGANAGAR
HANUMANGARH
Zone I b
CHURU
JHUNJHUNUN
BIKANER
Zone I c
SIKAR
ALWAR
Zone III b
Zone II a
BHARATPUR
NAGAUR
JAISALMER
JAIPUR
DAUSA
Zone I a
Zone III a
KARAULI
AJMER
JODHPUR
TONK
SAWAI MADHOPUR
BARMER
PALI
BUNDI
JALOR
Zone IV a
BHILWARA
KOTA
BARAN
Zone II b
RAJSAMAND
SIROHI
CHITTAURGARH
Zone V
UDAIPUR
JHALAWAR
DUNGARPUR
Zone IV b
BANSWARA
Legend:
Zone I a - Arid Western Plain
Zone I b - Irrigated North Western Plain
Zone I c - Hyper Arid Partially Irrigated Western Plain
Zone II a - Transitional Plain of Inland Drainage
Zone II b Transitional Plain of Luni Basin
Zone III a - Semi Arid Eastern Plain
Zone III b - Flood Prone Eastern Plain
Zone IV a - Sub Humid South Eastern Plain & Aravalli Hills
Zone IV b - Humid Southern Plain
Zone V - Humid South Eastern Plain
Source: Soil Resource Atlas of Rajasthan, 2010
State Remote Sensing Application Centre, Department of Science and Technology, Govt. of Rajasthan, Jodhpur.
Harshita Upadhyaya

3. *Hyper Arid Partial Irrigated Zone*

This zone is spread in the arid region of Bikaner, Jaisalmer and parts of Churu, where the farmers have partial dependence on the sources of irrigation. The normal rainfall in the region is 185 to 390 mm. the regions has desert soil characterized by sand dunes and aeolian soil. The soil is loamy coarse in texture and with calcareous characteristics.

4. Transitional Plain of Inland Drainage

This plain is spread in the central part of the state covering western, eastern and northern part of Nagaur and entire Sikar, Churu and Jhunjhunu districts. There is no drainage out of this area. The zone is covered with sandy plain, sand dunes and occasional hills. The area distinguishes from western sandy plain in having better rainfall (300-400mm). Livelihood of villagers depends mainly on livestock rearing along with some rain-fed farming.

5. Alluvial Plain of Luni Basin

The physiographic zone is located in the central part of the state where a number of ephemeral streams and River Luni and its tributaries flow through this area covering Pali, Jalore, part of Nagaur, Jodhpur and Barmer districts. Rainfall ranges between 400 and 500mm. water is saline in this zone. Cultivation of cash crops is Rainfed or done with the help of tube-wells. Dominant soils are medium to fine textured.

6. Semi Arid Eastern Plain

This plain is drained by the river Banas and its tributaries and receives 500-700mm rainfall. The zone is spread in the eastern part of the state covering Jaipur,

Ajmer, Dausa and Tonk districts. The plain is sandy plain. Occasional sand dunes and buried pediments and scattered hills with substantial area under alluvium are features of this zone.

7. Flood Prone Eastern Plain

This zone developed on the alluvium deposited by the river Yamuna and its tributaries and is spread over the eastern part of the state and forms western fringe of the Indo-Gangetic plain. This zone extends in Alwar, Bharatpur and Dholpur districts. Soils are yellowish-brown to dark yellowish brown, sandy loam to clay loam and non-calcareous. The rainfall in the zone is 600-700mm. A large area of this zone is under kharif and rabi crops.

8. Sub Humid Southern Plain and Aravallis

High hills are scattered through the zone and there is a contiguous appearance of the Aravalli hills, running south to north. The zone extends in the southern part of the state in Bhilwara, Rajsamand, Sirohi, Udaipur and Chittorgarh districts. The zone receives 700-900mm rainfall. Hills and pediments are under hills for rest which support natural vegetation cover including trees, shrubs and grasses. Cultivated land occurs in between the hills. Medium to fine textured deep soils are dominant in this region.

9. Humid Southern Plain

This plain characterized by hills and valley fills is spread in the southern part of the state in Dungarpur, Banswara and Pratapgarh districts. In Banswara and Pratapgarh districts the soils formed from lava flow of basalt are also found. In between, scattered areas of deep buried pediments are also encountered. This zone

receives 900-1000mm rainfall. The hills are covered with thick density of trees, shrubs and grasses.

10. Humid South Eastern Plain

This zone receives the highest rainfall in the state 700-1000mm. The plain is spread at the south eastern part of the state covering Sawai Madhopur, Karauli, Jhalawar, Baran, Kota and Bundi districts. The landscape is characterized by hills pediments and vast alluvial plain formed by the rivers Chambal, Parbati, Parwan, Kalisindh and their tributaries. Because of these rivers deep gullies and ravines have been formed. Because of the presence of fine textured alluvium deposited by the rivers in this zone the land is very productive.

4.2 ANALYSIS OF RAINFALL VARIABILITY

The degree to which rainfall amounts vary across an area or through time is an important characteristic of climate of that area. This subject area in meteorology and climatology is called 'Rainfall Variability'. Rainfall Variability explains the availability of water at a particular time and area. There are 2 components of rainfall variability – Areal and Temporal Variability. Temporal variation analysis helps to explain the nature of rainfall variability across time-span. Simulation models predict an increased hydrological cycle and an increase in mean annual rainfall over most of Asia but there is a large degree of variation in these predictions. Some studies suggest an increase of 30% or more in precipitation over north-western India by 2050 and an increase in the probability of extreme rainfall events. This increased precipitation intensity, particularly during the summer monsoon, could increase floods (Tideman and Khatana, 2004).

Here, in this chapter the Rajasthan state's rainfall variability has been analyzed. This may be termed as the large scale variability analysis. This form of analysis can reflect the presence or absence of cyclic nature in the rainfall availability and can also reveal the nature of rainfall variability for the coming period. The time span taken is of 50 years starting from 1960 up to 2009. Gupta (1990) has explained that the variability increases with decreasing of time which has been considered for the analysis of rainfall. Khan (1998) states that the time duration influences the value of rainfall variability and daily rainfall will always be higher than the annual one.

The analysis of rainfall variability of the state has been carried out on the basis of co-efficient of variation dividing the time span of 1960 to 2009 into class

interval of 5 years each. The coefficient of variation (CV) which is expressed in percentage is defined as below:

$$C.V. = \frac{\text{Standard deviation } (\sigma) \times 100}{\text{Normal Annual Rainfall } (N)}$$

Where, N = 564.89 and the standard deviation and CV are tabulated in Table – 6.

Table – 6 Standard Deviation (σ) and coefficient of variation (CV) of Rajasthan (1960-2009)

Years	σ	CV
1960 - 1964	106.71	18.8904
1965 - 1969	93.55	16.56075
1970 -1974	122.3	21.65023
1975 - 1979	110.05	19.48167
1980 - 1984	99.62	17.63529
1985 - 1989	83.36	14.75686
1990 - 1994	71.83	12.71575
1995 - 1999	91.14	16.13411
2000 - 2004	120.01	21.24484
2005 - 2009	91.001	16.10951

Source: http://waterresources.rajasthan.gov.in/Daily_Rainfall_Data/Rainfall_Index.htm

During 1960 to 1964 the CV of the state was 18.89% which decreased to 16.56% during 1965 and 1969. During 1970 and 1974 the state recorded the highest CV in the 50 years (1960 to 2009) which was 21.65%. For the next 5 years the CV was 19.48%. Continuing this low CV trend was during 1980 and 1984 when it reached 17.63%. Further lowering of CV in Rajasthan state was seen during 1985 and 1989 and 1990 and 1994 when CV was 14.75% and 12.71% respectively.

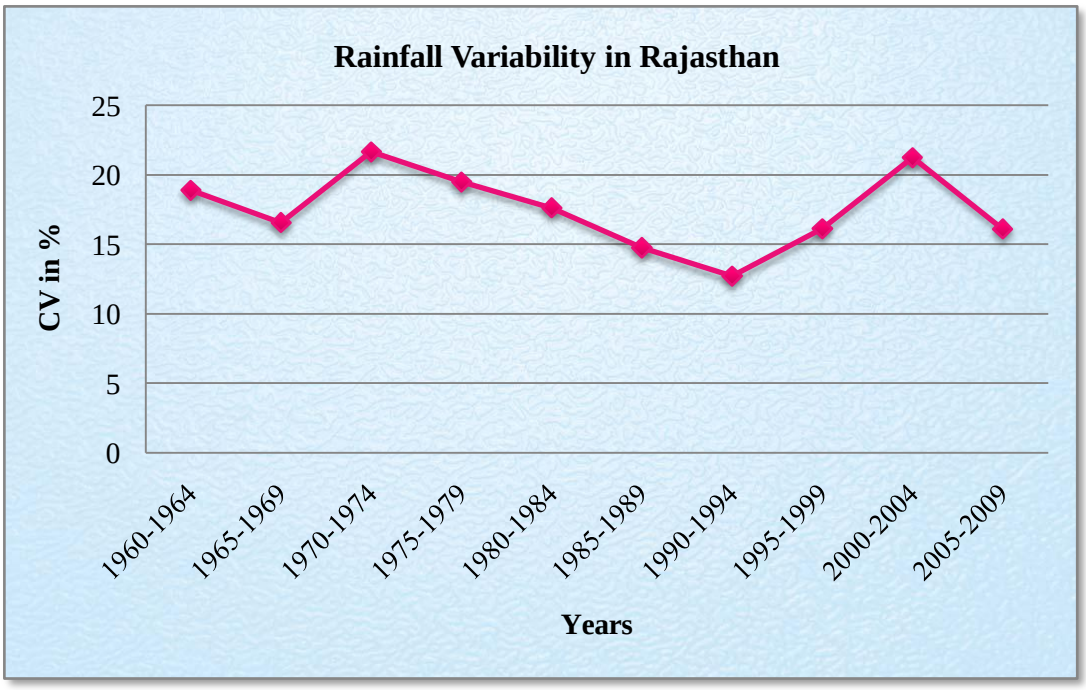
12.71% CV is the lowest of the observed 50 years in the state. During 1995 and 1999 time span the CV rose to 16.13 and further to 21.24% during 2000 and 2004. The CV reduced to 16.10% during 2005 and 2009.

Hence, it is seen that an alternatively temporal variation with increase and decrease of CV was observed from 1980 and 1964 to 1965 and 1969 to 1970 and 1974 and 1975 and 1979. There was found a continuous decrease of CV within the class interval of five years.

During 1995 to 1999 CV percentage again increased and the increasing trend continued further during 2000 and 2004. During 2005 and 2009 CV again decreased. It is seen that the time period with high rainfall variability have flood years and the ones with low rainfall variability have drought years, but it is not a rule.

It is also observed that the CV values ranged between as high as 21.65 % and fell down to 12.71 % in the observed 50 years. The same can be seen in Graph – 5.

Graph – 5



Rainfall variability at a time scale from years to days is as much a characteristic of climate as the total amounts recorded and low values do not necessarily lead to drought and high values do not necessarily lead to flooding. Variability of rainfall may be used to characterize a climate and to deduce evidences of climate change.

By the study of rainfall and variability the adaptation to future climate change can be developed through the experience of adapting to rainfall variability today on the various components like water resource availability, in increase or decrease of floods on drought or change in the nature of rainfall.

4.3 DISTRICT WISE ANALYSIS OF RAINFALL

Rainfall in large parts of the State is not only inadequate but also varies sharply from year to year and place to place. The average rainfall of Rajasthan is 564.89 mm (1960 to 2009) compared to the all-India average of 1,100mm (Government of Rajasthan, 2011) and a significant variation is seen across different regions. The South-west monsoon brings the maximum rainfall in the state. In certain areas south-east and intermediate rainfalls also contribute towards the total rainfall. Pre-monsoon showers start towards the end of June and post-monsoon showers may continue till the first week of October. At many of the places highest rainfall is received in July and August. The period of monsoon is shortest, ranging around 2 to 2.5 months. Its onset is late and withdrawal early as compared to other States and one or two dry spells is a common phenomenon. 90 percent of the total rainfall is received during monsoon season (July-September) (Commissionerate of Watershed Development and Soil Conservation, 2010).

In the western Rajasthan, the average annual rainfall during 1980 to 2009 ranges from less than 171.12 mm in north-western part of Jaisalmer (lowest in the state) to 400 mm in Sikar, Jhunjhunu region and along the western periphery of the Aravalli range. In the eastern region, the rainfall ranges from around 400 mm in Ajmer to 762.19 mm in Jhalawar. In plains, Banswara (795.25 mm) and Jhalawar (762.19 mm) districts receive the maximum annual rain. The highest rainfall is received in the southwest region of the State. The annual spatially averaged rainfall is highly variable and it is most erratic in the western region with frequent dry spells, punctuated occasionally by heavy downpour in some years associated with the passing low pressure systems over the region (Rathore, 2006). The number of rainy

days during the south west monsoon period from June end to mid-September over Rajasthan varies from 10 in Jaisalmer to 40 in Jhalawar and to 48 in Mount Abu. The quantum of rain and number of rainfall days during the rest of the year in different parts of Rajasthan range from 2.1 cm at Jaisalmer to 7.2 cm at Jaipur, distributed over 2.5 to 6 rainy days (Khan, 1998). During the rainfall deficit year of 2002, the state received just 220.4 mm rainfall up to September, against the normal of 518.6 mm in the overall monsoon (Government of Rajasthan, 2011). The maximum average rainfall of 726 mm was recorded in 1996 and minimum 291.6 mm was recorded in 1987, prior to 2002 (Goel and Singh, 2006). Rajasthan is heavily dependent on rainfall as it is the major source of water resource in the arid / semi-arid state. All the rivers of Rajasthan are rain-fed, the only exception being river Chambal. The major land use is rain-fed cropping, the Eastern Rajasthan that falls in the semi-arid 500–1000mm annual rainfall zone and is intensively cultivated. Thus, any fluctuation of rainfall in the climate sensitive state of Rajasthan can pose a multitude of socio-economic problems.

