DROLOGICAL ANALYSIS

FOR

WATER RESOURCES AND IRRIGATION PLANNING:

CASE STUDY OF NORTH GUJARAT AGROCLIMATIC ZONE

A Thesis Submitted to
The Maharaja Sayajirao University of Baroda
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IN

CIVIL ENGINEERING

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CERTIFICATE

This is to certify that the thesis entitled "Climateorological Analysis For Water Resources And Irrigation Planning: Case Study Of North Gujarat Agroclimatic Zone" which is being submitted to The Maharaja Sayajirao University of Baroda in fulfillment of the requirements for the award of degree of Doctor of Philosophy in Civil Engineering by Ms. Neha R. Patel has been written by her under my supervision and guidance. This is an original work carried out by her independently. The matter presented in this thesis has not been submitted for the award of any other degree.

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Place: Vadodara

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PREFACE

Science has made enormous inroads in understanding climate and its causes. This understanding is crucial because it allows decision makers to place climate change in the context of other large challenges facing the nation and the world. There are still some uncertainties, and these always will be, in understanding a complex system like Earth's climate. The improvements in dealing with these understandings are increasingly reflected in the performance of the operational hydrological models used for forecasting the impacts of floods, droughts and other environmental hazards. A key consideration with hydrometeorological forecasts is that the information provided is usually used for operational decision-making.

The climate of India defies easy generalisation, comprising a wide range of weather conditions across a large geographic extent and varied topography. India's unique geography and geology strongly influence its climate; this is particularly true of the Himalayas in the north and the Thar Desert in the northwest. As in much of the tropics, monsoonal and other weather conditions in India are unstable: major droughts, floods, cyclones and other natural disasters are sporadic, but have killed or displaced millions. India's long-term climatic stability is further threatened by global warming. Climatic diversity in India makes the analysis of these issues complex.

The revelation by the India Meteorological Department (IMD, 2008) that eight of the 10 warmest years on record since 1901 have been in the last one decade and that all years since 1993, barring one, have clocked higher than normal temperature established beyond doubt that India's climate has already changed on account of global warming– and this is irrespective of whether the warming is on the long-term ascendant or cyclical in nature. Some earlier studies conclude that temperatures in India would soar by 3^0 C to 6^0 C and monsoon rainfall would be up by 15 % to 50 % by the end of the 21st century. What is equally unnerving is that overall farm production is forecast to drop by 10 % to 40 % due to the temperature rise by the end of the century, making the agriculture sector the worst sufferer though its contribution to global warming is relatively meagre.

od production requires detailed knowledge of the
e within which the farmer must work

It has been my earnest desire to acquire more knowledge in the field of climate and share the same with the other engineers. Recognizing the importance of climate studies and the effects of global warming, I took up the present study with a view to develop a knowledge regarding the climate of the study area affected by the change. The identified study area was found to be the one of the most affected water scarce area. Therefore I decided to study the climate of the North Gujarat Agroclimatic Zone in order to assist the water resources and irrigation activities in the region. The analysis is based on the climate data obtained for the period of 1961 to 2008.

The study determines the maximum rainfall depths, which could assist in planning a new and re-examining an existing water resources project using a probabilistic approach. The study characterizes the climate parameters. The spatial variability of rainfall in the area is investigated. Even the magnitude and intensity of drought in the area is studied using standardized precipitation index for preliminary information regarding planning and managing the extreme scenarios. The main focus of study is to identify the optimum onset dates of monsoon for planning the agricultural activities in the region through improved techniques, so that the rainfed agriculture could be made more dependable.

The development of this research is enriched and motivated by indirect suggestions provided by the reviewers through the research publications related to the subject matter. It is a pleasure to acknowledge the substantial help and guidance I received from my Guide. He has always encouraged and supported me from the very initiation of my interest in the topic, which was even before my registration to my Ph.D.

I hope that this research work may be useful especially to the practicing Hydrologists, Engineers, Agriculturists, Agronomists and Farmers in the region for planning the water resources and agricultural activities.

ABSTRACT

Climatology is the scientific study of climate, including the causes and longï term effects of variation in regional and global climates. Climatology also studies how climate changes over time and is affected by human actions. Climate models are used for a variety of purposes from study of the dynamics of the weather and climate system to projections of future climate.

For a country like India, which is still largely dependent upon rainï fed agriculture, availability of freshwater is one of the foremost concerns for the future. Most of Indian plains receive about 80% of their annual quota of rain from the southwest monsoon during the four months, June to September. The coastal areas in peninsular India receive rain from the northeast monsoon during October to December, which includes cyclonic storms.

Gujarat State experiences diverse climate conditions In terms of the standard climatic types, tropical climates viz., subï humid, arid and semiï arid, are spread over different regions of the state. Out of total area of the state 58.60 % fall under arid and semiï arid climatic zone. The arid zone contributes 24.94 %, while the semiï arid zone forms 33.66 % of the total area of the state.

Gujarat is divided into eight agroclimatic zones. For the present study north Gujarat agroclimatic zone is considered. The major objectives of present study are to investigate the climate in the area to plan the water resources and to plan rainfed agriculture in the region. For the present study daily rainfall data from 167 raingauge stations for 48 years (1961ï 2008) and climate data from 5 climate stations are obtained and analyzed.

The present study deals with the methodology to fill the missing data using only one rainguage station and to identify the same. Amongst the different methods, the closest station, non linear regression and ANN are used, as other methods require more than one rainguage station. To determine the best method for filling the missing daily rainfall data different forecast verification as well as model verification parameters are used and presented in the study. Cluster analysis is used for forming the clusters of raingauge stations. Overall it is concluded that the model having the ANN method using the generalized regression network is

…e missing daily rainfall data, as out of 68 models this … in 39 cases and within 10% error in additional 19 cases.

Various probability distributions and transformations can be applied to estimate one day and 2 to 7 & 10 consecutive days maximum rainfall of various return periods. In the present study 16 different types of continuous probability distributions were tested using Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) for goodness of fit of an estimated statistical model for north Gujarat agroclimatic zone. Inverse Gaussian distribution is best fitted to one day and consecutive 2 to 7 & 10 days maximum rainfall dataset by both the AIC and BIC criteria.

Regression analysis is carried out to determine one day and consecutive 2 to 7 & 10 days maximum rainfall at required return period. It has been concluded that the relationship between the return period and one day maximum rainfall, consecutive two, three, four, five, six, seven and ten days maximum rainfall are logarithmic. The relationship is nearly perfect i.e. r is greater than 0.9976. It is established that a linear relationship exists between one day maximum rainfall and consecutive two, three, four, five, six, seven and ten days maximum rainfall. The relationship is nearly perfect with r greater than 0.9979. It is established that the relationships developed can be used for design or review of various hydraulic structures for planning and managing the resources in the region.

The characteristics of the rainfall and climate data representing the mean, median, standard deviation, coefficient of variation and the quartile values were determined. The mean annual rainfall varies from 350 mm to 900 mm for the region. The other climate parameters are also studied. It can be observed that the available climate data indicates significant effects of variation on the temperature and precipitation patterns. The maximum temperature is significantly following increasing trend for available climate stations. The annual rainfall pattern for all the 73 raingauge stations is either increasing or decreasing.

The present study methodologically attempts to determine the structure of the accumulated rainfall amounts contributed by the accumulated number of rainfall days using concentration index, COIN, to represent the distribution and intensity values are ranging from 0.54 to 0.66 with an average concluded that a concentration index, defined on the basis of the exponential curves, enables the evaluation of contrast or concentration of the different daily amounts of the rainfall by regionalizing the study area into lower and higher variability.

A detailed hydrometeorological study for the Hathmati catchment having an area of about 595 km^2 has been made in order to provide estimates of the design storm rainfalls for different return periods and the Probable Maximum Precipitation (PMP) likely to be experienced by the catchment using rainfall data for the period 1961 to 2008. The analysis revealed that the PMP estimates over the catchment for 1, 2, 3, 4 and 5 day duration have been found to be 28.5 cm, 37 cm, 55.5 cm, 64.7 cm and 70 cm respectively by adjusting the envelope Depthï Duration (DD) raindepths with appropriate moisture maximization factors. Design storm raindepths given in the study will be useful in the planning and design of new water resources projects as well as in re-examining the spillways of existing water control devices.

A new approach to determine the Standardized Precipitation Index (SPI) using the best fitted distribution and comparing it with the conventional approach (using unfitted i.e. in its original form or gamma distribution) is presented. Different time scales of 4, 12 and 24 months are adopted for short and long duration drought predictions. It is identified that the area is drought affected.

An improved technique for analyzing wet and dry spells using Markov Chain is presented. The performance of zero, first and second order Markov chain models are studied based on AIC and BIC. It is found that the zero-order model is superior to the first and second order models in representing the probabilities of dry spell length of 7 to 14 days. Climatic indices are determined on monthly and weekly basis. It is found that the July and August are most reliable for rainfed agriculture. The detailed analysis for the weekly CI and Kci values indicated that, crops can be taken up starting from 25th standard meteorological week (18th June) till the end of 37th standard meteorological week (16th September).