As rainfall is one of the most important climatic parameter of Rajasthan the following chapter analyses the rainfall pattern of Rajasthan district wise on the basis of the intensity of rainfall they have received in the past 30 years ranging from 1980 to 2009. These 'Category of Intensity' are based on the general terminology used by Indian Meteorological Department in its weather bulletins. This categorization is shown in Table – 7. The average annual rainfall have been collected and computed from 1980-2009 district wise, station wise for all Rajasthan.

Table – 7: Category of Intensity of Rainfall

S. No.	Category	
1.	Abnormal	60% or more
2.	Excess	20% to 59%
3.	Normal	19% to (-)19%
4.	Deficit	(-)20% to (-)59%
5.	Scanty	(-)60% or less

Source: Monsoon Report – 2010, Indian Meteorological Department

1. AJMER

The Ajmer district received 409.06 mm rainfall from 1980 to 2009. In this span of 30 years i.e. ranging from 1980 to 2009, fluctuations were seen in the annual average rainfall, which ranged from 267.74 mm, less than average in 1987 to 314.95 mm above the average in 1983. During 1980 to 1989 there was only one incidence of abnormally high rainfall in 1983, whereas 1986 and 1987 received deficit followed by scanty rain fall respectively. Rest 7 years registered normal rainfall.

During the next decade from 1990 to 1999, there were 2 years each of abnormally high, normal and deficit rainfall and 3 years of excess and 1 year of scanty rainfall. In the last decade i.e. from 2000 to 2009 there was no abnormally high or scanty rainfall. Only 1 year with excess and 2 with deficit rainfall. Rest 7 years received normal rainfall. Thus, it is observed that years of abnormal and scanty rainfall have decreased to zero from 1 each from 1980 to 1989. During 2000 to 2009 wider fluctuations were seen during 1990 to 1999 as compared to the two decades. But the district has mostly received normal rainfall in the observed time span.

2. ALWAR

The average rainfall in Alwar district during 1980 to 2009 is 575.75 mm. In 1996 the rainfall was abnormally high i.e. 580.94 mm above the average and 371.27 mm less than the average in 1999. During 1980 to 1989 there was one incidence each of abnormal and excess rainfall and 4 years of normal as well as deficit rainfall. There is no incidence of scanty rainfall. The 1990-1999 decade shows a great range of fluctuations in rainfall, with excess rainfall year 1998 followed by scanty rainfall year i.e. 1999. The highest and lowest rainfall of the observed 30 years is also recorded in this decade.

During 2000-2009, there is 1 year of each of abnormal, excess and scanty rainfall, with 2 deficit years. 5 years recorded normal rainfall. In general, in the last 30 years, 14 years received normal rainfall followed by 7 years of deficit rainfall.

3. BANSWARA

The average rainfall of Banswara during 1980 to 2009 is 795.24 mm. The region in the observed years has never registered the occurrence of scanty rainfall and only 2 years of abnormal rainfall during 2006 and 2007. The district has 14 years of normal rainfall out of the 30 years followed by 10 years of deficit rainfall.

The occurrence of excess rainfall has also decreased from 1980-89 to 1990-1999 and 2000-2009. During the 2000-2009 decade wide variations are seen as 2000 to 2002 are rainfall deficit years, whereas, 2004 was excess rainfall year and 2006 and 2007 were abnormally high rainfall years again followed by 2008’s deficit rainfall.

Hence, the district has a trend towards greater variation in the last decade of 2000-2009 compared to 1980-1989 decade where 2, 5, and 3 years of excess, normal and deficit rainfall were observed respectively.

4. BARAN

The average rainfall of the region during 1980 to 2009 has been 756.37 mm. and in this span of 30 years there has been no year of abnormally high rainfall and only 2002 has been an exception year where the district registered scanty rainfall. The year 2002 received rainfall below normal in the entire state. Normal rainfall is seen as a feature of the district. Out of the observed 30 years, 23 years observed normal rainfall. During 1980-1989 there was only 1 year and during 1990-1999 there were 3 years of excess rainfall in the district. 1986 and 1989 are the only deficit years from 1980 to 2009.

5. BARMER

The average rainfall of the district during the observed years is 244.74 mm. The fluctuations in tin rainfall in the region vary largely. During 1980 and 2009 rainfall received in 23 out of 30 years is either normal or below normal. During 1980 to 1989 there have been 2 years (1980 & 1981) of scanty and 3 years (1985 to 1987) of deficit rainfall and 3 years of rainfall above normal as well. The trend of more years having normal rainfall or below normal continues during 1990 to 1999 and 2000 to 2009 as well i.e. 7 and 8 years respectively. It is mostly seen that years with abnormal rainfall are followed by the year which has either scanty or deficit rainfall. During 1990-1999 there is one 1 of abnormal and 2 years of excess rainfall, whereas during 2000-2009 there are 2 years of abnormal rainfall and no year of excess rainfall.

6. BHARATPUR

The average rainfall in Bharatpur district during 1980-2009 was 535.38 mm. The maximum departure from the average was observed in 1995 when the average annual rainfall was 384.34 mm, above the normal and in 1987 when it was lowest below the normal by 252.17 mm.

Generally the region has received normal rainfall i.e. 46.6% of the observed years. During 1980-1989 there was neither scanty nor abnormal rainfall. Excess rainfall was observed for 2 years consecutively in 1982-83. Deficit rainfall was observed for 4 years with 1986-87 in succession.

In 1990-1999 decade 1995-1996 were abnormal rainfall years. 1998 had excess rainfall whereas 1991 had deficit rainfall. During 200-2009 there were 2 years of excess rainfall and 4 years of both normal and deficit rainfall. There was no year with abnormal or scanty rainfall during this decade.

7. BHILWARA

The average rainfall during the observed years is 512.65 mm. In the year 2002 the district received least rainfall which was 240.61 mm, below normal and the maximum rainfall in the 30 years slot between 1980 and 2009 was observed in 2004 which was 261.32 mm, above normal. 50% of the observed years have recorded normal rainfall years in the district. During 1980-1989 decade there were 3 years of deficit rainfall years, with 1980-1981 were consecutively deficit followed by 2 years of excess rainfall in 1982-1983. During 1990-1999 there were 3 years of excess and deficit rainfall with 4 normal rainfall years. 1998-1999 were consecutive deficit rainfall years.

In the 2000-2009 decade 6 years recorded normal rainfall and 2 years each of excess and deficit rainfall.

There has been no abnormal or scanty rainfall year from 1980 to 2009; and in each decade the number of excess and deficit years is same.

8. BIKANER

The average rainfall of the district during 1980 to 2009 is 233.94 mm. During this time span of 30 years, 8 years had excess and deficit rainfall and 1983 and 2002 were the only years that had abnormal and scanty rainfall respectively. In all the 3 decades i.e. 1980-89, 90-99 and 2000-2009, there have been 4 normal years. During these 4 normal years of deficit rainfall consecutively from 1984-1987 and year 1982 was of excess and deficit rainfall; and during 2000-2009. 2002 was such year with scanty rainfall and 2004 with deficit rainfall. 40% of the observed years had normal rainfall and 26.6% each had excess and deficit rainfall.

9. BUNDI

The average rainfall of Bundi district from 1980 to 2009 is 558.65 mm. The maximum rainfall was seen in 1994 when it was 286.84 mm above the average and minimum was 251.44mm below the average in 2002. There has been no year of abnormal or scanty rainfall in the district during 1980-2009. Mostly the years have recorded normal rainfall, i.e. 20 out of 30 years. There have been 4 incidents of deficit rainfall, 2 each during 1980-89 and 2000-2009 respectively. Excess rainfall was once during 1980-89, thrice during 1990-1999 and twice during 2000-2009.

10. CHITTORGARH

The average annual rainfall during 1980-2009 at Chittorgarh district was 588.81 mm. The maximum average annual rainfall was recorded in 2006 which was 388.15 mm, above the average and in 1987 average annual rainfall was recorded 257.36 mm below the average. There has been no year of scanty rainfall and only 2006 had abnormal rainfall.

During 1980-1989 there were 5 years of normal rainfall and 2 consecutive excess rainfall years i.e. 1983-1984; whereas 1986 to 1988 were 3 deficit rainfall years. During 1990-1999 there were 2 excess, 3 deficit and 5 normal rainfall years where rainfall deficit years were followed by excess rainfall years alternately from 1993 to 1996.

In the 2000-2009 decade 2006 recorded normal rainfall, 2 years each recorded excess and deficit rainfall.

11. CHURU

The average rainfall of Churu district from 1980 to 2009 was 343.74 mm. During 1980-1989 there were 4 deficit years with 2 in succession in 1986-1987, 2 excess and 3 normal rainfall years were recorded. 1983 recorded abnormally high rainfall, which was 242.93 mm above the average and also highest in the observed years. There are no abnormal or scanty years in the district during 1990 to 2009 and 5 years each of normal rainfall years. During 1990-1999 there are 3 excess and 2 deficit years whereas during 2000-2009 there are 2 excess and 3 deficit years.

Generally the district has recorded normal rainfall i.e. 13 out of 30 years followed by deficit which is 9 out of 30 years.

12. DAUSA

The average annual rainfall of the district during 1980-2009 is 661.05 mm. The maximum rainfall was recorded in 1996 which was 995.94 mm above the average and in 2002 it was 458.60 mm below the average and it was the only year in which it recorded scanty rainfall in last 30 years. During 1980-1989 there were 5 deficit years with 3n in succession from 1986-1988 – 2 excess and 2 normal years.

In the 1990-1999 decade 6 years were normal and 2 years, 1995 and 1996 were normal and 2 years 1995, 1996 were consecutively abnormal. The year 1992 was excess rainfall and 1999 was deficit rainfall year. In 2000-2009 decade years 2000 and 2001 had deficit rainfall along with 3 other years. 2008 had excess rainfall and 2002 had scanty rainfall, 3 years had normal rainfall. The district generally received normal or below normal rainfall for 23 years out of the observed 30 years.

13. DHOLPUR

The average rainfall of the district from 1980 to 2009 is 531.45 mm. the district had no record of scanty rainfall in past 30 years and just one year with abnormal rainfall in 2008 when the average annual rainfall was 433.52 mm, above the district average. Excess rainfall was received for 4 years during 1990-1999 decade only with consecutively in 1995-1996. During 1980-1999 decade only 1991 was deficit year, 4 years were excess rainfall and 5 normal rainfall years were observed. From 2000 to 2009, 2008 was abnormal rainfall year, 2 years were deficit and rest 7 years had normal rainfall. In general, mostly normal rainfall years have been seen in the region, which have increased during 2000-2009 decade.

14. DUNGARPUR

The average rainfall in the district during 1980 to 2009 is 654.58 mm. There was no scanty rainfall year during the observed time span. There are only 2 years of abnormal rainfall i.e. 1994 and 2006. 1983-1984 and 1990 are excess rainfall years and 1985-1986, 1999-2000 are consecutive deficit years along with 3 other years. The deficit years during 2000-2009 were more than other decades. There were 6 years of normal rainfall in each decade.

15. GANGANAGAR

The district during 1980-2000 received rainfall below average for 15 years out of 30 and received rainfall above normal for 11 years. Though, it can be seen that the deficit and scanty rainfall years have decreased during2000-2009 decade as compared to 1990-1999 decade. The average rainfall for the observed 30 years has been 164.85 mm. There is not much variation in the number of abnormal rainfall years and in total there were 5 such years with succession in 1982-83, 2007-2008 and 1996 which recorded the maximum rainfall in the district, which was 524.93 mm above the average. There were 3 excess rainfall years in the 1st and last decade each and none during the 2nd decade. 1984-85 were the consecutive excess rainfall years. Normal rainfall years have increased from 1 year to 3 years in the last decade. 1988-1993 were continuous 6 rainfall deficit years followed by scanty rainfall years from 1994 to 2001 leaving 1999 and 2000. The state has more frequency of witnessing deficit or scanty rainfall years and their frequency was more during 1990-1999 decade.

16. HANUMANGARH

The average annual rainfall of the district during the observed 30 years was 296.40 mm and there has been no scanty rainfall year in the district. 1983 was the only year to register abnormal rainfall and this year the rain was 198.74 mm above the average. There has been 1 excess rainfall year in the 1st decade, 4 in 2nd and 2 in the last decade, with 1994-95, 1997-98 and 2007-08 as consecutive years of this category. Deficit rainfall years were 3, 1 and 4 during the 3 decades respectively with 1986-87, 89-90 as consecutive ones. Year 2002 recorded the least rainfall in the district which was 163.54 mm below the average. Rest 5, 3 and 4 years were normal rainfall years in the respective 3 decades.

17. JAIPUR

The average annual rainfall of the district for the 30 observed years is 433.24 mm. There have been 11 years of normal and deficit rainfall in the district, 6 of excess and two of abnormal and no year with scanty rainfall in the observed time span. The maximum and minimum rainfall were recorded in the same decade i.e. 1983 had rainfall 380.11 mm above the average whereas 1987 had rainfall 234.07 mm below the average. 1981 and 1983 are the only abnormal years in the entire 30 year span and 1982 and 1985 were excess rainfall years. Deficit rainfall was observed for 4 years with 1986-87 in continuation. Rest 2 were normal rainfall years.

The 1990-99 decade had no year with abnormal or excess rainfall. Most years received normal rainfall and there were 4 deficit rainfall years with 1993-1994 in continuation.

In the last decade there are 4 years with excess rainfall each. 2001-2002 were consecutive deficit rainfall years. It can be seen that no incidence of abnormal rainfall occurred in the last 2 decades and years with excess rainfall have increased. The inter-decadal fluctuations were more during 1990-1999.

18. JAISALMER

The average annual rainfall in the district during 1980-2009 is 171.11 mm above the average. The frequency of excess rainfall was 1 during the 1st decade, in the second it rose to 6 with 1994-1996 and 1998-99 being successive rainfall years and in the 3rd decade 2003 and 2007-08 experienced excess rainfall. Normal rainfall has fluctuated from 5 to 3 years each in the 2nd and 3rd decades. There were 3 deficit rainfall years during 1980's and all in sequence since 1984 to 1986. During 1990's only 1991 was deficit rainfall year. 2004 and 2009 were the deficit rainfall years of the last decade. 1987 and 2002 are the only occurrences of scanty rainfall in the district. Year 1987 registered least rainfall which was 129.90 mm less than the average. It can be seen that the frequency of rainfall near the normal or above it is rising in the district.

19. JALORE

The average annual rainfall of the district from 1980 to 2009 was 330.11 mm. The lowest was observed in the 1st decade in 1987 which was 273.16 mm below the average and the maximum rainfall was received in 2006 which was 412.34 mm above the average. The frequency of abnormal rainfall years has increased from 1 to 2 each in the last 2 decades. 1994 was the only year with excess rainfall in the 30 observed years. The frequency of normal rainfall years has increased to 6 during 1st

and 2nd decade. The frequency of deficit and scanty rainfall has decreased from 4 to 2 years and 1 year to no occurrence in the last decade respectively. In the last 30 years there have been 12 years of rainfall below average and 11 years with normal and 7 years of above normal rainfall.

20. JHALAWAR

The average annual rainfall of the district during the observed years was 762.18 mm. mostly the frequency of years having normal rainfall has been very high and is 20 out of 30 years. There is no occurrence of scanty rainfall. 2006 had the only occurrence of abnormal rainfall which was 553.66 mm above the average. There were 2 years of excess rainfall during 1st and 2nd decade and none in the last decade. Deficit rainfall varied from 2 years during 19889 to 1 during 1990-99 to 2 again during 2000-09.

21. JHUNJHUNUN

The average annual rainfall of the district is 420.62 mm. There has been only one year of abnormal rainfall i.e. 1996 when it rained 292.75 mm above the average. In 2002 the only scanty rainfall has occurred when it rained 272.49 mm below average. The excess rainfall years have fluctuated from 2 to 3 and 3 to 2 again in the 3 decades respectively. Normal rainfall varied from 3 to 5 to 4 in the 3 decades. A significant variation is seen i9n the deficit years which fluctuated from 5 during 80's to just 1 in 90's to 3 years in 2000-2009 decade. Generally the normal rainfall years have been higher in the district i.e. 40% years.

22. JODHPUR

The average annual rainfall of the district was 237.62 mm during 1980-2009. There is only one year with abnormal rainfall i.e. 1983 when it rained 207.43 mm above the average. The scanty rainfall year was also one only in 2002 when it rained 151.08 mm below the average. The years of excess rainfall have increased gradually during the decades whereas deficit rainfall years have decreased. Normal rainfall years have been almost uniform and also have been maximum in the observed time spent i.e. 13 years out of 30 years followed by 7 deficit rainfall years and 6 excess rainfall years.

23. KARAULI

The average annual rainfall of Karauli district was 535.95 during 1980 and 2009. Year 1983 has been the only abnormal rainfall year with rainfall of 333.44 mm above normal and in the same decade in 1989 the rainfall was a minimum of 30 years with 305.08 mm below the average. There is no year with scanty rainfall. The frequency of excess rainfall years has increased whereas frequency of deficit years has decreased. Most of the years in the district during the observed period have been of normal rainfall.

24. KOTA

There has been only 1 abnormal rainfall year i.e. 2001 during the observed time span with 370.16 mm rainfall, above the average annual rainfall of 523.57 mm. The frequency of excess rainfall days widely fluctuated from 5 to 1 to 6 in the 3 decades. Normal rainfall years decreased by 3 to 2 to 1 in the respective three decades. Deficit rainfall years were 2 in the 1st and last decade whereas they rose to

6 in the 2nd decade. There is only 1 scanty rainfall year i.e. 1998, when it rained 399.56 mm below the average.

25. NAGAUR

The average annual rainfall during 1980 and 2009 has been 322.00 mm in the district. During 1980 and 1989 decade there was 1 abnormal and 1 excess rainfall year. There are 3 normal rainfall years and 5 deficit years with 1984 to 1987 being consecutive deficit years. Year 1987 recorded the least rainfall which was 189.48 mm below the average. There are no scanty rainfall years in the district.

In the 1990 to 1999 decade, 1996 was the abnormal rainfall year with 290.44 mm above normal rainfall. There were 3 years each of excess, normal and deficit rainfall. Last decade had 2 excess and deficit rainfall years and 6 normal rainfall years. It can be seen that only normal rainfall years have increased, rest decreased.

26. PALI

The average annual rainfall of the district during 1980 and 2009 was 270.43 mm. the maximum and minimum rainfall of the observed years has been seen during 1980 and 1989 decade. 1981 recorded maximum rainfall which was 505.93 mm above average and 1987 recorded 246.75 mm below average being the lowest rainfall. It can be observed that the frequency of abnormal years above increased from 1st to last decade, so have excess rainfall years. Normal rainfall years have fluctuated from 2 to1 to 2 in the 3 decades. Scanty rainfall years were three in 1980's which increased to 5 years during 1990's and there was none during 2000 and 2009.

In the last 30 years there have been 8 scanty rainfall followed by 6 deficit and abnormal years and 5 excess and normal years.

27. PRATAPGARH

In 2006 the district received its only abnormal rainfall which was 761.95 mm. There was 1 record of excess rainfall during 1980-89 in 1984 and twice during 1990-99 and again once in 2004. The district in 57.69% of the years received normal rainfall. Deficit rainfall was during 23.07% times in the state with consecutive occurrence from 1998-2000. The year 1998 received minimum rainfall out of the 30 observed years, which was 362.04 mm less than the average.

28. RAJSAMAND

With an average annual rainfall of 510.38 mm, the district has no record of abnormal or scanty rainfall. The maximum rainfall was observed in 2009 with 266.06 mm above average. The no. of excess years has increased in the past 30 years from 2 during 1980-1989 to 3 in 1990-1999 and 2000-2009. 2005 and 2006 were consecutive excess rainfall years. Deficit rainfall years have increased from 4 to 2 in 1980-89 to 19901999 and 2000-2009. 1984-85 and 1999 and 2000 are consecutive deficit years. Rests have normal rainfall out of 30. The frequency of normal years has increased from 2 to 4 to 5 in the 3 decades respectively. Generally the district has normal rainfall succeeded by 8 excess and 8 deficit years.

29. SAWAI MADHOPUR

The average annual rainfall of the district is 525.36 mm. The maximum rainfall was in 1983 which was 565.67 mm, above average and other than this another abnormal rainfall year was 1995. In all there are 7 years of excess rainfall in the district, which came down from 3 in the first decade to 2 each in the next two decades. The number of deficit years has fluctuated from 3 to 4 to 2 during the 3

decades respectively. 1986-1987 and 1997-1998 were successive deficit rainfall years. Year 2002 only had scanty rainfall which was 329.55 mm below average. Rest all years had normal rainfall. In all, 10 years had rainfall below average and 9 years had rainfall above average.

30. SIKAR

The district had no year with scanty rainfall. Abnormal rainfall was recorded in 1983 and 1996. 1983 had maximum rainfall, which was266.45 mm above the average of 400.60 mm excess rainfall years fluctuated from 2 to 3 to 2 in the respective 3 decades from 1980-89, 1990-1999 and 2000-2009.

Deficit years 8 in total which was 3 in 1st decade fell to just 1 in 2nd decade and then again rose to 4 during the last decade. Number of normal years fluctuated from 2 to 3 to 2 in the respective 3 decades. Like many other districts Sikar too had maximum no. of normal rainfall followed by 8 deficit and 7 excess rainfall years.

31. SIROHI

The average annual rainfall of the district during the observed period is 438.57 mm. During the 1980-1989 decade there were 3 continuous years of excess rainfall – 1980, 1981, 1982 along with 1985; 2 abnormal rainfall years 1983 and 1987; 2 consecutive scanty rainfall years – 1986 & 1987. 1987 recorded the lowest rainfall out of 30 years; it was 381.97 mm below normal. These scanty years were followed by 2 consecutive deficit rainfall years- 1988 and 1989. This decade had no year with normal rainfall.

In the second decade i.e. during 1990-1999, there is no year with abnormal rainfall, 1992 had excess rainfall and 1990 had normal rainfall. 1993-1994 were 2

consecutive deficit years along with 1997. 1991, 1995-96 and 1998-99 were years with scanty rainfall. In the last decade from 200 to 2009, there was no year of scanty rainfall. 2000, 2004 and 2008 were abnormal rainfall years where in 2006 highest rainfall of 30 years was received, was 733.50 mm above average. 2002 & 2009 received deficit rainfall and rest 3 years were of excess rainfall. It can be seen that out of 30, maximum 8 years were of excess rainfall along with 4 years of abnormal rainfall. There were 7 years of each deficit and scanty rainfall and just 4 years of normal rains.

32. TONK

Here, there has been no year of scanty rainfall in 30 years from 1980 to 2009 and just 1 year i.e. 1983 of abnormal rainfall. This year had the maximum rainfall out of the 30 years when it rained 332.20 mm, above the average of 415.39mm. Year 2002 had the minimum rainfall when it rained 216.70 mm, below average. In the first decade 1986 and 1987 were deficit rainfall years. In the second 1993 and 1996-97 were deficit and during the last decade 2002 and 2009 were deficit years. Normal rainfall varied from 6 to 4 to 7 in the respective 3 decades. During 1st and 3rd decade there was 1 rainfall excess year but during 1990-1999 the no. Of excess rainfall days was 3. Generally more years were of normal rainfall followed by deficit and excess rainfall years.

33. UDAIPUR

The average annual rainfall of Udaipur district from 1980 to 2009 is 441.48 mm. During 1980-1989 decade only 1982 had abnormal rainfall; 4 years had excess

rainfall in 1980-1981 and 1984-1985, 1986-1987 were rainfall deficiency years. No year had scanty rainfall in this decade.

During 1990-1999, 1995 had scanty rainfall, which was 304.99 mm, less than the average and was least of 30 years. Two years were normal rainfall years. 1991, 1993-1994, 1996-1997, 1999 were rainfall deficit years.

In the last decade i.e. 2000-2009, had 5 excess rainfall years in 2004-2005 and 2007-2009 and 3 normal rainfall years. 2006 had the maximum rainfall out of the 30 years which was 678.30 mm, above the average. 2000 was a deficit year. The frequency of excess and deficit rainfall years during the 30 years is same i.e. 9 years followed by 7 normal years.

On the basis of the analysis done above the rainfall intensities in Rajasthan from 1980 to 2009 can be summed up in the Table – 8.

Table – 8: District-wise rainfall intensities in Rajasthan (1980 to 2009)

S. No	District	No. of Year	Abnormal Rainfall		Excess Rainfall		Normal Rainfall		Deficit Rainfall		Scanty Rainfall	
			No.of years	% of years	No.of years	% of years	No.of years	% of years	No.of years	% of years	No.of years	% of years
1	Ajmer	30	3	10	4	13.33	16	53.33	5	16.66	2	6.66
2	Alwar	30	4	13.33	3	10	14	46.66	7	23.33	2	6.66
3	Banswara	30	2	6.66	4	13.33	14	46.66	10	33.33	0	0
4	Baran	30	0	0	4	13.33	23	76.666	2	6.66	1	3.33
5	Barmer	30	4	13.33	3	10	10	33.33	9	30	4	13.33
6	Bharatpur	30	2	6.66	5	16.66	14	46.66	9	30	0	0
7	Bhilwara	30	0	0	7	23.33	15	50	8	26.66	0	0
8	Bikaner	30	1	3.33	8	26.66	12	40	8	26.66	1	3.33

S. No	District	No. of Year	Abnormal Rainfall		Excess Rainfall		Normal Rainfall		Deficit Rainfall		Scanty Rainfall	
			No.of years	% of years	No.of years	% of years	No.of years	% of years	No.of years	% of years	No.of years	% of years
9	Bundi	30	0	0	6	20	20	66.66	4	13.33	0	0
10	Chittorgarh	30	1	3.33	6	20	15	50	8	26.66	0	0
11	Churu	30	1	3.33	7	23.33	13	43.33	9	30	0	0
12	Dausa	29	2	6.89	4	13.79	11	37.93	11	37.93	1	3.44
13	Dholpur	29	1	3.44	4	13.79	17	58.62	7	24.13	0	0
14	Dungarpur	30	2	6.66	3	10	18	60	7	23.33	0	0
15	Ganganagar	30	5	16.66	6	20	4	13.33	7	23.33	8	26.66
16	Hanumangarh	28	1	3.57	7	25	12	42.85	8	28.57	0	0
17	Jaipur	30	2	6.66	6	20	11	36.66	11	36.66	0	0
18	Jaisalmer	30	1	3.33	10	33.33	11	36.66	6	20	2	6.66
19	Jalore	30	5	16.66	2	6.66	11	36.66	10	33.33	2	6.66
20	Jhalawar	30	1	3.33	4	13.33	20	66.66	5	16.66	0	0
21	Jhunjhunu	30	1	3.33	7	23.33	12	40	9	30	1	3.33
22	Jodhpur	28	1	3.57	6	21.42	13	46.42	7	25	1	3.57
23	Karauli	23	1	4.34	5	21.73	12	52.17	5	21.73	0	0
24	Kota	30	12	40	1	3.33	5	16.66	10	33.33	1	3.33
25	Nagaur	30	2	6.66	6	20	12	40	10	33.33	0	0
26	Pali	30	6	20	5	16.66	5	16.66	6	20	8	26.66
27	Pratapgarh	26	1	3.84	4	15.38	15	57.69	6	23.07	0	0
28	Rajsamand	27	0	0	8	29.62	11	40.74	8	29.62	0	0
29	Sawai Madhopur	29	2	6.89	7	24.13	10	34.48	9	31.03	1	3.44
30	Sikar	28	2	7.14	7	25	11	39.28	8	28.57	00	0
31	Sirohi	30	4	13.33	8	26.66	4	13.33	7	23.33	7	23.33
32	Tonk	30	1	3.33	5	16.66	17	56.66	7	23.33	0	0
33	Udaipur	28	2	7.14	9	32.14	7	25	9	32.14	1	3.57

Source: http://waterresources.rajasthan.gov.in/Daily_Rainfall_Data/Rainfall_Index.htm

4.4 WATER SURPLUS AND DEFICIENCY ANALYSIS

Rajasthan which is the largest state in India has only 1.16 % of the country's water resources. These too are highly unevenly distributed with most of the available water resources been confined to south and south-eastern part of the State. River Chambal is the only perennial river of the state rest all the rivers are rain-fed. The west-central part of western Rajasthan is devoid of any drainage network. This scenario makes Rajasthan the driest state with nearly 70 percent (2/3rd) of the area classified as arid and semi arid region. such a scenario any change in climate variables can affect the hydrological cycle by directly increasing evaporation of available surface water as a result influencing precipitation amount and intensity which indirectly impact the storage of water in surface and groundwater reserves.