The onset is identified by using water balance technique for the raingauge stations. The identified onset is presented in the form of dependable probability

... n are quite valuable for planning of rainfed agricultural ... average onset dates are 17th June, 29th June and 13th July which are earliest, normal and latest onset dates respectively. The average cessation dates obtained are 13th September, 14th September and 16th September for the respective earliest, normal and latest onset dates. The average length of growing season is 88 days, 78 days and 65 days for early, normal and late onset respectively.

In the present study, the sowing dates are suggested for the 73 raingauge based on the results obtained by analyzing dry spell length, the climate indices, the onset, the cessation and length of growing period. It is recommended to adopt normal onset date to be the sowing date for rainfed crops in the region. When one considers the earliest or latest onset dates, supplemental irrigation will be required for the crops which are not able to withstand the long dry spell of 7 to 10 days. In general, one can conclude for Pearl millet, one of the major crops grown in the region, that the excess amount of water requirement may be maximum around 52 % to 20 % of total water requirement, for dry spell length of 7 to 10 days respectively.

NOTATIONS

1D	One day
A	Number of event forecasts that correspond to event observations
A′	Area
AEHDSL	Annual extreme hydrologic dry spell length
AET	Actual evapotranspiration
AIC	Akaike's information criterion
ANCOVA	Analysis of covariance
ANFIS	Adaptive neuro fuzzy inference system
ANN	Artificial neural network
ARMA	Autoregressive or models
AWC	Available water content
A	Constant
B	Number of event forecasts that do not correspond to observed events
BHS	Bright hours of sunshine
BIAS	Bias score
BIC	Bayesianôs information criterion
BSï slope	Bootstrapï based slope
B	Constant
C	Number of noï event forecasts corresponding to observed events
C_1	Constant
C_2	Constant
C_3	Constant
C_4	Constant
C_v	Coefficient of variation
C10D	Consecutive 10 days
C2D	Consecutive 2 days
C3D	Consecutive 3 days
C4D	Consecutive 4 days
C5D	Consecutive 5 days
C6D	Consecutive 6 days

	days
	ased ANN
	organization
CFNN	Counterpropagation fuzzy-neural network
CI	Climate index
CLIGEN	Climate generator
COIN	Concentration index
CS	Closest station
CWPFï PDs	Cropï water production functions
C	Constant
D	Number of noï event forecasts corresponding to no events observed
DAC	Divide and conquer
DD	Depthï duration
DWT	Discrete wavelet transform
D	Index of agreement
Ej	Coefficient of efficiency
EOF	Empirical orthogonal functions
Eta	Actual evapotranspiration
Etc	Crop evapotranspiration
ETo	Reference crop evapotranspiration
ETS	Equitable threat score
EV2	Extreme value type II
E	Standard error
FA	Factor analysis
FAO	Food and agriculture organization
FAR	False alarm ratio
FC	Fraction of correct
G	Gamma
GA	Genetic algorithm
GCMs	Global circulation models
GDD	Growing degree days
GPD	Generalized Pareto distribution
GRNN	Generalized regression neural network

	s
	t index
HK	Hanssen Kuipers
I	Inverse Gaussian
IDM	De Martonne aridity index
IDP	Incremental dynamic programming
IDRP	Intensityï durationï return period
IM	Interï monsoon
IMD	India meteorological department
IUK	Iterative universal kriging
JC	Johansson continentality
Kc	Crop coefficients
Kcï adj	Adjusted crop coefficient
Kcb	Basal crop coefficient
Kci	Initial crop coefficient
Ke	Surface evaporation
KOI	Kerner oceanity index
Ks	Water stress coefficient
K	No. of parameters
L	Maximized value of the likelihood function for the estimated model
LLJ	Lowï level jet
M	Model preparation data
M_3	Third moment about mean
M_4	Fourth moment about mean
M.S.L.	Mean sea level
MAE	Mean absolute error
MAF	Moisture adjustment factor
MAI	Moisture availability index
MK	Mannï Kendall
ML	Maximum likelihood
MLPï ANN	Multiï layer perceptron form of ANN
MMF	Moisture maximization factor
MOK	Monsoon onset over Kerala
	Multiï channel singular spectrum analysis

	...egression line
Mt	Number of groups of tied ranks
N	Minimum acceptable length of records
NEM	Northeast monsoon
NLR	Non linear regression
NRC	Normalized rainfall curves
N	No. of observations
Ni	Frequencies in each class obtained from the observed rainfall
O	Original
$\overline{O}$	Average of the observed data points
O_i	Observed data points
Origiï PDSI	Original Palmer drought severity index
P	Probability of occurrence of a rainfall
P_i	Rainfall amount of the i^{th} month
P.M.	Penmanï Monteith
P3	Pearson type III
PANN	Periodic ANN
PCA	Principal component analysis
PCI	Precipitation concentration index
PCR	Principal component regression
Pdf	Probability density function
PDSI	Palmerôs drought severity index
Pe	Effective rainfall
PET	Potential evapotranspiration
PMF	Probable maximum flood
PMP	Probable maximum precipitation
PMS	Probable maximum storm
POD	Probability of detection
PV	Pinna combinative
PW	Preï whitening
p_i	Predicted data points
R	Ratio of 100 years maximum event to 2 years maximum event
	Coefficient of determination

	...mum rainfall
R_i	...rvations x_i of the time series
R_j	Ranks of observations
R_{mod}	Ratio of 100 years maximum event to 2 years maximum event of a fitted distribution
R_x	Consecutive 2 to 7 & 10 days maximum rainfall
RAW	Readily available soil water
RBN	Radial basis network
RCM	Regional climate model
RH	Relative humidity
RMSE	Root mean square error
RSS	Residual sum of squares
R	Coefficient of correlation
Sô	Area between the equidistribution line and polygonal line
S_r	Standard error of the estimate
S_t	Standard deviation
SCï PDSI	Selfï calibrated version of Palmer drought severity index
SIC	Schwarz information criterion
SMW	Standard meteorological week
SOI	Southern oscillation index
SPI	Standardized precipitation index
SPI_{mod}	Modified standardized precipitation index
SPS	Standard project storm
SSA	Singular spectrum analysis
SW	Southwest
SWDC	State water data centre
SWI	Soil water index
SWM	Southwest monsoon
T	Return period / recurrence interval
TANN	Thresholdï based ANN
TAW	Total available water
TGD	Three gorges dam
	Maximum temperature

	…erature
t_{10}	Student …value at 90% significance level and {n ï 6} degrees of freedom
t_j	Tied observations
U	Inequality coefficient
U_z	Standardized variable
UAE	United Arab Emirates
V	Model validation data
W_M	Maximum dew point
W_s	Precipitable water corresponding to the storm dew point
X	Accumulated percentage of days
X_{ip}	Fitted probability of rainfall at i^{th} observation
x	Rainfall data from the selected station for finding missing record
$\bar{x}$	Mean of the data set
$\bar{x}_p$	Mean of probability
x_j	Rainfall time series
Y	Accumulated percentage of rainfall
y	Missing rainfall record from the station in question
Z	Standard normal variate
α	Desired significance level
ε	Mean / scale parameter
λ	Shape parameter
з	Variance
ů	Standard deviation
σ_p	Standard deviation of probability

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139	6.114	AIC for Wagdod Raingauge Station, Patan District	CD
140	6.115	BIC for Wagdod Raingauge Station, Patan District	CD
141	6.116	AIC for Badoli Raingauge Station, Sabarkantha District	CD
142	6.117	BIC for Badoli Raingauge Station, Sabarkantha District	CD
143	6.118	AIC for Bayad Raingauge Station, Sabarkantha District	CD
144	6.119	BIC for Bayad Raingauge Station, Sabarkantha District	CD
145	6.120	AIC for Bhiloda Raingauge Station, Sabarkantha District	CD
146	6.121	BIC for Bhiloda Raingauge Station, Sabarkantha District	CD
147	6.122	AIC for Dantral Raingauge Station, Sabarkantha District	CD
148	6.123	BIC for Dantral Raingauge Station, Sabarkantha District	CD
149	6.124	AIC for Himmatnagar Raingauge Station, Sabarkantha District	CD
150	6.125	BIC for Himmatnagar Raingauge Station, Sabarkantha District	CD
151	6.126	AIC for Idar Raingauge Station, Sabarkantha District	CD
152	6.127	BIC for Idar Raingauge Station, Sabarkantha District	CD
153	6.128	AIC for Khedbrahma Raingauge Station, Sabarkantha District	CD
154	6.129	BIC for Khedbrahma Raingauge Station, Sabarkantha District	CD
155	6.130	AIC for Kundlacampo Raingauge Station, Sabarkantha District	CD
156	6.131	BIC for Kundlacampo Raingauge Station, Sabarkantha District	CD
157	6.132	AIC for Limla Dam Raingauge Station, Sabarkantha District	CD
158	6.133	BIC for Limla Dam Raingauge Station, Sabarkantha District	CD
159	6.134	AIC for Malpur Raingauge Station, Sabarkantha District	CD
160	6.135	BIC for Malpur Raingauge Station, Sabarkantha District	CD

[illegible]	[illegible]	[illegible] Dry Spell for Chandola Raingauge Station [illegible] Threshold Value	CD
[illegible]	[illegible]	[illegible] Dry Spell for Dehgam Raingauge Station Using 2.5 mm Threshold Value	CD
223	6.198	Probability of Dry Spell for Dehgam Raingauge Station Using 8 mm Threshold Value	CD
224	6.199	Probability of Dry Spell for Nal Lake Raingauge Station Using 2.5 mm Threshold Value	CD
225	6.200	Probability of Dry Spell for Nal Lake Raingauge Station Using 8 mm Threshold Value	CD
226	6.201	Probability of Dry Spell for Sanand Raingauge Station Using 2.5 mm Threshold Value	CD
227	6.202	Probability of Dry Spell for Sanand Raingauge Station Using 8 mm Threshold Value	CD
228	6.203	Probability of Dry Spell for Wasai Raingauge Station Using 2.5 mm Threshold Value	CD
229	6.204	Probability of Dry Spell for Wasai Raingauge Station Using 8 mm Threshold Value	CD
230	6.205	Probability of Dry Spell for Ambaji Raingauge Station Using 2.5 mm Threshold Value	CD
231	6.206	Probability of Dry Spell for Ambaji Raingauge Station Using 8 mm Threshold Value	CD
232	6.207	Probability of Dry Spell for Amirgadh Raingauge Station Using 2.5 mm Threshold Value	CD
233	6.208	Probability of Dry Spell for Amirgadh Raingauge Station Using 8 mm Threshold Value	CD
234	6.209	Probability of Dry Spell for Bapla Raingauge Station Using 2.5 mm Threshold Value	CD
235	6.210	Probability of Dry Spell for Bapla Raingauge Station Using 8 mm Threshold Value	CD
236	6.211	Probability of Dry Spell for Chandisar Raingauge Station Using 2.5 mm Threshold Value	CD
237	6.212	Probability of Dry Spell for Chandisar Raingauge Station Using 8 mm Threshold Value	CD
238	6.213	Probability of Dry Spell for Chitrasani Raingauge Station Using 2.5 mm Threshold Value	CD
239	6.214	Probability of Dry Spell for Chitrasani Raingauge Station Using 8 mm Threshold Value	CD
240	6.215	Probability of Dry Spell for Danta Raingauge Station Using 2.5 mm Threshold Value	CD
241	6.216	Probability of Dry Spell for Danta Raingauge Station Using 8 mm Threshold Value	CD
242	6.217	Probability of Dry Spell for Dantiwada Raingauge Station Using 2.5 mm Threshold Value	CD
243	6.218	Probability of Dry Spell for Dantiwada Raingauge Station Using 8 mm Threshold Value	CD
244	6.219	Probability of Dry Spell for Deesa Raingauge Station Using 2.5 mm Threshold Value	CD

		Dry Spell for Deesa Raingauge Station Using old Value	CD
		f Dry Spell for Dhanera Raingauge Station Using 2.5 mm Threshold Value	CD
247	6.222	Probability of Dry Spell for Dhanera Raingauge Station Using 8 mm Threshold Value	CD
248	6.223	Probability of Dry Spell for Gadh Raingauge Station Using 2.5 mm Threshold Value	CD
249	6.224	Probability of Dry Spell for Gadh Raingauge Station Using 8 mm Threshold Value	CD
250	6.225	Probability of Dry Spell for Hadad Raingauge Station Using 2.5 mm Threshold Value	CD
251	6.226	Probability of Dry Spell for Hadad Raingauge Station Using 8 mm Threshold Value	CD
252	6.227	Probability of Dry Spell for Junisarotri Raingauge Station Using 2.5 mm Threshold Value	CD
253	6.228	Probability of Dry Spell for Junisarotri Raingauge Station Using 8 mm Threshold Value	CD
254	6.229	Probability of Dry Spell for Nava Raingauge Station Using 2.5 mm Threshold Value	CD
255	6.230	Probability of Dry Spell for Nava Raingauge Station Using 8 mm Threshold Value	CD
256	6.231	Probability of Dry Spell for Palanpur Raingauge Station Using 2.5 mm Threshold Value	CD
257	6.232	Probability of Dry Spell for Palanpur Raingauge Station Using 8 mm Threshold Value	CD
258	6.233	Probability of Dry Spell for Panthawada Raingauge Station Using 2.5 mm Threshold Value	CD
259	6.234	Probability of Dry Spell for Panthawada Raingauge Station Using 8 mm Threshold Value	CD
260	6.235	Probability of Dry Spell for Sanali Ashram Raingauge Station Using 2.5 mm Threshold Value	CD
261	6.236	Probability of Dry Spell for Sanali Ashram Raingauge Station Using 8 mm Threshold Value	CD
262	6.237	Probability of Dry Spell for Wadgam Raingauge Station Using 2.5 mm Threshold Value	CD
263	6.238	Probability of Dry Spell for Wadgam Raingauge Station Using 8 mm Threshold Value	CD
264	6.239	Probability of Dry Spell for Mansa Raingauge Station Using 2.5 mm Threshold Value	CD
265	6.240	Probability of Dry Spell for Mansa Raingauge Station Using 8 mm Threshold Value	CD
266	6.241	Probability of Dry Spell for Raipur Weir Raingauge Station Using 2.5 mm Threshold Value	CD
267	6.242	Probability of Dry Spell for Raipur Weir Raingauge Station Using 8 mm Threshold Value	CD
268	6.243	Probability of Dry Spell for Balasinor Raingauge Station Using 2.5 mm Threshold Value	CD

[illegible]	[illegible]	[illegible] f Dry Spell for Balasinor Raingauge Station [illegible] Threshold Value	CD
270	6.245	Probability of Dry Spell for Dakor Raingauge Station Using 2.5 mm Threshold Value	CD
271	6.246	Probability of Dry Spell for Dakor Raingauge Station Using 8 mm Threshold Value	CD
272	6.247	Probability of Dry Spell for Kapadwanj Raingauge Station Using 2.5 mm Threshold Value	CD
273	6.248	Probability of Dry Spell for Kapadwanj Raingauge Station Using 8 mm Threshold Value	CD
274	6.249	Probability of Dry Spell for Kathlal Raingauge Station Using 2.5 mm Threshold Value	CD
275	6.250	Probability of Dry Spell for Kathlal Raingauge Station Using 8 mm Threshold Value	CD
276	6.251	Probability of Dry Spell for Kheda Raingauge Station Using 2.5 mm Threshold Value	CD
277	6.252	Probability of Dry Spell for Kheda Raingauge Station Using 8 mm Threshold Value	CD
278	6.253	Probability of Dry Spell for Mahemadabad Raingauge Station Using 2.5 mm Threshold Value	CD
279	6.254	Probability of Dry Spell for Mahemadabad Raingauge Station Using 8 mm Threshold Value	CD
280	6.255	Probability of Dry Spell for Mahisa Raingauge Station Using 2.5 mm Threshold Value	CD
281	6.256	Probability of Dry Spell for Mahisa Raingauge Station Using 8 mm Threshold Value	CD
282	6.257	Probability of Dry Spell for Nadiad Raingauge Station Using 2.5 mm Threshold Value	CD
283	6.258	Probability of Dry Spell for Nadiad Raingauge Station Using 8 mm Threshold Value	CD
284	6.259	Probability of Dry Spell for Pinglaj Raingauge Station Using 2.5 mm Threshold Value	CD
285	6.260	Probability of Dry Spell for Pinglaj Raingauge Station Using 8 mm Threshold Value	CD
286	6.261	Probability of Dry Spell for Savli Tank Raingauge Station Using 2.5 mm Threshold Value	CD
287	6.262	Probability of Dry Spell for Savli Tank Raingauge Station Using 8 mm Threshold Value	CD
288	6.263	Probability of Dry Spell for Vadol Raingauge Station Using 2.5 mm Threshold Value	CD
289	6.264	Probability of Dry Spell for Vadol Raingauge Station Using 8 mm Threshold Value	CD
290	6.265	Probability of Dry Spell for Vaghroli Tank Raingauge Station Using 2.5 mm Threshold Value	CD
291	6.266	Probability of Dry Spell for Vaghroli Tank Raingauge Station Using 8 mm Threshold Value	CD
292	6.267	Probability of Dry Spell for Ambaliyasan Raingauge Station Using 2.5 mm Threshold Value	CD