Due to the insufficiency of surface water resources the dependence on groundwater resources is significantly high. This is evident from the fact that the number of safe blocks on Rajasthan has decreased from 203 to 31 and the number of over-exploited blocks has increased from 12 to 166 during1984 to 2009 respectively. Table – 9 indicates that the groundwater resources have reached a very crucial stage and very limited ground water available in the region.

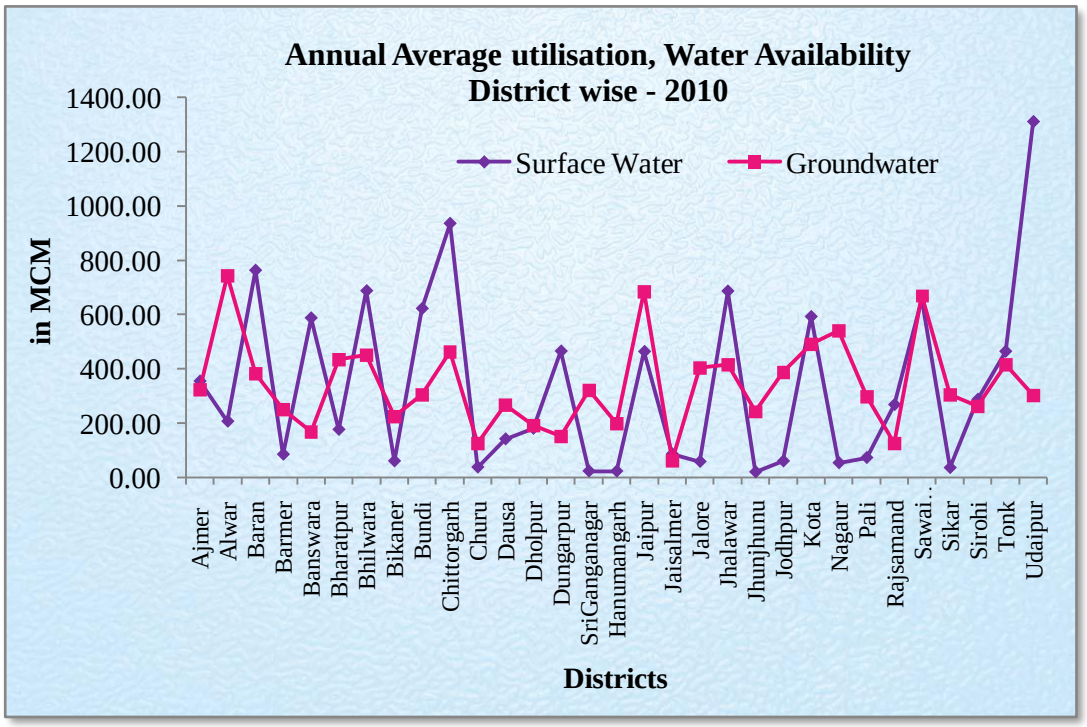
Table – 9 Changing Groundwater scenario of Rajasthan (1984 to 2009)

Category	1984	1988	1998	2001	2004	2008	2009
Over-Exploited (>100%)	12	44	41	86	140	164	166
Critical (90-100%)	11	18	26	80	50	34	25
Semi-Critical (70-90%)	10	42	34	21	14	8	16
Safe (<70%)	203	122	135	49	32	30	31
Total Blocks*	237	237	237	237	237	237	239

* Tara Nagar block of Churu district has not been assessed as the entire block has saline groundwater
Source: Compiled from various Groundwater Reports.

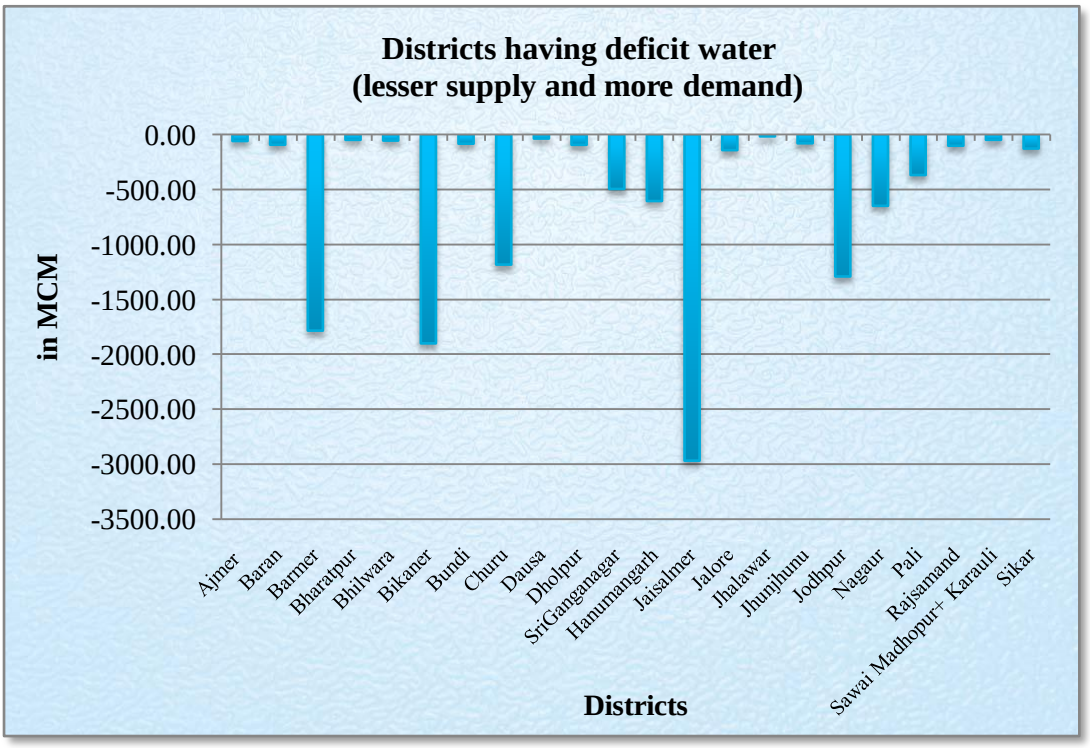
For the surplus and deficiency analysis a comparative study has been done between the district wise availability and demand during the year 2010. Being in the water scarce region it is inevitable that the available water is not enough to cater to the needs and requirements of the state. The annual average demand in 2010 in the state was of 31333.74 million cubic meter (MCM) with an availability of 10448.59 MCM annual average surface water (having 75% dependability) and 10563.01 MCM of annual average ground water, i.e. Total Annual Average Utilization Water Availability was 21011.60 MCM, which is depicted district-wise in Graph – 6. Hence, the deficit between demand and supply is 10322.14 MCM.

Graph – 6

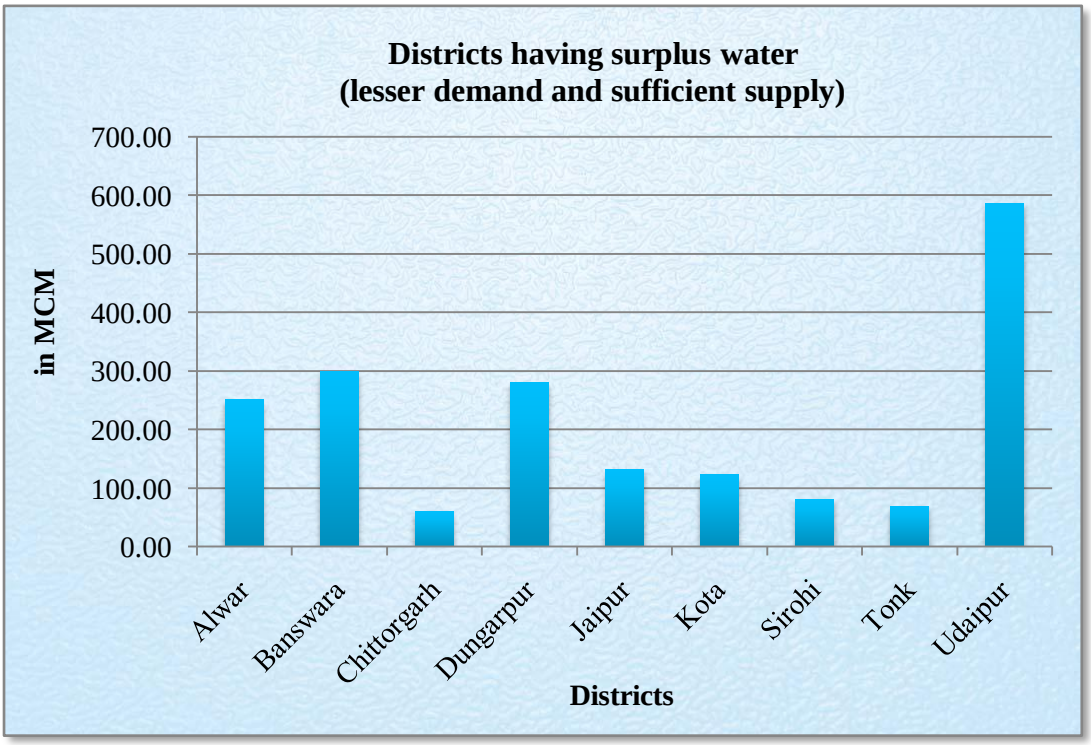


The groundwater scenario and the surface water in terms of river basin too have been discussed in the following chapter. Districts which have deficit water (i.e. lesser supply and more demand) and the Districts which have surplus water (i.e. lesser demand and sufficient supply) have been depicted in the Graph – 7 and Graph – 8 respectively.

Graph – 7



Graph – 8



The water Surplus and deficiency analysis depending on its demand and availability from the surface and groundwater resources in each agro-climatic zone has been as follows:

1. Arid North Western Sandy Plain

The Arid North Western Sandy Plain is a water deficit region as it is not able to meet the demand posed by the region. The deficit is of 1783.29 MCM. Out of the 14 major catchment regions in the region has 17.6% basin of river Luni and 13.0% of the other small regional streams in this zone. There are 8 groundwater blocks in this zone. Here safe blocks have increased from 0 in 2001 to 1 in 2004 and 2009. The semi-critical blocks decreased to 0 in 2004 and 2009. Whereas the number of semi-critical and over exploited blocks were remained 2 and 5 respectively from the years 2001 to 2009.

2. Irrigated North Western Plain

The Irrigated North Western Plain is a water deficit region with more dependence on the scarce groundwater resources of the region. Its total annual average water availability is 564.4 MCM which is met from groundwater (518.6 MCM) and surface water (45.7 MCM.) resources. The annual average demand creates a deficiency or gap of 1098.3 MCM. Only some small streams contribute 25.5% of their basin in this region.

On the groundwater scenario this region is divided into 18 blocks and most of the region 10 to 11 blocks are constantly safe and 5 blocks are over exploited since 2001 to 2009. This distribution shows a good status of Groundwater in this region.

3. Hyper Arid Partial Irrigated Zone

The Hyper Arid Partial Irrigated Zone has an annual average deficit of 4865.49 MCM, as only 428.64 MCM water is available annually on an average. Out of this 145.66 MCM is available from surface resources and 282.97 MCM is available from groundwater resources of the region. Here the region has 8 blocks which were critical in 2009. There are a considerable number of safe blocks in the region numbering 4 and 3 during 2001 and 2009 respectively. The region is drained by small local streams which have their 39.8% basin in this zone.

4. Transitional Plain of Inland Drainage

Transitional Plain of Inland Drainage is a water deficient agro-climatic zone as it is not able to meet its average annual demand of water. Here, the annual average availability of water is 145.68 MCM from surface resources and 1207.97 MCM from groundwater resources, total 1353.65 MCM which is deficit by 2035.01 MCM. River Shekhawati, Sabi and Luni have 68.8%, 11.2%, and 4.9% basin in this region respectively. The local small streams also have 23% of their basin in this region. There are 33 groundwater blocks out of which only 3 blocks were in the safe category during the years 2001 to 2009. On the other hand the region has 19, 22 and 26 blocks in the over-exploited category during the years 2001, 2004 and 2009 respectively.