[illegible]	[illegible]	... Dry Spell for Ambaliyasan Raingauge Station ... hreshold Value	CD
[illegible]	[illegible]	... Dry Spell for Dharoi Raingauge Station Using ... shold Value	CD
295	6.270	Probability of Dry Spell for Dharoi Raingauge Station Using 8 mm Threshold Value	CD
296	6.271	Probability of Dry Spell for Kadi Raingauge Station Using 2.5 mm Threshold Value	CD
297	6.272	Probability of Dry Spell for Kadi Raingauge Station Using 8 mm Threshold Value	CD
298	6.273	Probability of Dry Spell for Kalol Raingauge Station Using 2.5 mm Threshold Value	CD
299	6.274	Probability of Dry Spell for Kalol Raingauge Station Using 8 mm Threshold Value	CD
300	6.275	Probability of Dry Spell for Katosan Raingauge Station Using 2.5 mm Threshold Value	CD
301	6.276	Probability of Dry Spell for Katosan Raingauge Station Using 8 mm Threshold Value	CD
302	6.277	Probability of Dry Spell for Kheralu Raingauge Station Using 2.5 mm Threshold Value	CD
303	6.278	Probability of Dry Spell for Kheralu Raingauge Station Using 8 mm Threshold Value	CD
304	6.279	Probability of Dry Spell for Mehsana Raingauge Station Using 2.5 mm Threshold Value	CD
305	6.280	Probability of Dry Spell for Mehsana Raingauge Station Using 8 mm Threshold Value	CD
306	6.281	Probability of Dry Spell for Ransipur Raingauge Station Using 2.5 mm Threshold Value	CD
307	6.282	Probability of Dry Spell for Ransipur Raingauge Station Using 8 mm Threshold Value	CD
308	6.283	Probability of Dry Spell for Thol Raingauge Station Using 2.5 mm Threshold Value	CD
309	6.284	Probability of Dry Spell for Thol Raingauge Station Using 8 mm Threshold Value	CD
310	6.285	Probability of Dry Spell for Unjha Raingauge Station Using 2.5 mm Threshold Value	CD
311	6.286	Probability of Dry Spell for Unjha Raingauge Station Using 8 mm Threshold Value	CD
312	6.287	Probability of Dry Spell for Vijapur Raingauge Station Using 2.5 mm Threshold Value	CD
313	6.288	Probability of Dry Spell for Vijapur Raingauge Station Using 8 mm Threshold Value	CD
314	6.289	Probability of Dry Spell for Visnagar Raingauge Station Using 2.5 mm Threshold Value	CD
315	6.290	Probability of Dry Spell for Visnagar Raingauge Station Using 8 mm Threshold Value	CD
316	6.291	Probability of Dry Spell for Patan Raingauge Station Using 2.5 mm Threshold Value	CD

[illegible]	[illegible]	[illegible] Dry Spell for Patan Raingauge Station Using 8 [illegible]d Value	CD
[illegible]	[illegible]	[illegible] Dry Spell for Sidhpur Raingauge Station Using [illegible]shold Value	CD
319	6.294	Probability of Dry Spell for Sidhpur Raingauge Station Using 8 mm Threshold Value	CD
320	6.295	Probability of Dry Spell for Wagdod Raingauge Station Using 2.5 mm Threshold Value	CD
321	6.296	Probability of Dry Spell for Wagdod Raingauge Station Using 8 mm Threshold Value	CD
322	6.297	Probability of Dry Spell for Badoli Raingauge Station Using 2.5 mm Threshold Value	CD
323	6.298	Probability of Dry Spell for Badoli Raingauge Station Using 8 mm Threshold Value	CD
324	6.299	Probability of Dry Spell for Bayad Raingauge Station Using 2.5 mm Threshold Value	CD
325	6.300	Probability of Dry Spell for Bayad Raingauge Station Using 8 mm Threshold Value	CD
326	6.301	Probability of Dry Spell for Bhiloda Raingauge Station Using 2.5 mm Threshold Value	CD
327	6.302	Probability of Dry Spell for Bhiloda Raingauge Station Using 8 mm Threshold Value	CD
328	6.303	Probability of Dry Spell for Dantral Raingauge Station Using 2.5 mm Threshold Value	CD
329	6.304	Probability of Dry Spell for Dantral Raingauge Station Using 8 mm Threshold Value	CD
330	6.305	Probability of Dry Spell for Himmatnagar Raingauge Station Using 2.5 mm Threshold Value	CD
331	6.306	Probability of Dry Spell for Himmatnagar Raingauge Station Using 8 mm Threshold Value	CD
332	6.307	Probability of Dry Spell for Idar Raingauge Station Using 2.5 mm Threshold Value	CD
333	6.308	Probability of Dry Spell for Idar Raingauge Station Using 8 mm Threshold Value	CD
334	6.309	Probability of Dry Spell for Khedbrahma Raingauge Station Using 2.5 mm Threshold Value	CD
335	6.310	Probability of Dry Spell for Khedbrahma Raingauge Station Using 8 mm Threshold Value	CD
336	6.311	Probability of Dry Spell for Kundlacampo Raingauge Station Using 2.5 mm Threshold Value	CD
337	6.312	Probability of Dry Spell for Kundlacampo Raingauge Station Using 8 mm Threshold Value	CD
338	6.313	Probability of Dry Spell for Limla Dam Raingauge Station Using 2.5 mm Threshold Value	CD
339	6.314	Probability of Dry Spell for Limla Dam Raingauge Station Using 8 mm Threshold Value	CD
340	6.315	Probability of Dry Spell for Malpur Raingauge Station Using 2.5 mm Threshold Value	CD

[illegible]	[illegible]	[illegible] mount of Supplemental Irrigation Water [illegible] Pearl Millet Crop Considering Sowing Date to [illegible] t Date for Banaskantha District	CD
365	6.340	Maximum Amount of Supplemental Irrigation Water Required for Pearl Millet Crop Considering Sowing Date to be Early Onset Date for Gandhinagar District	CD
366	6.341	Maximum Amount of Supplemental Irrigation Water Required for Pearl Millet Crop Considering Sowing Date to be Late Onset Date for Gandhinagar District	CD
367	6.342	Maximum Amount of Supplemental Irrigation Water Required for Pearl Millet Crop Considering Sowing Date to be Early Onset Date for Kheda District	CD
368	6.343	Maximum Amount of Supplemental Irrigation Water Required for Pearl Millet Crop Considering Sowing Date to be Late Onset Date for Kheda District	CD
369	6.344	Maximum Amount of Supplemental Irrigation Water Required for Pearl Millet Crop Considering Sowing Date to be Early Onset Date for Mehsana District	CD
370	6.345	Maximum Amount of Supplemental Irrigation Water Required for Pearl Millet Crop Considering Sowing Date to be Late Onset Date for Mehsana District	CD
371	6.346	Maximum Amount of Supplemental Irrigation Water Required for Pearl Millet Crop Considering Sowing Date to be Early Onset Date for Patan District	CD
372	6.347	Maximum Amount of Supplemental Irrigation Water Required for Pearl Millet Crop Considering Sowing Date to be Late Onset Date for Patan District	CD
373	6.348	Maximum Amount of Supplemental Irrigation Water Required for Pearl Millet Crop Considering Sowing Date to be Early Onset Date for Sabarkantha District	CD
374	6.349	Maximum Amount of Supplemental Irrigation Water Required for Pearl Millet Crop Considering Sowing Date to be Late Onset Date for Sabarkantha District	CD

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		… SPI24 for Junisarotri raingauge station, Banaskantha district	CD
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118	6.99	SPI4, SPI12, SPI24 for Palanpur raingauge station, Banaskantha district	CD
119	6.100	SPI4, SPI12, SPI24 for Panthawada raingauge station, Banaskantha district	CD
120	6.101	SPI4, SPI12, SPI24 for Sanali Ashram raingauge station, Banaskantha district	CD
121	6.102	SPI4, SPI12, SPI24 for Wadgam raingauge station, Banaskantha district	CD
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123	6.104	SPI4, SPI12, SPI24 for Raipur Weir raingauge station, Gandhinagar district	CD
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125	6.106	SPI4, SPI12, SPI24 for Dakor raingauge station, Kheda district	CD
126	6.107	SPI4, SPI12, SPI24 for Kapadwanj raingauge station, Kheda district	CD
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134	6.115	SPI4, SPI12, SPI24 for Vadol raingauge station, Kheda district	CD
135	6.116	SPI4, SPI12, SPI24 for Vaghroli Tank raingauge station, Kheda district	CD
136	6.117	SPI4, SPI12, SPI24 for Ambaliyasan raingauge station, Mehsana district	CD
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141	6.122	SPI4, SPI12, SPI24 for Kheralu raingauge station, Mehsana district	CD
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144	6.125	SPI4, SPI12, SPI24 for Thol raingauge station, Mehsana district	CD
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146	6.127	SPI4, SPI12, SPI24 for Vijapur raingauge station, Mehsana district	CD
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151	6.132	SPI4, SPI12, SPI24 for Badoli raingauge station, Sabarkantha district	CD
152	6.133	SPI4, SPI12, SPI24 for Bayad raingauge station, Sabarkantha district	CD
153	6.134	SPI4, SPI12, SPI24 for Bhiloda raingauge station, Sabarkantha district	CD
154	6.135	SPI4, SPI12, SPI24 for Dantral raingauge station, Sabarkantha district	CD
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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Climate (from Ancient Greek klima, meaning inclination) is commonly defined as the weather averaged over a long period of time. Climate encompasses the statistics of temperature, humidity, wind, rainfall, atmospheric pressure, atmospheric particle count and numerous other meteorological parameters in a given region over long periods of time. The standard averaging period is 30 years, but other periods may be used depending on the purpose. Climate also includes statistics other than the average, such as the magnitudes of dayï toï day or yearï toï year variations.

The climate of a location is affected by its latitude, terrain, altitude, ice or snow cover, as well as nearby water bodies and their currents. Climates can be classified according to the average and typical ranges of different variables, most commonly temperature and precipitation. The widely used classification criteria is the one originally developed by Wladimir Koppen. The Thornthwaite system, in use since 1948, incorporates evapotranspiration in addition to temperature and precipitation information and is used in studying the potential impacts of climate changes. The Bergeron and spatial synoptic classification systems focus on the origin of air masses defining the climate for certain areas.

Climate can be contrasted to weather, which is the present condition of climate parameters over periods upto two weeks. Meteorology is the interdisciplinary scientific study of the atmosphere that focuses on weather processes and forecasting. Studies in the field stretch back millennia, though significant progress in meteorology did not occur until the eighteenth century. The nineteenth century saw breakthroughs occur after observing networks developed across several countries. Breakthroughs in weather forecasting were achieved in the latter half of the twentieth century, after the development of the computers.

Meteorological phenomena are observable weather events which illuminate and are explained by the science of meteorology. These events are bound by the th's atmosphere: These are temperature, air, water teractions of each variable, and how they change in time. The majority of Earth's observed weather is located in the troposphere. Different spatial scales are studied to determine how systems on local, regional, and global levels impact weather and climatology. Meteorology, climatology, atmospheric physics, and atmospheric chemistry are subï disciplines of the atmospheric sciences. Meteorology and hydrology compose the interdisciplinary field of hydrometeorology. Meteorology has application in many diverse fields such as the water resources, agriculture, construction, military, energy production, transport, etc.

Climatology is the scientific study of climate, including the causes and longï term effects of variation in regional and global climates. Climatology also studies how climate changes over time and is affected by human actions. Climate models are used for a variety of purposes from study of the dynamics of the weather and climate system to projections of future climate.

1.2 CLIMATE PARAMETER BASICS

As climatology deals with aggregates of weather properties, statistics are used to reduce a vast array of recorded properties into one or a few understandable numbers. For example if one wished to calculate the daily mean temperature at a given place, through a number of methods, first one can take all recorded temperatures throughout the day add them together and then divide the same by the total number of observations. As an example one can take all hourly recordings of temperature sum them and divide by 24. This will yield an average temperature for the day.

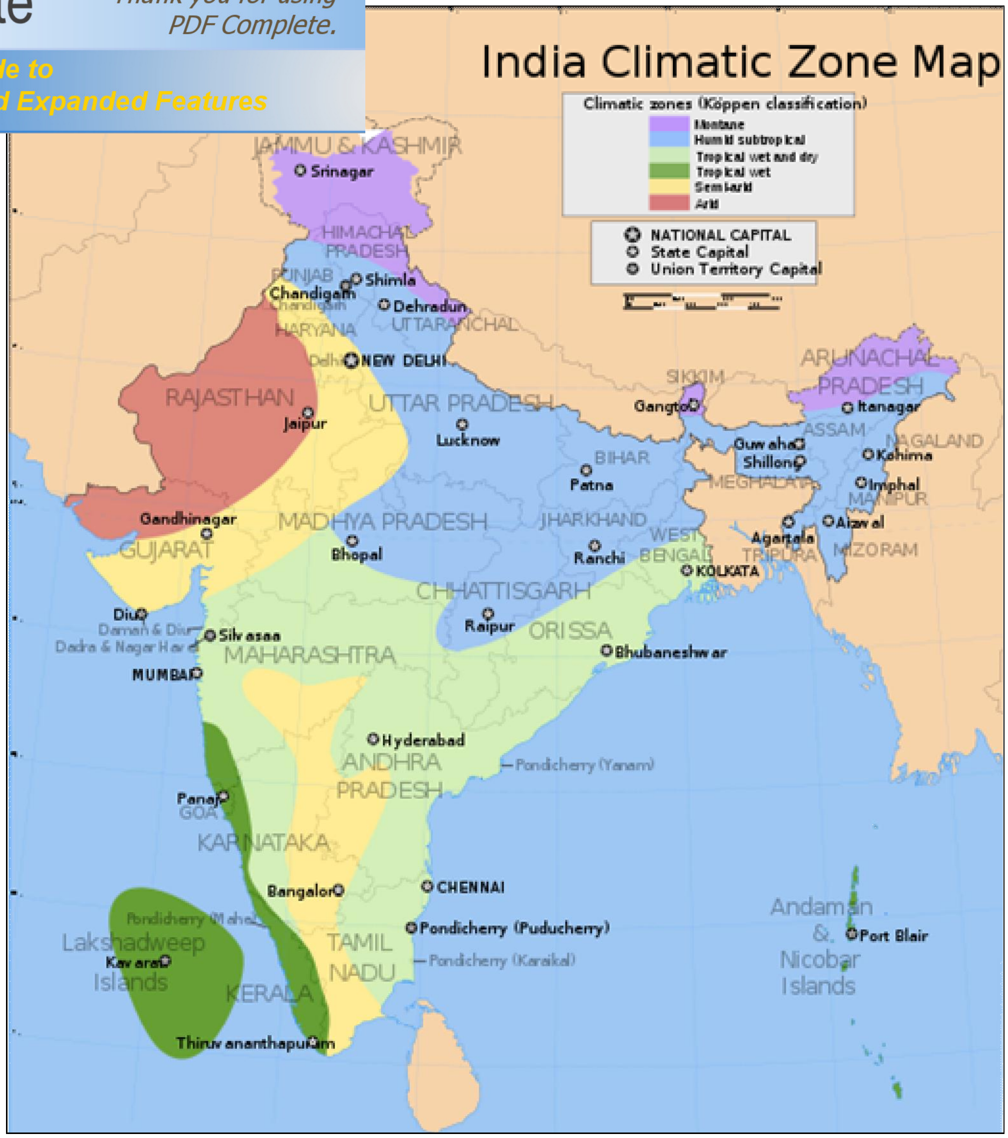
A much simpler but less accurate method of calculating the daily mean temperature is actually the one that is in vogue. A simple average is calculated for the maximum and minimum temperatures recorded for the day. This method is the one most commonly employed because in the days before computers were used to measure and record temperature, special thermometers that operated on the principle of a bathtub ring were able to leave a mark at the highest and lowest temperature experienced since the last time that thermometer was reset. Each day human observers would be able to determine the maximum and minimum us 24 hours, but they would not know any of the other d over that time span. Thus, for most of the period of weather records, only the maximum and the minimum daily temperatures are known. Of course the numerical average calculated by the maximumï minimum method will differ somewhat from the one obtained by taking all hourly temperatures and dividing by 24. Even though computers are available now that can measure and record temperatures every second, one do not calculate mean daily temperatures using this more accurate method because this may change the method of calculating the means in the middle of our long term weather records. What would happen if the temperatures began to rise abruptly at the same point in the period of record that the method of calculating the mean temperature changed? One would not be able to know whether the change represented an actual change in climate or was just an artifact of a change in the method of calculating the mean temperature.

1.3 CLIMATE OF INDIA

The climate of India defies easy generalisation, comprising a wide range of weather conditions across a large geographic scale and varied topography. India is home to an extraordinary variety of climatic regions, ranging from tropical in the south to temperate and alpine in the Himalayan north, where elevated regions receive sustained winter snowfall. The nation's climate is strongly influenced by the Himalayas and the Thar Desert. Four major climatic groupings predominate, into which fall seven climatic zones that, as designated by experts, are defined on the basis of such traits as temperature and precipitation. Groupings are assigned codes according to the Köppen climate classification system as presented in Map 1.1.

The India Meteorological Department (IMD) designates four official seasons:

Winter, occurs during January to February. Summer or preï monsoon season lasts from March to May (April to July in northwestern India). In western and southern regions, the hottest month is April; for northern regions, May is the hottest month. Temperatures average around 32ï 40°C in most of the interior.



Map 1.1 India Climatic Zone

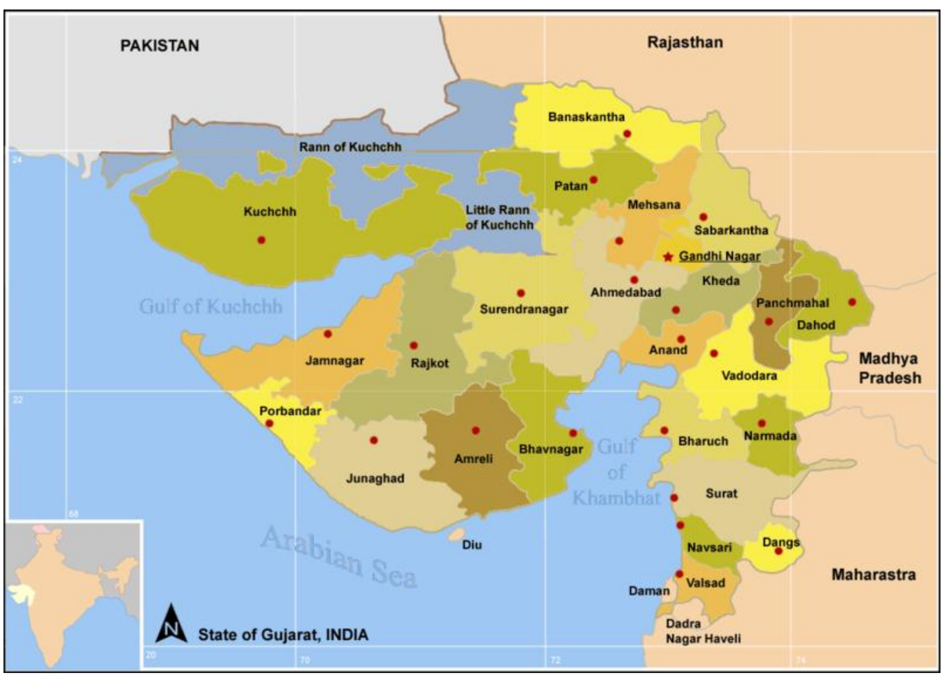
Monsoon or rainy season occurs from June to September. The season is dominated by the humid southwest summer monsoon, which slowly sweeps across the country beginning in late May or early June. July is the wettest month. Average daily temperature ranges between 16° C and 28° C.