5. Alluvial Plain of Luni Basin

The Alluvial Plain of Luni Basin is a water deficient agro-climatic zone as it is not able to meet its average annual demand. Here, the annual average availability of water is 477.40 MCM from surface resources and 1345.52 MCM from groundwater resources, which is deficit by 1718.62 MCM. The surface water resources include River Sukli, West Banas, Luni and Sabarmati which have their 100%, 99.9%, 70.6% and 2.1% basins in this region respectively. The entire basin of the Nallas of Jalore

is present in this region along with the small streams having their 11.7% basin. In the groundwater scenario out of the 31 blocks there are only 2 safe blocks since 2001 to 2009. In 2001 the number of critical blocks was 13 but by 2004 their number decreased to 10. The blocks under the over exploited category also increased greatly from 15 to 19 blocks during 2001 to 2004 and 23 blocks in 2009.

6. Semi Arid Eastern Plain

The Semi Arid Eastern Plain agro-climatic zone is a water surplus region as it is able to meet its annual average water demand. Total annual average availability of water is 3104.29 MCM out of which major dependence is on ground water resources i.e. 1682.82 MCM. The agro-climatic zone is divided into 32 groundwater blocks. There were 6 safe and 3 semi-critical groundwater blocks in 2001, both of which decreased to zero 2004 onwards. The number of over exploited blocks increased from 16 to 28 from 2001 to 2009. The surface water scenario of this region includes the basin of a few rivers. The region has 26.5% basin of River Shekhawati, 41% basin of River Banganga; 2.9% basin of River Gambhir; 26.9% Sabi; 42.6% basin of Banas, 17% of Chambal and 5.4% Luni basin.

7. Flood Prone Eastern Plain

The Flood Prone Eastern Plain has been blessed with both surface (890.37 MCM) and ground water (1699.19 MCM) resources. River Ruparail has its entire basin in this region. River Parbati has its 82.7%, River Sabi has its 61.9%, River Banganga has its 55.9%, River Gambhir has its 34.2%, River Shekhawati has its 4.7% and River Chambal has its 2.8% basin in this region. In the context of ground water resources the region has been divided into 32 blocks. The number of safe blocks has decreased from 9 to 0 from 2001 to 2009. During 2009 the semi-critical

blocks decreased to just 1 and critical blocks were 5 in number. The situation of over exploited blocks is also alarming as they rose from 13 to 26 during 2001 to 2009.

8. Sub Humid Southern Plain and Aravallis

The Sub-Humid Southern Plain and Aravalli Zone is a water surplus region. It has a surplus of 492.20 MCM. There are a significant percentage of river basins in the region which include – River Sabarmati's 82.3% basin, River Mahi's 51.7% basin, River Banas's 46.7% basin, River Chambal's 13.1% basin, River Luni's 1.5% basin and West Banas's 0.1% basin. The ground water of the region has been exploited inappropriately. Out of the 43 ground blocks of this region there was just 1 safe zone and 2 semi-critical zones during 2009. The number of critical blocks decreased from 25 to 5 from 2001 to 2009. Whereas the over exploited blocks increased from 17 to 37 during the observed years.

9. Humid Southern Plain

This Humid Southern Plain Region is also water surplus, with a total availability of 1368.63 MCM. The water resources of the region are optimally utilized. River Mahi and Sabarmati have their 48.3% and 15.6% basin respectively in this region and there are 13 groundwater blocks in the district. In 2001 there were six blocks which fell in the category of safe blocks but by 2009 the number was raised to 8. The semi-critical blocks were 2 during 2001 which was raised to 8 in 2004 but again reduced to 5 in 2009. There are no critical or over exploited blocks in the district in 2009.

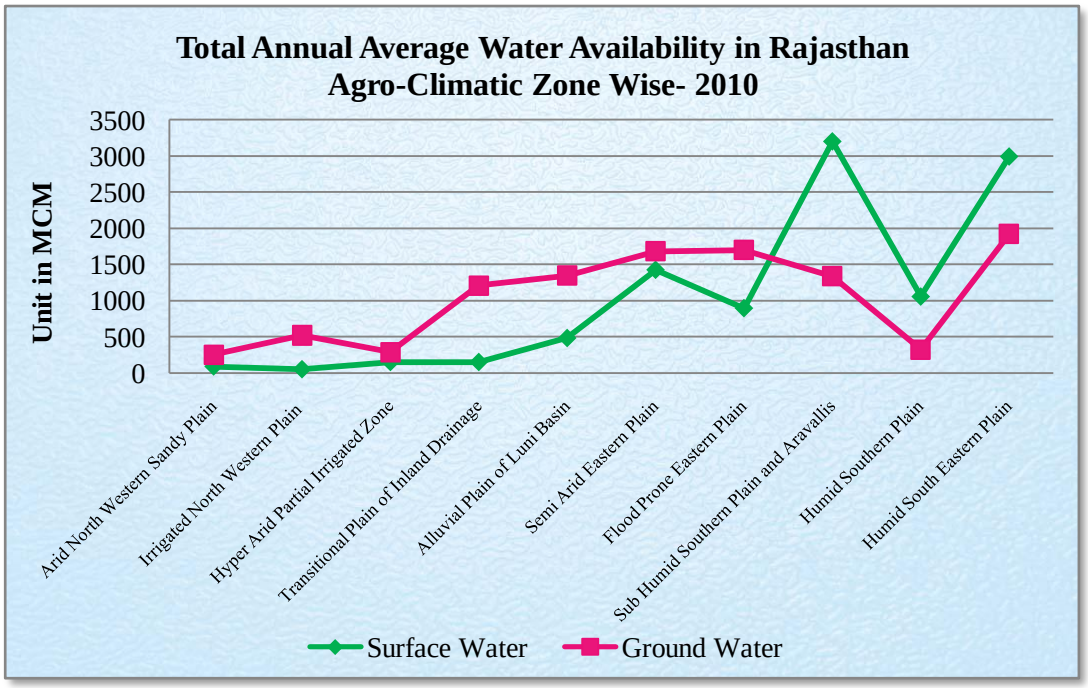
10. Humid South Eastern Plain

The Humid South Eastern Plain is water deficit region. It has an availability of 4910.03 MCM water from surface and groundwater resources, which is deficit by 90.48 MCM. Out of the 27 ground water blocks of the region the number of safe

blocks decreased from 9 to 3 during 2001 to 2009. The semi-critical and critical blocks decreased from 7 and 10 respectively to 4 during 2001 to 2009. But unfortunately the number of over exploited blocks increased from 1 in 2001 to 16 in 2009. This region has 82.4% basin of River Chambal, 62.9% basin of River Gambhir, 17.3% basin of River Parbati, 10.7% basin of River Banas and 3.1% basin of River Banganga to cater to the needs of the region.

Many agro climatic regions of the state come under the various river basins but as these rivers are mostly seasonal and due to other constraints their benefit cannot be taken annually. Hence, this too aggravates the situation of water deficit. The paucity of surface water increases dependence on groundwater in the state. The Total Annual Average Utilization Water Availability is depicted Agro-Climatic Zone wise in Graph – 9.

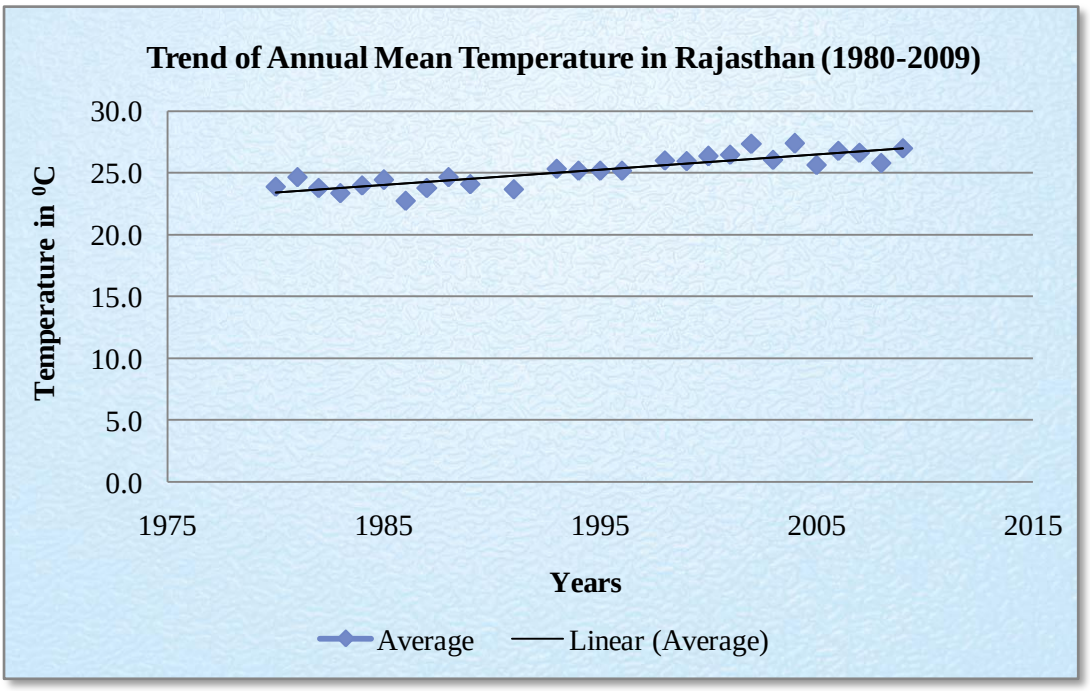
Graph – 9



4.5 TEMPERATURE ANALYSIS

The state witnesses great peculiarities in temperature. Winters are very severe and temperature falls below freezing point at places like Ganganagar; summers are intense and quite severe in region like the western Rajasthan. High resolution regional model projections for 2071-2100 have predicted an increase in annual mean surface temperature for all parts of India with an increase of 2-4^{0}C for the state of Rajasthan (Government of Rajasthan, 2010). May is generally the hottest month and generally January records the lowest daily maximum and minimum temperature. Changes in the climate variables like temperature increase can affect the hydrologic cycle and agriculture and allied sectors which exhibit high sensitivity to climate stresses.

Graph – 10



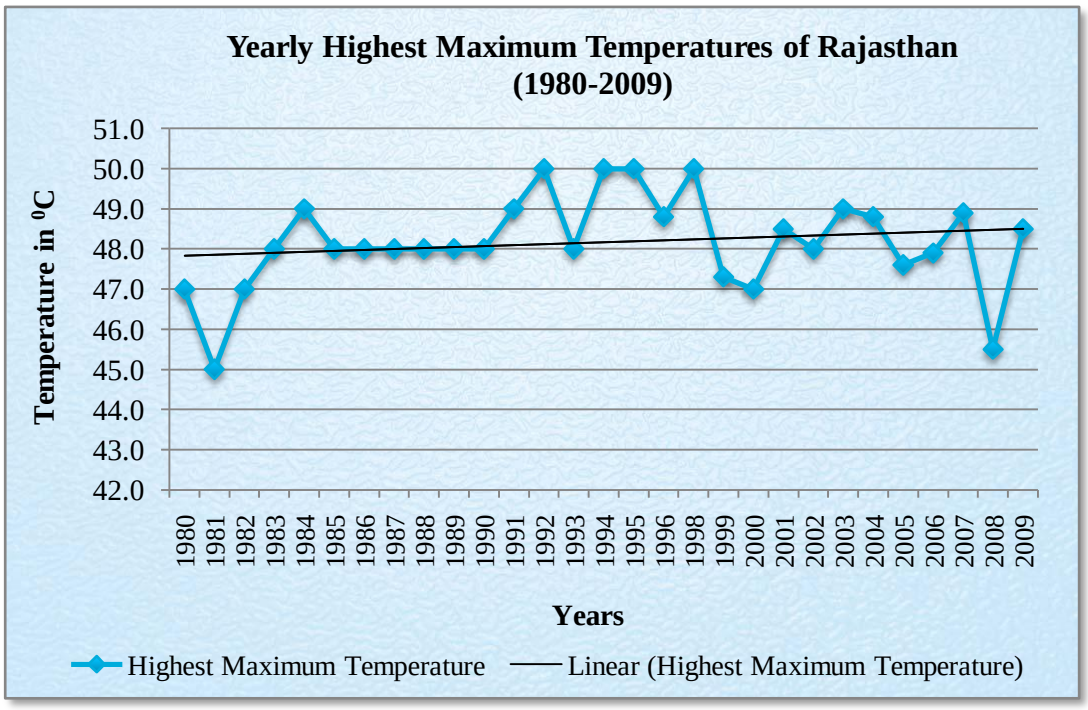
The Graph – 10 depicts the temperature variation in the state in the observed 30 years. This graph indicates an overall increase in the temperature, as the mean

decadal temperature witnessed a rise from 23.8^{0}C during 1980 and 1989 to 25.1^{0}C during 1990 and 1999 and maintained itself during 2000 and 2009 as well.

Here, according the data the average temperature is 25.2^{0}C and the highest mean average annual temperature was recorded during 2002, which was 2.2^{0}C above the average and the minimum temperature was 2.5^{0}C below the average in 1986.