Postï monsoon season lasts from October to December. South India typically receives more precipitation. Monsoon rains begin to recede from north India at the beginning of October. In northwestern India, October and November are usually cloudless. Parts of the country experience the dry northeast monsoon. Average temperature of the season is 17°C.

ich is still largely dependent upon rainï fed agriculture, one of the foremost concerns for the future. Most of 80% of their annual quota of rain from the southwest monsoon during the four months, June to September. The coastal areas in peninsular India receive rain from the northeast monsoon during October to December, which includes cyclonic storms.

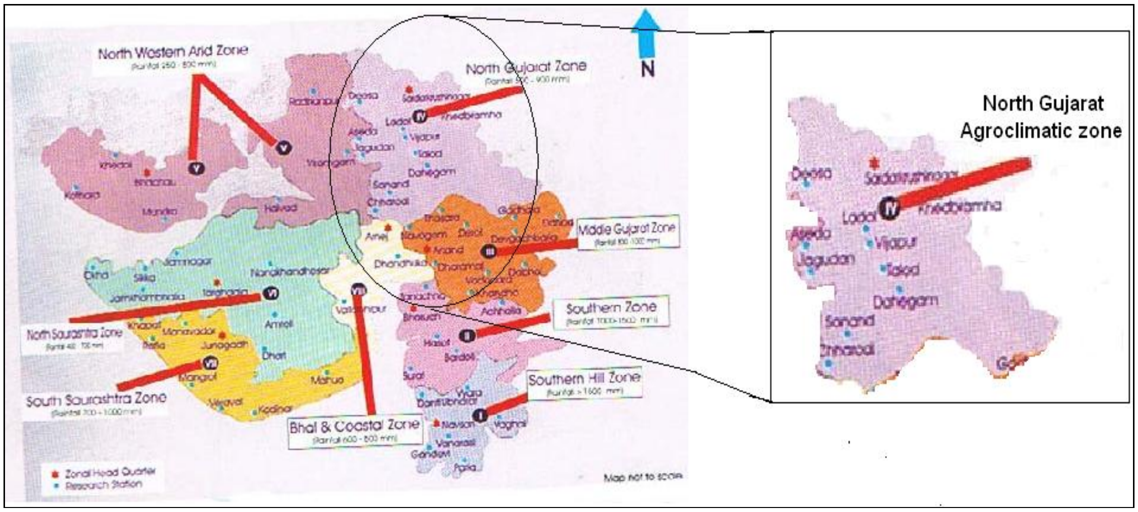
1.4 CLIMATE OF GUJARAT

Gujarat State (Map 1.2) experiences diverse climate conditions In terms of the standard climatic types, tropical climates viz., subï humid, arid and semiï arid, are spread over different regions of the state. Out of total area of the state 58.60 % fall under arid and semiï arid climatic zone. The arid zone contributes 24.94 %, while the semiï arid zone forms 33.66 % of the total area of the state. The regions in the extreme north comprising the district of Kachchh and the western parts of Banaskantha and Mehsana, the northern fringe of Saurashtra (Jamnagar) and its western part have arid climate and the rest of the State has semiï arid climate. The districts of Valsad, Dangs, Surat, Vadodara and Kheda have subï humid climate. The principal weather parameters that build the climate of the State are rainfall and temperature, although others like humidity, cloudiness, dew and fog are also important from the agricultural point of view.



Map 1.2 State of Gujarat, India

Gujarat is divided into eight agroclimatic zones (Map 1.3). Table 1.1 gives the details of the agroclimatic zones prevailing in Gujarat. For the present study north Gujarat agroclimatic zone is considered.



Map 1.3 Study Area

Table 1.1 Agroclimatic Zones in Gujarat State

Sr. No.	Agro–climatic zone	Area (districts and talukas)	Type of soil	Crops grown
1	South Gujarat (heavy rain area)	Area south of river Ambica (1) Whole of Dang district (2) Part of Valsad district (excluding Navsari and Gandevi talukas) (3) Part of Surat district (Valod, Vyara, Uchchhal, Songadh and Mahuva)	Deep black soil with patches of coastal alluvial, laterite and medium black soil	Cotton, pearl millet, paddy, vegetables, horticultural crops and sugarcane
2	South Gujarat	Area between rivers Abmica and Narmada (1) Part of Valsad district (Navsari and Gandevi talukas) (2) Part of Surat district (kamrej, Nizar, Palsana, Bardolil, Mangrol and Mandavi talukas) (3) Part of Bharuch district (Ankleshwar, Valia, Junagadh, Rajpipla, Dediapada and sagabara talukas)	Deep black clayey soils	Cotton, pearl millet, wheat, vegetables, horticultural crops and sugarcane
3	Middle	Area between rivers Narmada and Vishwamitri	Deep black,	Cotton, pearl

		mahals district chmahals district dodara district (3) Part of Bharuch district (Bharuch, Amod and Jambusar talukas) (4) Borsad taluka of Kheda district	medium black to loamy sand soils	millet,great millet, tobacco, pulses, wheat, paddy, maize, and sugarcane
4	North Gujarat	Area between rivers Vishwamitri and Sabarmati and part of Mehsana, Ahmedabad and Banaskantha districts (1) Whole of Sabarkantha district (2) Part of Ahmedabad district (includes Dehgam, DasKroi and Sanand talukas) (3) Whole of Kheda district except Borsad and part of Khambhat and Matar talukas (4) Whole of Mehsana district and some parts of Patan (except Chanasama, Sami & Harij talukas (5) Part of Banaskantha district (Deesa, Dhanera, Palanpur, Danta and Wadgam talukas)	Sandy loam to sandy soils	Tobacco, wheat, great millet, vegetables, spices and condiments, oilseeds
5	Bhal and coastal areas	Area around the gulf of Khambhat and Bhal and coastal region in Bharuch and Surat districts (1) Olpad taluka of Surat district, (2) Hansot & Wagra talukas of Bharuch district (3) Dholka and Dhandhuka talukas of Ahmedabad district (4) Vallabhipur and Bhavnagar talukas of Bhavnagar district (5) Limbdi talukas of Surendranagar district	Medium black,poorly drained and saline soil	Groundnut, cotton, pearl millet,dry wheat pulse and great millet
6	South Saurasthra	(1) Whole of Junagadh district (2) Part of Bhavanagar district (Sihor, Ghogha, Savarkundla, Gariadhar, Palitana, Talaja and Mahuva talukas) (3) Part of Amreli district (Dhari, Kodinar, Rajula, Jafrabad, Khambha, Amreli, Babra, Lilia, Lathi and Kunkavav talukas) (4) Part of Rajkot district (Jetpur, Dhoraji Upleta and Gondal talukas)	Shallow medium black calcareous soils	Groundnut, cotton, pulses, wheat, pearl millet, great millet, sugarcane
7	North	(1) Whole of Jamnagar district	Shallow	Groundnut,

		… district (Padadhari, Lodhika, …ajkot, Wakaner, Morvi, …Kotda and Sangani talukas) (3) Part of Surendranagar district (Wadhvan, Muli, Chotila and Sagalay talukas) (4) Part of Bhavnagar district (Gadhada, Umrala and Botad talukas)	medium black soil	cotton, wheat, pearl millet, great millet, sugarcane
8	North west zone	(1) Whole of Kachchh district (2) Malia taluka of Rajkot district (3) Halvad, Dhangadhra and Dasada talukas of Surendranagar district (4) Sami, Harij and Chanasama talukas of Mehsana district (5) Santalpur, Radhanpur, Kankrej, Diyodar Vav and Tharad talukas of Banaskantha district (6) Viramgam and Daskroi city of Ahmedabad district	Sandy and saline soil	Groundnut, cotton, wheat, pearl millet, great millet,

Source: http://agri.gujarat.gov.in/informations/agroï climatic.htm

1.6 OBJECTIVES OF PRESENT STUDY

The goal of the present study is to analyse the climate data for water resources and irrigation plannings for the irrigation projects in the north Gujarat agroclimatic zone.