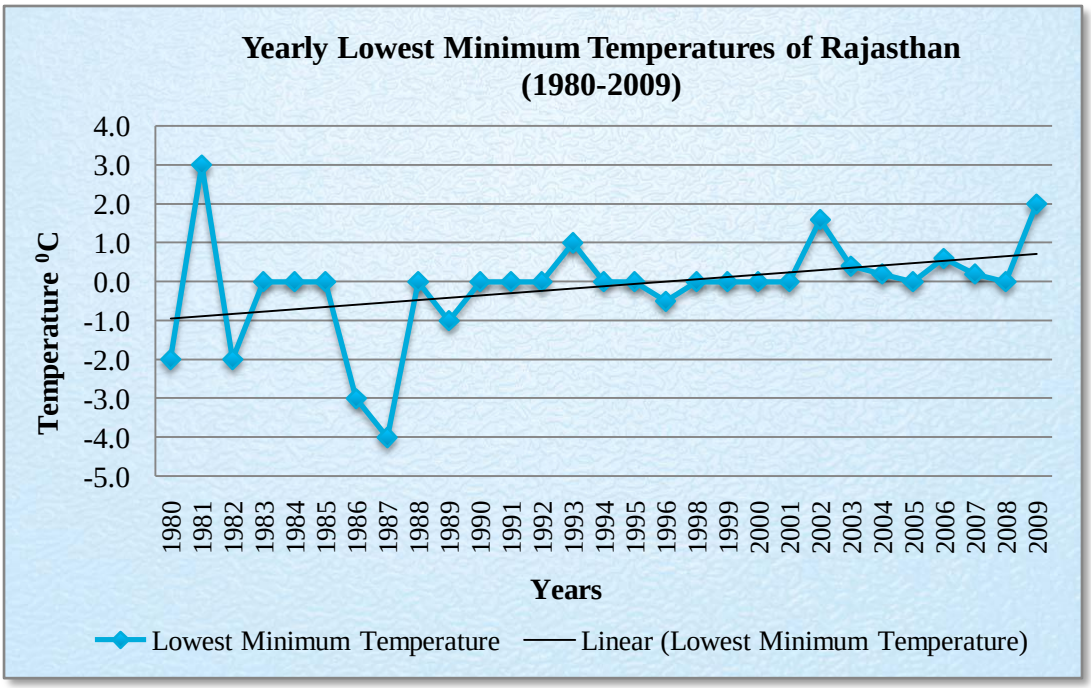
The highest maximum temperature was 50.0^{0}C, which was observed during 1992, 1994, 1995 and 1998. The maximum temperatures in Rajasthan indicate an increase, these varied between 45 ^{0}C to 50^{0}C. It can be seen that the maximum temperatures rose during the 1990's more that than the other two decades, but a general trend towards the increase of maximum temperature can also be seen. The Graph – 11 depicts the highest maximum temperatures over the 30 observed years in Rajasthan.

Graph – 11



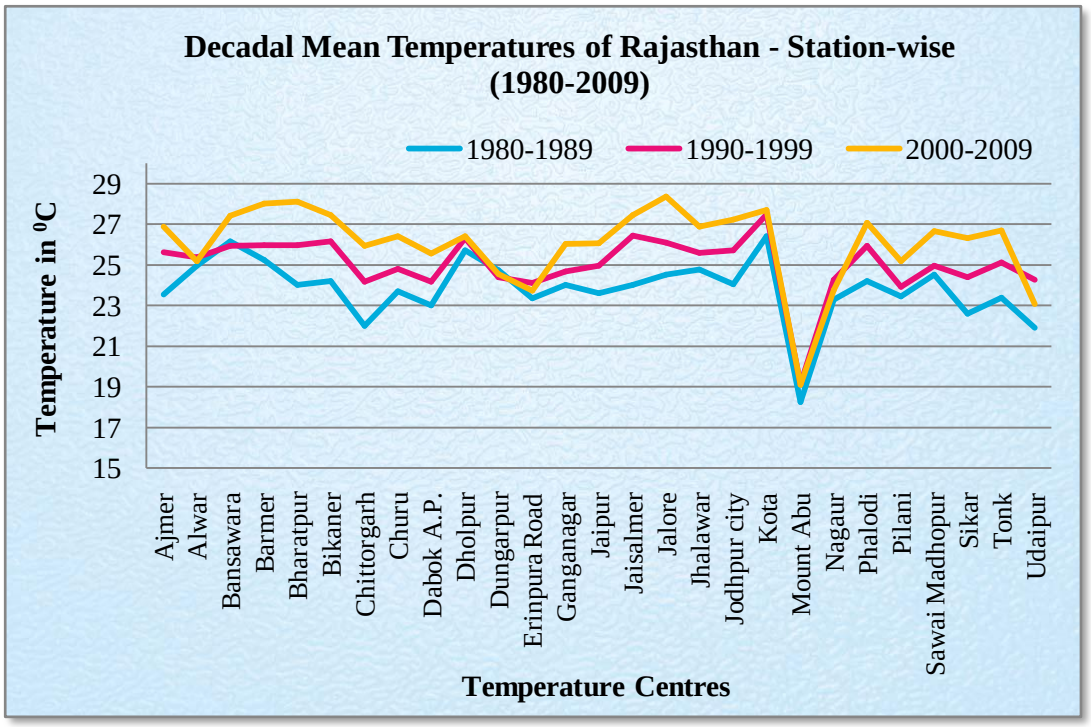
The Graph – 12 depicts the highest minimum temperatures over the 30 observed years in Rajasthan. The lowest minimum temperature was -4.0^{0}C, which was observed during 1987. It can be seen that the minimum temperatures too are gradually increasing, as is also indicated by the upward moving trend line.

Graph – 12



The chapter tries to look at the mean annual temperature observations to trace if there is any trend of increase or decrease of mean annual temperature in the state. The temperature observatories in the state are at the following centers:- Ajmer; Alwar; Anoopgarh; Bansawara; Barmer; Bharatpur; Bhilwara; Bikaner; Bundi; Chittorgarh; Churu; Dabok A.P.; Dholpur; Dungarpur; Erinpura Road; Ganganagar; Jaipur; Jaisalmer; Jalore; Jawai Bandh;Jhalawar; Jodhpur A.P.; Jodhpur city; Kota; Mount Abu; Nagaur; Phalodi; Pilani; Rawat Bhata; Sawai Madhopur; Sikar; Tonk; and Udaipur. It can be seen that there is a rise of temperature at almost all these temperature centre/stations in the state. The increasing decadal mean temperatures have been depicted through Graph – 13.

Graph – 13



To study the variation of temperature in the 10 agro-climatic regions of Rajasthan in the observed time span of 30 years ranging from 1980 to 2009 too depicts the same trend, which has been discussed below.

1. Arid North Western Sandy Plain

The temperature data at Arid North Western Sandy Plain zone suggests a rise in average annual mean temperature from 25.25^{o} C to 25.9^{o} C during 1980-1989 and 1990-1999 respectively. The mean temperature increased up to 28.0 ^{o}C during 2000-2009. During these decades the highest temperature was recorded during 2002 which was 2.1^{o} C above average annual mean temperature of 26.4^{o} C and the lowest was during 1992 which was 5.9^{o} C below the average.

2. Irrigated North Western Plain

The mean annual temperature of this zone during 1980-2009 was 25.1^{o} C. During this time span the highest temperature was recorded in 2006 where the temperature was 1.3^{o}C above the average and minimum was recorded in 1982 when it was 2.6^{o} C below the average. The comparison of decadal averages suggests that this centre has an increase in the temperature as the temperature rose from 24.2^{o} C during 1980-1989 to 25.1^{o}C during 1990-1999 to 26.0^{o}C during 2000-2009.

3. Hyper Arid Partial Irrigated Zone

The annual average mean temperature of the Hyper Arid Partial Irrigated Zone in the studied 30 years i.e. 1980-2009 has been 25.9^{o}C. The minimum temperature of these 30 years was recorded in 1986 when it was 2.4^{o}C below the average and the highest was recorded in 2004 which was 2.0^{o}C above the average. During 1980-1989 the average mean annual temperature was 24.1^{o}C with lowest in 1986 and highest in 1989. In the second decade the annual average mean temperature rose to 26.2^{o}C. The annual average mean temperature further rose to 27.4^{o}C during 2000-2009. According to the decade annual average mean temperature comparisons it can be seen that there has been a rise of temperature in the last 30 years in the centre, from 24.1^{o}C to 26.2^{o}C to 27.4^{o}C during the 3 decades.

4. Transitional Plain of Inland Drainage

In the Transitional Plain of Inland Drainage Zone the average mean annual temperature during 1980-2009 has been 24.5^{o} C. The lowest temperature was recorded during the first decade in 1983 when it was 2.6^{o} C below the average and the maximum temperature of the 3 decades was recorded in the last decade i.e. 2004

when it was 2.4^{o} C above the average. The decadal mean temperature shows a rise in temperature at this centre too. Here, the mean annual temperature during 1980-1989 is 23.2^{o} C which rose to 24.4^{o} C during 1990-1999 to 25.9^{o} C during 2000-2009.

5. Alluvial Plain of Luni Basin

The temperature data at Alluvial Plain of Luni Basin suggests a rise in average annual mean temperature from 23.1^{o} C to 24.4^{o} C during 1980-1989 and 1990-1999 respectively. The mean temperature increased up to 26.0 ^{o}C during 2000-2009. During these decades the highest temperature was recorded during 2002 which was 3.3^{o} C above average annual mean temperature of 24.5^{o} C and the lowest was during 1986 which was 2.3^{o} C below the average.

6. Semi Arid Eastern Plain

The average annual mean temperature in this zone during 1980-2009 has been 25.0^{o}C. This centre too shows and increases in temperature as the temperature increased from 23.5^{o} C to 25.1^{o} C to 26.4^{o} C over the 3 observed decades. The highest and the lowest temperature of the observed 30 years were during 2002 and 1983, which were 2.8^{o} C above and 2.4^{o} C below the average.

7. Flood Prone Eastern Plain

The average annual mean temperature of the Flood Prone Eastern Plain Zone during 1980-2009 has been 25.9^{o}C. The highest mean temperature was recorded in 2002 which was 2.1^{o}C above the average where the lowest mean temperature was 2.6^{o}C below the average recorded in 1986. The comparison between the decadal averages show that the temperature rose from 25.3^{o}C (1980-1989) to 25.9^{o}C (1990-

1999) to 26.6°C (2000-2009). This implies that there is a rise of mean annual temperature at this centre.

8. Sub Humid Southern Plain and Aravallis

The temperature data at Sub Humid Southern Plain and Aravallis region suggests a rise in average annual mean temperature from 22.8°C to 24.7° C during 1980-1989 and 1990-1999 respectively. The mean temperature increased up to 24.3° C during 2000-2009. During these decades the highest temperature was recorded during 1994 which was 2.4° C above average annual mean temperature of 23.5° C and the lowest was during 1982 and 1986 which was 1.8° C below the average.

9. Humid Southern Plain

The average annual mean temperature in this zone during 1980-2009 had been 25.5°C. During these 30 years the highest annual mean temperature was recorded in 1985 which was 1.4°C above the average and the lowest annual mean temperature was 2.2°C below the average in the year 1989. This centre suggests the decadal fluctuation in temperature but an eventual rise as the average annual mean temperature during 1980-1989 was 25.3° C which dropped to 24.8° C during 1990-1999 and then again rose to 26.2° C during 2000-2009.

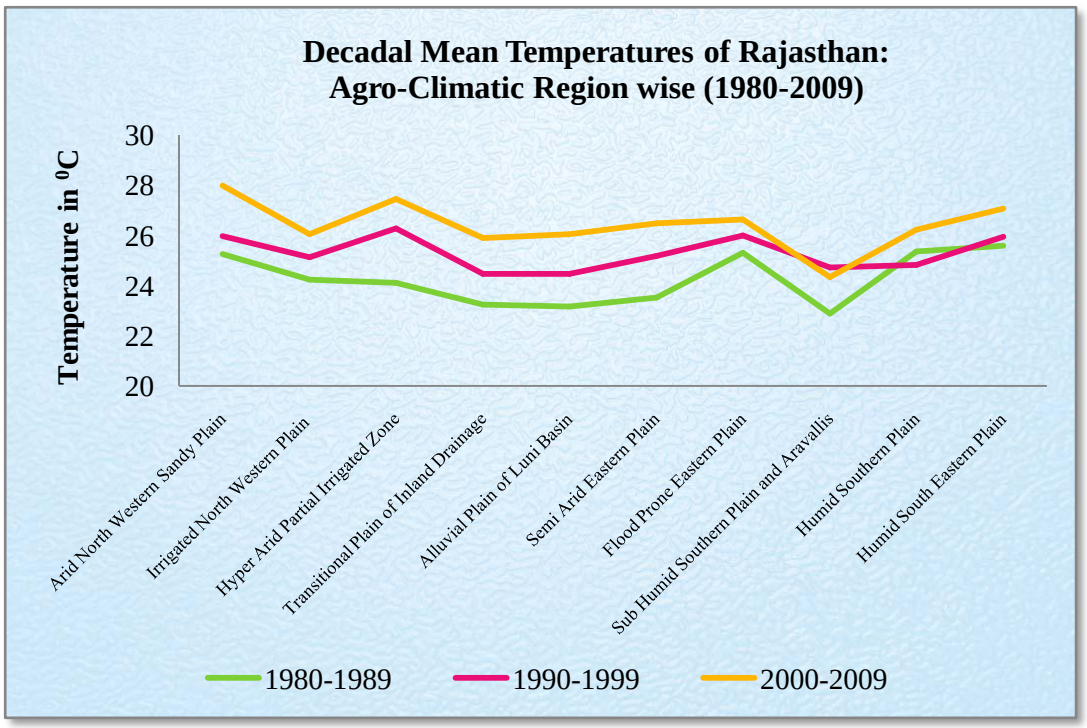
10. Humid South Eastern Plain

At the Humid South Eastern Plain Zone the average mean annual temperature during 1980-2009 has been 26.2° C. The lowest temperature was recorded during the first decade in 1986 when it was 1.6° C below the average and the maximum temperature of the 3 decades was recorded in the last decade i.e. 2002 when it was 3.4° C above the average. The decadal mean temperature shows a rise in temperature

at this centre too. Here, the mean annual temperature during 1980-1989 is 25.5^{o} C which rose to 25.9^{o} C during 1990-1999 to 27.0^{o} C during 2000-2009.

In each of the agro climatic zones of the state it can be seen that the temperature has increased. This suggests that the temperature is towards an increase during the observed 30 years in the state. Graph - 14 depicts the rising temperature trend in the state in the various Agro-Climatic Regions.

Graph - 14



4.6 SEASONAL TEMPERATURE ANALYSIS

Due to warm-dry continental climate of the state which is characterized by arid and semi-arid climatic conditions there is a significant diurnal and seasonal range of temperature. The variations in seasons are based on rainfall and temperature conditions that differ amongst different seasons. The Aravallis play a significant role here, as on the west of Aravallis the climate is arid having low rainfall, low humidity and extremes of diurnal and annual temperature. To the east of Aravallis the climate is semi-arid to sub-humid having lesser extremes of temperature, higher humidity and rainfall.

According to the Indian Meteorological Department the year may be divided into four seasons, namely:

1. The Winter Season from January to February
2. The Pre-Monsoon season from March to May
3. The Southwest Monsoon season from June to September
4. The Post Monsoon Season from October to December

January is the coldest month, with minimum temperature ranging between 2^0C in the north and 7.8^0C in the south-west (Rajasthan State Pollution Control Board, 1994) Sharp decrease in the night temperature is attributed to the presence of sandy soil at places like Sikar, Churu, Bikaner and Pilani. Also during the winters the entire state is brought under under a spell of series of cold-waves due to the western disturbances which bring along with them chilling winds for 2-5 days. During the winter and monsoon season the temperatures increase southwards and northwards respectively. The month of March marks the beginning of the hot

weather season. From here on the temperatures start increasing reaching the highest during June with the mean maximum temperature reaching as high as 48^0C. The plateau regions have comparatively lower temperatures during summers. The night minimum temperatures are lower in higher latitudes except during the southwest monsoon when they are more or less uniform. Weather during July generally remains harsh due to high temperature and humidity. Rest of the monsoon period has high humidity but the day temperature reduces.

To study the temperature variation during the 4 seasons in Rajasthan 4 districts one from each climatic region as classified according to the Thornthwaite are taken into account. The districts are namely:

1. Udaipur - CA'w Climatic Region
2. Jaipur - DA'w Climatic Region
3. Churu - DB'W Climatic Region
4. Barmer - EA'd Tropical Desert Climatic Region

Udaipur District

The district has on the whole a dry climate, with the hot season milder than in the Rajasthan desert areas to the northwest of the district. The cold season is from December to February and is followed by the hot season which lasts till about the middle of June. Mid June to mid September constitutes the southwest monsoon season. The post monsoon season from the middle of September to the end of November is one of transition from monsoon to winter conditions (Indian Meteorological Department, 2010).

There are two meteorological observatories in the district, one at Udaipur and other at Udaipur City. During the winter season both day and night temperatures begin to drop steadily which starts during late November. During 1980-2009 the mean yearly maximum temperature during the cold season was 26.24^0C and the mean yearly minimum temperature has been 7.39^0C. The minimum temperature sometimes reaches the freezing point of water and frost may occur occasionally. During winter and summer months the diurnal range of temperature is large. During early March the temperatures start rising rapidly till May early June. The mean yearly maximum temperature during the hot/pre-monsoon season in the district during 1980-2009 was 36.79^0C and the mean yearly minimum temperature was 19.37^0C.

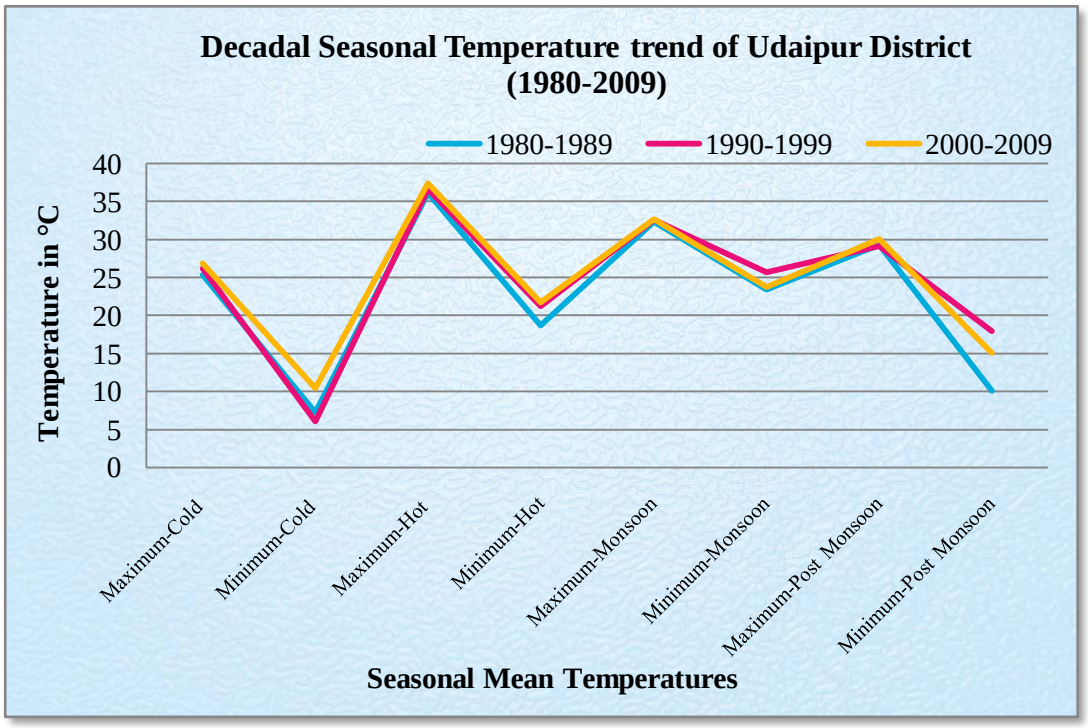
By the third or fourth week of June the temperatures drop significantly as the southwest monsoon reaches the district. But after the withdrawal of the southwest monsoon there is again a slight increase in day temperatures around mid-September. During 1980-2009 the mean yearly maximum temperature during the monsoon season and post-monsoon season was 32.73^0C and 29.62^0C respectively and the mean yearly minimum temperature during the monsoon season and post-monsoon season has been 23.76^0C and 11.95^0C respectively.

The temperature of the cold season registers slight increase. The mean maximum and the mean minimum temperature rose from 25.37 ^{o}C to 26.19 ^{o}C to26.85 ^{o}C and 7.22 ^{o}C to 6.05^{o}C reaching 10.45 ^{o}C during 1980-1989, 1990-1999 and 2000-2009 respectively. The hot season too had an increase in both mean maximum and mean minimum temperature. The mean maximum and mean minimum temperature in summers during 1980-1989, 1990-1999 and 2000-2009 varied from

36.15 °C to 36.62 °C reaching 37.42 °C and 18.71 °C to 21.17 °C reaching 21.72 °C respectively.

The mean maximum and the mean minimum temperature during monsoon season fluctuated around 32.37 °C, 32.61 °C and 32.73 °C; and 23.40 °C, 25.66 °C and 23.76 °C during 1980's, 1990's and 2000's respectively.

Graph – 15



The post monsoon season's mean maximum and mean minimum temperature recorded an increased during 1980-1989, 1990-1999 and 2000-2009 from 29.35 °C to 29.13°C reaching 30.08°C and 10.09°C rising 17.96°C and then falling to 15.12°C respectively. The mean minimum temperature during the post monsoon season showed the greatest variation of a rise of 7.87 °C and then a fall of 2.84 °C between the 1st and the 2nd; and 2nd and 3rd decade. See Graph – 15 depicts the seasonal fluctuations of Udaipur district. The highest mean maximum temperature in the cold,

hot, monsoon and post monsoon seasons in the district were 32.45^{o}C(1993), 42.19^{o}C (2006), 40.45 ^{o}C (1995) and 37.4 ^{o}C (1987) and lowest mean maximum temperature were 20.9 ^{o}C(1983), 30.09^{o}C(1990), 26.95 ^{o}C(1983) and 24.2^{o}C(1991) respectively.

The highest mean minimum temperature in the cold, hot, monsoon and the post-monsoon seasons was 10.67 ^{o}C (1987), 27.5 ^{o}C (2003), 30.25 ^{o}C(1994) and the lowest mean minimum temperature was 4.83 ^{o}C(1984), 10.54 ^{o}C(1988), 19.03 ^{o}C (1984) and 4.85^{o}C(1986) respectively.

Barmer District

The characteristic feature of the climate of this district in common with the adjoining districts of Rajasthan is its dryness, large diurnal range of temperature and the fitful and erratic nature of the rainfall. The year may be divided into four seasons, the winter from November to March, the summer from April to June, the southwest monsoon season from July to mid September and the post monsoon season from mid September to the end of October (Indian Meteorological Department, 2010).

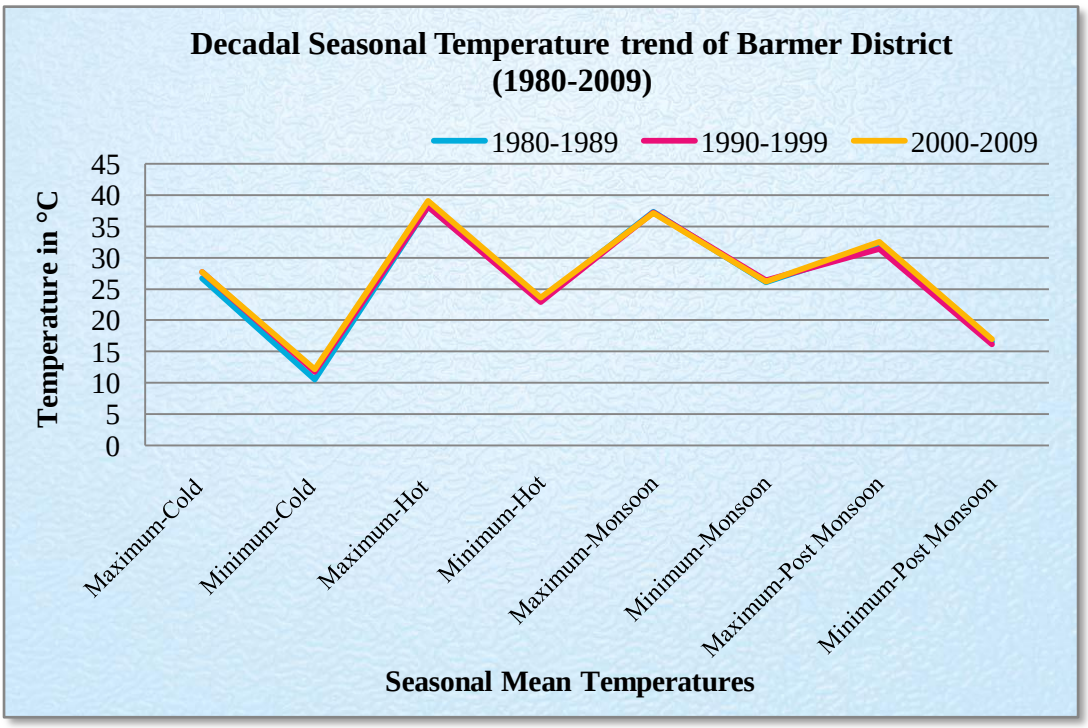
At Barmer the hot season attains its highest value in May or June which begins by March when the temperature begins to rise rapidly. The district witnesses' intense heat and heat waves intensify summers in the region. During 1980-2009 the mean yearly maximum temperature during the hot/pre-monsoon season was 38.50 ^{0}C and the mean yearly minimum temperature has been 23.28^{0}C. With the onset of the monsoon there is decrease in temperature and after the withdrawal of the monsoon there is again an increase in temperature. The mean yearly maximum temperature during the monsoon season was 37.28^{0}C and the mean yearly minimum

temperature has been 26.25^{0}C during 1980-2009. And during the post monsoon season the mean yearly maximum temperature was 31.98^{0}C and the mean yearly minimum temperature was 16.56^{0}C.

During the cold season, the temperatures are low especially in the night and January is the coldest month. The diurnal range of temperature is large in all the months. During this season the mean yearly maximum temperature was 27.42^{0}C and the mean yearly minimum temperature was 11.48^{0}C.

The temperature gradient of the Barmer district does not fluctuate much which can be seen in the Graph – 16. The temperature during the cold season show some rise during the observed time span of 1980 to 2009. The mean maximum temperature and the mean minimum temperature rose from 26.76^{o}C to 27.75 ^{o}C to 27.78 ^{o}C and 10.54 ^{o}C to 11.72 ^{o}C to 12.18 ^{o}C during 1980-1989, 1990-1999 and 2000-2009 respectively. The mean maximum temperature of the hot season too shows an increase from 38.18 ^{o}C in 1980's to 38.20 ^{o}C in 1990's reaching 39.13 ^{o}C in 2000's. The mean minimum temperature of this season fluctuated from 23.33 ^{o}C to 22.87 ^{o}C to 23.6 ^{o}C during 1980-1989 to 1990-1999 and 2000-2009 respectively.
The mean maximum and mean minimum temperature of the monsoon season showed very slight variation. The mean maximum temperature was 37.31 ^{o}C in 1980-1989 and 1990-1999 which showed a 0.08 ^{o}C decrease in 2000-2009 reaching 37.23 ^{o}C. Similarly, the mean minimum temperature during the same season varied around 26.11 ^{o}C in 1980-1989 to 26.40 ^{o}C in 1990-1999 and 26.23 ^{o}C during 2000-2009.

Graph – 16



The post-monsoon temperatures too reflect a slight increase. The mean maximum temperature during 1980-1989 was 31.99 ^{o}C which was 31.40 ^{o}C during 1990-1999 and 32.55 ^{o}C during 2000-2009. The mean minimum temperature was 16.54 ^{o}C during 1980-1989 and 16.13 ^{o}C during 1990-1999 which increased to 17.02^{o}C in 2000-2009. The highest mean maximum temperature during the cold, hot, monsoon and post-monsoon seasons was 34.1 ^{o}C(2006), 44.1 ^{o}C(1995), 43.9 ^{o}C (1995), and 39.8 ^{o}C(2000) respectively.