The objectives of the present study are

1. To fill the missing climate data.
2. To determine the best fitted probability distributions for the given rainfall data set in order to ascertain the design rainfall at required return period for the region using the probabilistic approach.
3. To develop relationship between return period and one day and consecutive 2 to 7 & 10 days maximum rainfall to determine design rainfall at required return period for planning or re-examining various hydraulic stuructures and to determine the drainage coefficient for the region.
4. To develop relationship between one day and consecutive 2 to 7 & 10 days maximum rainfall to determine design rainfall given maximum one day rainfall.

l pattern and intensity of its concentration spatially in

6. To study the drought pattern using improved technique of determining standardized precipitation index in order to predict the magnitude of droughts.
7. To evaluate the design storm raindepths by hydrometeorological and statistical studies for the catchment in the study area.
8. To determine climatic suitability of growing crops.
9. To determine the probabilities of dry spell lengths by evaluating different orders of Markov chain for planning the agriculture activities in the region.
10. To determine onset & withdrawal of monsoon and length of growing period using water balance approach.
11. To determine the sowing dates for the rainfed crops in the region.

1.7 OVERVIEW

The subsequent text of the thesis has been organised in the following chapters:

Chapter II deals with the literature review pertaining to the objectives of the present study. For achieving the foresaid objectives various literatures have been reviewed and presented here. Numerous research papers have been reviewed from various international and national journals, proceedings of conferences/ seminars/symposiums/workshops, covering various sections such as missing data, probability distributions, development of regression relationships, characteristics of climate data, regionalization based on spatial and temporal behaviour of rainfall, design storm from rainfall depths, drought analysis and crop planning for rainfed agriculture. Total 312, papers, books etc. are reviewed.

Chapter III presents the details of study area. North Gujarat agroclimatic zone is spread over seven districts namely Ahmedabad, Banaskantha, Gandhinagar, Kheda, Mehsana, Patan and Sabarkantha. Information related to the agriculture scenario, water resources, soil resources and cropping pattern is presented.

Chapter IV deals with the data collection. The climate data i.e. minimum and maximum temperatures, relative humidity, wind speed, sunshine hours and rainfall are collected. For agricultural analysis, data regarding onset of monsoon ted. For water resources project analysis, data of the schemes in north Gujarat region are obtained.

Chapter V discusses the methodology adopted for analyzing the climate data in the study area. A detailed description of the approach for planning / re-examining the water resources and agricultural activities, in the region, for conducting the research as well as the analytical procedure in order to draw conclusions based on the climate data obtained, will be presented.

Chapter VI presents the results and analysis obtained using above mentioned methodology. A detailed analysis of the research, the explanation and findings are discussed.

Chapter VII concludes the thesis by discussing the overall contribution of the research in the context of related work in the area. It also presents recommendations for further research and development work.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

The objectives of the study in general are to analyze the climate parameters for planning various water resources structures and irrigation activities. For achieving the aforesaid objectives various literatures have been reviewed and presented here.

2.2 LITERATURE REVIEW

Numerous research papers have been reviewed from various international and national journals, proceedings of seminars/conferences/symposiums/workshops, either in print or through electronic search engines via internet, etc. Total 312 are reviewed. Literature review of 54 papers are presented herein and the remaining 258 are enclosed in CD.

To assist the objectives of the study, the literature review carried out is divided into various sections as follows:

1. Missing data
2. Probability distributions
3. Development of regression relationships
4. Characteristics of climate data
5. Regionalization based on spatial and temporal behaviour of rainfall
6. Design storm from rainfall depths
7. Drought analysis
8. Crop planning for rainfed agriculture

Missing data related to rainfall

Missing data related to climate parameters other than rainfall

Missing data related to other parameters

Missing data related to forecasting models

Missing data related to rainfall

(1) The objectives of the study by **Mair and Fares (2010)** were to examine records from longï term rain gauges in Makaha Valley for data homogeneity and to compare methods of estimating missing data. Double mass analysis was used to investigate data homogeneity. Four methods for estimating missing daily rainfall data were tested using index gauges selected from a network of 21 active rain gauges. The number of index gauges and their order of selection were varied according to proximity and correlation. Selection by correlation significantly improved the performance of the station average and inverse distance methods for most cases, as well as the normal ratio method for the case when only one gauge is used. The normal ratio method produced the lowest error when two to five index gauges were used; the inverse distance method yielded the lowest error when six or seven index gauges were used. Direct substitution produced better accuracy than the normal ratio method when using only one index gauge. Problems related to multicollinearity, heteroscedasticity, and assumptions of data normality preclude the use of multiple linear regression.

(2) Precipitation data are one of the most important inputs in rainfallï runoff models. Long records often contain gaps which are to be filled. Linear regression and multiple linear regression techniques were applied for the estimation of monthly precipitation by **Villazon and Willems (2010)**. For the multiple linear regressions technique the tool called HEC4 developed by the U.S. Corps of Engineers was used. The disaccumulation from monthly to daily time scales was carried out assuming that each station has the same distribution of daily precipitation intensities as the recording station with the highest correlation. The study area considered for this study was part of the Pirai River basin located in Santa Cruzï Bolivia, which is a tributary of the Amazon River. The available data were from 33 daily rainfall stations where 8 had more than 25 years of recorded data. These

...e regional meteorological and hydrological services ... spatial distribution and the range of altitudes of the stations were quite high (...34 a.m.s.l. to 1875 a.m.s.l.). The rain gauge density for the study area was 81.97 km^2 per station. The gap filling techniques were evaluated based on 32 months extracted from the recorded data. The evaluation was carried out for 6 days, 3 days and 1 day of disaccumulation period. The multiple linear regression technique applied for the monthly rainfall estimation gave an important reduction (36%) in the standard deviation and root mean squared error over the linear regression. It was observed that the accuracy of the disaccumulated results decreased when the period of accumulation was smaller. At the daily time scale, the multiple linear and linear regression methods had similar performance.

(3) Accurate estimate of missing daily precipitation data remains a difficult task particularly for large watersheds with coarse rain gauge network. Reliable and representative precipitation time series are essential for any rainfallï runoff model calibration as well as for settingï up any downscaling model for hydrologic impact study of climate change. **Coulibaly and Evora (2007)** investigated six different types of artificial neural networks namely the multilayer perceptron (MLP) network and its variations (the timeï lagged feedforward network (TLFN)), the generalized radial basis function (RBF) network, the recurrent neural network (RNN) and its variations (the time delay recurrent neural network (TDRNN)), and the counterpropagation fuzzyï neural network (CFNN) along with different optimization methods for infilling missing daily total precipitation records and daily extreme temperature series. Daily precipitation and temperature records from 15 weather stations located within the Gatineau watershed in northeastern Canada, were used to evaluate the accuracy of the different models for filling data gaps of daily precipitation and daily extreme temperatures. The experiment results suggested that the MLP, the TLFN and the CFNN provided the most accurate estimates of the missing precipitation values. However, overall, the MLP appeared the most effective at filling missing daily precipitation values. Furthermore, the MLP also appears the most suitable for filling missing daily maximum and minimum temperature values. The CFNN was similar to the MLP at filling missing daily maximum temperature, however, it was less effective at estimating minimum temperature. The experiment results show that the

...ks (RNN and TDRNN) were less suitable for filling the ...precipitation and the extreme temperature records, whereas the RBF appeared fairly suitable only for estimating maximum and minimum temperature.

Missing data related to climate parameters other than rainfall

(1) Solar radiation is a primary driver for many physical, chemical and biological processes on the earth's surface, and complete & accurate solar radiation data at a specific region are quite indispensable to the solar energy related researches. **Wu et al. (2007)**, using Nanchang station, China, as a case study, aimed to calibrate existing models and develop new models for estimating missing global solar radiation data using commonly measured meteorological data and proposed a strategy for selecting the optimal models under different situations of available meteorological data. Using daily global radiation, sunshine hours, temperature, total precipitation and dew point data covering the years from 1994 to 2005, calibrated or developed and evaluated seven existing models and two new models. Validation criteria included intercept, slope, coefficient of determination, mean bias error and root mean square error. The best result (R^2 = 0.93) was derived from Chen model 2, which used sunshine hours and temperature as predictors. The Bahel model, which only used sunshine hours, was almost as good, explaining 92% of the solar radiation variance. Temperature based models (Bristow and Campbell, Allen, Hargreaves and Chen 1 models) provided less accurate results, of which the best one (R^2 = 0.69) was the Bristow and Campbell model. The temperature based models were improved by adding other variables (daily mean total precipitation and mean dew point). Two such models could explain 77% (Wu model 1) and 80% (Wu model 2) of the solar radiation variance. A strategy for selecting an optimal method for calculating missing daily values of global solar radiation: (1) when sunshine hour and temperature data were available, use Chen model 2; (2) when only sunshine hour data were available, use Bahel model; (3) when temperature, total precipitation and dew point data were available but not sunshine hours, use Wu model 2; (4) when only temperature and total precipitation were available, use Wu model 1; and (5) when only temperature data were available, use Bristow and Campbell model.

eveloped by **Lavergnat and Gole (2005)** based on e release of raindrops from cloud bases and on a previously found model of raindrop inter arrival time and size distributions at ground level. The simulator was designed so that the main characteristics of rain observed on the ground were preserved: size distribution, inter arrival time distribution and autocovariance of drop sizes. Results showed that derived characteristics of rain, such as rain rate, were in good agreement with observations.