The lowest mean maximum temperature during cold, hot, monsoon and post-monsoon seasons was 23.5 ^{o}C(2005), 31.6 ^{o}C(1982), 31.8 ^{o}C(2006) and 0 ^{o}C in 1991 respectively. Likewise, the higher mean minimum temperature during hot, cold, monsoon and post-monsoon seasons was 15.9 ^{o}C in 2009, 28.1 ^{o}C in 2009, 29.1 ^{o}C in 1991 and 25.0 ^{o}C in 1987 and lowest mean minimum temperature was 0 ^{o}C in 1982, 16.4 ^{o}C in 1995, 22.4 ^{o}C in 1994 and 0 ^{o}C in 1981 respectively.

CHURU DISTRICT

The district has a dry desert climate, with large variations of temperature and scanty rainfall. The winter period from November to March is followed by the summer season from April to June. The period from July to mid September is the southwest monsoon season. Mid September to October is the period of transition from monsoon to the cold season (Indian Meteorological Department, 2010).

In the Churu district the variation in the minimum and maximum temperature is perhaps greatest for any place in the world. Perhaps it is the only place in the world where temperature dips below sub-zero but does not have snowfall (http://churu.nic.in/AboutUs/geography.html). Here, May and June are the hottest months with the mean yearly maximum temperature in the hot season during 1980-2009 was 36.02^0C and the mean yearly minimum temperature at about 18.34^0C. It is intensely hot and scorching dust laden winds prevail. The temperatures fluctuate with the advance of the southwest monsoon season and the humidity is very high. During the monsoon season the mean yearly maximum temperature was 37.85^0C and the mean yearly minimum temperature has been 24.99^0C. After the monsoon withdraws, the mean yearly maximum temperature and the mean yearly minimum temperature begin to decrease. During the post monsoon season in the observed years they were 30.12^0C and 12.01^0C respectively. In the cold season the diurnal range of temperature is very large. After October the drop in temperature is rather sudden and January is the coldest month. Cold waves in association with passing western disturbances, affect the district and the minimum temperatures sometimes drop to four to five degrees below the freezing point of water and frost occurs,

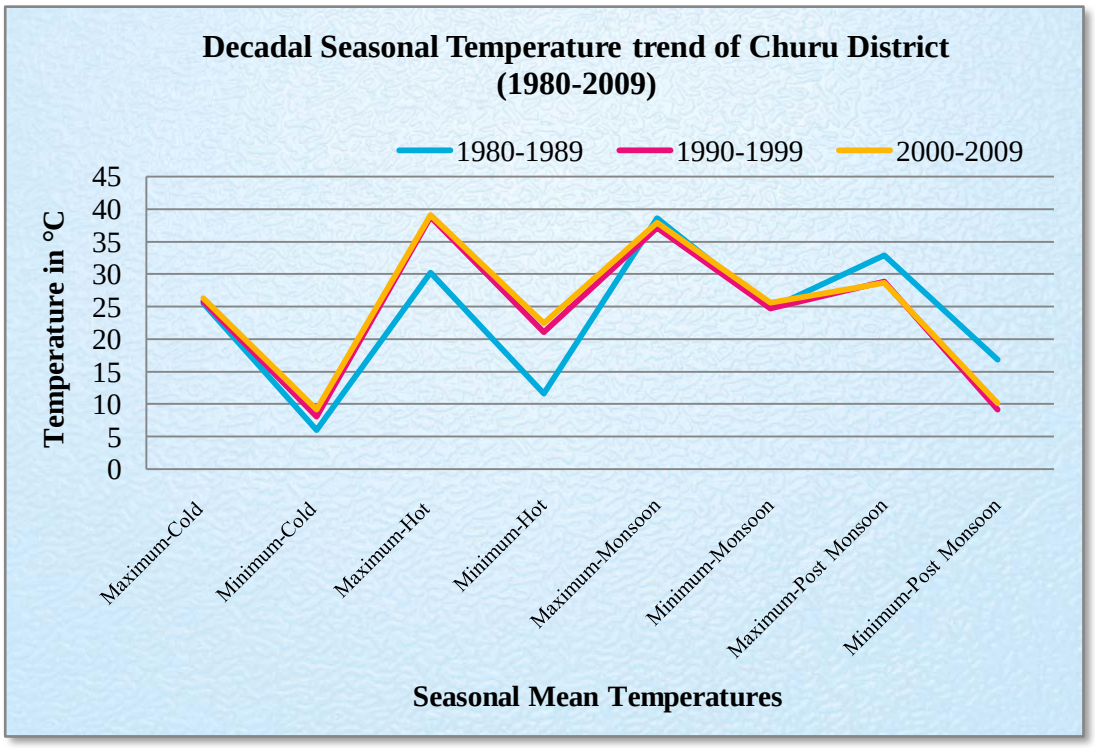
during winter season. The mean yearly maximum temperature in the cold season was 25.85^{0}C and the mean yearly minimum temperature was 7.74^{0}C.

During the observed 30 years from 1980 to 2009, in the 4 major seasons there were some fluctuations in the temperature. During the cold season the mean maximum temperature rose from 25.46^{0}C to 25.82^{0}C to 26.26^{0}C during 1980 to 1989 and 1990 to 1999 and 2000 to 2009 respectively. A similar rising trend is seen in the mean minimum temperature as well. Here, the mean minimum temperature rose from 6.02^{o}C to 8.07 ^{o}C to 9.14 ^{o}C during the above said 3 decades. During the hot season both the mean maximum temperature and the mean minimum temperature rose from 30.26^{o}C to 38.79^{o}C to 39.03^{o}C and 11.59^{o}C to 21.05^{o}C to 22.3^{o}C respectively during 1980s 1990s and 2000 to 2009 decade. During the monsoon season the mean maximum temperature showed slight variation from 38.59^{o}C to 37.15^{o}C to 37.81^{o}C; whereas the mean minimum temperature increased 24.69^{o}C to 24.70^{o}C to 25.58oC during the three decades.

The post monsoon season registered a fall in both mean maximum and mean minimum temperature of the three decades. The mean maximum temperature varied from 32.92^{o}C to 28.81^{o}C to 28.64^{o}C and mean minimum varied from 68.80^{o}C to 98.11^{o}C to 10.13^{o}C during 1980-1989, 1990 to 1999 and 2002-2009.

In this decadal analysis it can be seen that the major temperature differences were seen between 1980-1989 and 1990-1999 whereas during 1990-1999 and 2000-2009 there was not that much variation. See Graph – 17.

Graph – 17



From 1980 to 2009 the highest mean maximum temperature during cold, hot, monsoon and post-monsoon season was 35.2^{o}C (2003), 44.9 ^{o}C (1994), 44.1 ^{o}C (1995), and 28.5^{o}C (1981)respectively; the lowest mean maximum temperature cold, hot, monsoon and post-monsoon season was 20.7 ^{o}C (1988,1994) 20.3 ^{o}C (1983), 32.5 ^{o}C(1990) and 21.0 ^{o}C (1989).

Similarly, the highest mean minimum temperature and the lowest mean minimum temperature was recorded was 15.0^{o}C (2003), 30.0 ^{o}C (2003), 29.9 ^{o}C (1986) and 25.9 ^{o}C (1983); and 1.7 ^{o}C (1987), 0.8 ^{o}C (1980), 13.8 ^{o}C (1997) and 2.5 ^{o}C (2002) respectively during the cold, hot, monsoon and post-monsoon seasons.

JAIPUR DISTRICT

The district has a dry climate except during the southwest monsoon season. December to February is the cold season after which the hot season commences and continues till about the third week of June when the southwest monsoon sets in. The southwest monsoon season is comparatively short in this region and lasts only till mid September. The period from the second half of September to the end of November is the post monsoon season or retreating monsoon season (Indian Meteorological Department, 2010).

The period from March to June is one of continuous increase in temperatures, May and the first half of June being the hottest part of the year. During the observed years i.e. 1980 to 2009 the mean yearly maximum temperature of the hot season was 36.44^0C and the mean yearly minimum temperature was 21.70^0C. During the on-set of the southwest monsoon the temperatures may lower down to some extent but the humidity increases. Here the mean yearly maximum temperature during monsoon season was 35.34^0C and the mean yearly minimum temperature was 25.55^0C.

After the withdrawal of the monsoon, in the post-monsoon season the mean yearly maximum temperature was 29.28^0C and the mean yearly minimum temperature was 14.38^0C. After November both day and night temperatures drop till January, which is the coldest month. During the cold season the district gets affected by the cold waves which get associated with the passing western disturbances across north India. The mean yearly maximum temperature and the mean yearly minimum temperature during the observed years were 24.09^0C and 9.90^0C respectively.

During 1980 and 2009 in the cold season the mean maximum temperature has gradually increased. It was 28.58 ^{o}C during 1980-1989 which rose to 23.96 ^{o}C during 1990-1999 and reached 24.72 ^{o}C during 2000-2009. Whereas, the mean minimum temperature of the same season varied from 9.49 ^{o}C in the1st decade to 10.31 ^{o}C in the 2nd and 9.91 ^{o}C in the last decade of the observed years.

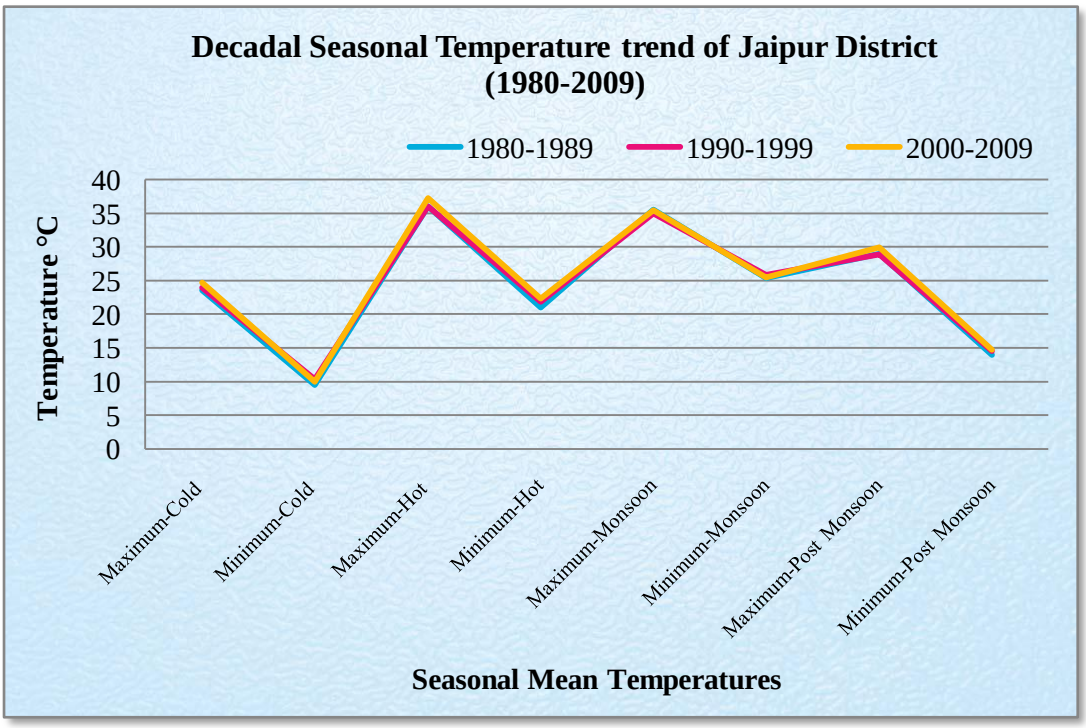
In the hot season both mean maximum and the mean minimum temperature increased gradually. The mean maximum temperature rose from 36.00 ^{o}C to 36.02^{o}C reaching 37.30^{o}C and the mean minimum temperature rose from 20.97 ^{o}C to 21.84^{o}C reaching 22.3^{o}C during 1980-1989 to 1990-1999 and 2000-2009 respectively. There was slight variation in the monsoon season's mean maximum and mean minimum temperature. The mean maximum temperature varied from 35.55 ^{o}C to 34.98 ^{o}C to 35.51 ^{o}C and the mean minimum temperature varied from 25.38 ^{o}C to 25.79 ^{o}C to 25.47 ^{o}C during 1980-1989 to 1990-1999 and 2000-2009 respectively.

In the post-monsoon season the mean maximum and the minimum temperature did not very much but fluctuations were seen. The mean maximum temperature varied from 29.00^{o}C to 28.90 ^{o}C to 29.95 ^{o}C and the mean minimum temperature varied from 13.99 ^{o}C to 14.50 ^{o}C to 14.65 ^{o}C during 1980-1989 to 19990-1999 and 2000-2009 respectively. The Graph – 18 depicts the temperature variation in the district during the 30 observed years.

The highest mean maximum temperature in the district in the observed 30 years in the cold, hot, monsoon and the post-monsoon season was 31.5 ^{o}C in 2006, 43.2 ^{o}C in 1988, 41.8 ^{o}C in 1981 and 1995 and 36.5 ^{o}C in 2000 and the lowest mean

maximum temperature observed was 20.9 ^{o}C (1995, 2005), 27.4 ^{o}C (1982), 30.6 ^{o}C (1995) and 19.5 ^{o}C (1995) respectively.

Graph – 18



The highest mean minimum temperature in the cold, hot, monsoon and the post-monsoon seasons was 14.5 ^{o}C (2006), 28.8 ^{o}C(2002), 29.9(1995) and 21.3 ^{o}C(1995) and the lowest mean minimum temperature recorded was 6.9 ^{o}C (2001), 13.8 ^{o}C (1982), 21.6 ^{o}C (1984) and 6.9 ^{o}C (1986) respectively.

It can be seen that Barmer, Churu, Jaipur and Udaipur districts have a trend of rise in temperature but the rate varies from region to region.