(3) Typical approaches to climate signal estimation from data are susceptible to biases if the instrument records are incomplete, cover differing periods, if instruments change over time, or if coverage is poor. A method (Iterative Universal Kriging, or IUK) was presented by **Sherwood (2001)** for obtaining unbiased, maximumlikelihood (ML) estimates of the climatology, trends, and/or other desired climatic quantities given the available data are from an array of fixed observing stations that report sporadically. The conceptually straightforward method followed a mixed model approach, making use of well known data analysis concepts, and avoided gridding the data. It was resistant to missing data problems, including ñselection bias,ò and also in dealing with common data heterogeneity issues and gross errors. Perhaps most importantly, the method facilitated quantitative error analysis of the signal being sought, assessing variability directly from the data without the need for any auxiliary model. The method was applied to raw insonde data to examine weak meridional winds in the equatorial lower stratosphere, providing some improvements on existing climatologies.

Missing data related to other parameters

(1) An improved methodology for the determination of missing values in a spatiotemporal database was presented by **Sorjamaa et al. (2010)**. This methodology performed denoising projection in order to accurately fill the missing values in the database. The improved methodology was called empirical orthogonal functions (EOF) pruning, and it was based on an original linear projection method called empirical orthogonal functions (EOF). The experiments demonstrated the performance of the improved methodology and presented a

al EOF and with a widely used optimal interpolation
alysis.

(2) **Ng et al. (2009)** evaluated the performance of different estimation techniques for the infilling of missing observations in extreme daily hydrologic series. Generalized regression neural networks (GRNNs) were proposed for the estimation of missing observations with their input configuration determined through an optimization approach of genetic algorithm (GA). The efficacy of the GRNNï GA technique was obtained through comparative performance analyses of the proposed technique to existing techniques. Based on the results of such comparative analyses, especially in the case of the English River (Canada), the GRNNï GA technique was found to be a highly competitive technique when compared to the existing artificial neural networks techniques. In addition, based on the criteria of mean square and absolute errors, a detailed comparative analysis involving the GRNNï GA, *k*ï nearest neighbors, and multiple imputation for the infilling of missing records of the Saugeen River (Canada), also found the GRNNï GA technique to be superior when evaluated against other competing techniques.

(3) **Bustami et al. (2007)** aimed to improve water level prediction at Bedup River with estimations made to missing precipitation data, using Artificial Neural Network (ANN). Studies to predict water level in the state of Sarawak, Malaysia had been actively carried out. However, among problem faced was modeling precipitation readings, which inevitably affected water level precipitation accuracies. A Backpropagation property of ANN was used in the study to predict both missing precipitation and water level. ANN model developed in this study successfully estimated missing precipitation data of a recorder in Bedup River, Sarawak with 96.4% accuracy. The predicted values of precipitation were then used to forecast water level of the same gauging station and yielded accuracy value of 85.3%, compared to only 71.1% accuracy of water level prediction with no estimation made to its missing precipitation data. These results showed that ANN was an effective tool in forecasting both missing precipitation and water level data, which are utmost essential to hydrologists around the globe.

recasting models

(1) **Partal and Cigizoglu (2009)** aimed to predict the daily precipitation from meteorological data of Turkey using the waveletï neural network method, which combined two methods: discrete wavelet transform (DWT) and artificial neural networks (ANN). The waveletï ANN model provided a good fit with the observed data, in particular for zero precipitation in the summer months, and for the peaks in the testing period. The results indicated that waveletï ANN model estimations were significantly superior to those obtained by either a conventional ANN model or a multi linear regression model. In particular, the improvement provided by the new approach in estimating the peak values had a noticeably high positive effect on the performance evaluation criteria. Inclusion of the summed subï series in the ANN input layer brought a new perspective to the discussions related to the physics involved in the ANN structure.

(2) For better and sustainable output, timely and necessary input is the basic requirement. This is also true in case of monsoon rainfall. At present farmers do not know the availability of rainfall either date wise or quantity wise in the forth coming monsoon. Further, the trends of monsoon, onset, dry spell, wet spell, withdrawal, heavy to very heavy rain spells etc. are also completely unknown. Even with the latest developments in meteorological instruments, super computers satellite images media communication the agricultural community is able to receive weather information 2ï 3 days in advance only but not well before. In this regard an attempt was made by **Shah (2008)** to establish a model for forecasting daily trend of summer monsoon behaviour well in advance in its due course from the onset to withdrawal phases. The model was very unconventional with respect to its input parameters.

(3) Weather generators were widely used in hydrological, ecological, and cropï yield modeling. CLIGEN was a frequently adopted weather generator. According to **Kou et al. (2007)** although CLIGEN was tested in many parts of the world, still before being applied to the Loess Plateau, China, it was needed to be validated because of the unique climate of the region. Only the generated daily precipitation were validated, for it was assumed to be the most important climatic factor affecting the precision of SWAT, which was selected as the main tool to do

oil erosion. Five sites, which had 30 years of relatively n records along an aridity gradient, were selected for the validation of CLIGEN. The main purposes of the study were to test the usefulness of CLIGEN in precipitation simulation and to determine whether the performance varied with the aridity gradient. Means and standard deviations of five rainfall variables between measured and each of the 10 sets of CLIGEN generated precipitation were compared for each site. The precipitation variables analyzed were: yearly total precipitation, yearly number of rainy days, monthly total precipitation, logï transformed monthly average wetï spell length, and logï transformed monthly average dryï spell length. Tï tests and Fï tests were used to determine if there were significant differences in the means and standard deviations, respectively, between observed data and CLIGENï generated data. Results showed that CLIGEN preserved the means quite well, and preserved standard deviations reasonably well, although there were considerable variations among sites, among precipitation variables, and among seasons. There was no obvious trend of performance along the aridity gradient.

2.2.2 Probability Distribution

(1) Daily point rainfall records at Agrometeorological observatory of Assam Agricultural University, Jorhat for a period of 36 years were analysed by **Bora et al. (2010)** for their statistical behaviour. Daily extreme annual events as well as 2 to 5 consecutive day rainfalls have been determined from the records. Weibullôs plotting position formula was used to determine the probabilities of these extreme values from 1972 to 2007. Commonly used extreme value distribution functions such as Gumbel, Log Pearson Type III and Log Normal were used to test the fitness for regeneration. These were tested against the observed records with the help of Chi Square goodness of fit. It was found that Gumbel extreme value distribution function was better to regenerate the records at 84% probability level and much better than Log Pearson Type III (21%) and Log Normal (6.6%) distribution.

(2) Probability distributions were determined by **Barkotulla et al. (2009)** to predict rainfall status of various return period estimating one day and two to seven consecutive days annual maximum rainfall of Boalia, Rajshahi, Bangladesh.

obability distributions (viz: Normal, Log Normal and tested to determine the best fit probability distribution using the comparison of chiï square values. Results showed that the logï normal distribution was the best fit probability distribution for one day and two to seven consecutive days annual maximum rainfall for the region. Based on the best fit probability distribution the maximum rainfall of 116.15 mm, 161.09 mm, 190.14 mm, 205.96 mm, 220.37 mm, 234.66 mm and 245.21 mm was expected to occur 1, 2, 3, 4, 5, 6 and 7 days respectively at Boalia (Rajshahi City Corporation and surrounding areas) every two years. For a recurrence interval of 100 years, the maximum rainfall expected in 1, 2, 3, 4, 5, 6 and 7 days were 290.24 mm, 406.49 mm, 544.08 mm, 558.56 mm, 600.33 mm, 631.28 mm and 633.89 mm respectively. The results of this study would be useful for agricultural scientists, decision makers, policy planners and researchers in order to identify the areas where agricultural development and construction of drainage systems in Boalia as one of the major factors causing flooding should be focused as a longï term environmental strategy for Bangladesh.

(3) **Dabral et al. (2009)** presented a study of excess ï deficit analysis of rainfall for Umaiam (Barapani) Meghalya, India. Three commonly used probability distribution function (normal, lognormal and gamma) were tested on weekly rainfall and evaporation data by comparing the chiï square values. For weekly rainfall and evaporation data, all three distributions were found to be best fitted for different weeks. At 60 % and 90 % probability levels expected rainfall was scarce in week nos. 1 to 12 and 43 to 52. For 10 % to 50 % probability level expected rainfall was not scarce. Expected value of evaporation varied from 3.7 mm to 57.1 mm at 10 % probability levels and from 1.8 mm to 27.9 mm at 90 % probability levels for all the weeks. From water management planning point of view 30 % and 40 % risk levels can be adopted. At 30 % risk level, there was deficit of rainfall from week nos. 1 to 21, 24, 26, 28, 30 to 33 and 46 to 52. Total computed deficit was 126.2 mm. At 40 % risk levels there was deficit of rainfall in week nos. 1 to 17, 19ï 22, 23, 26, 28, 40ï 52. Total computed deficit was 434.4 mm. Excess of rainfall was in week nos. 18, 22, 24, 25, 27, 29 to 39. Therefore, drainage was required during that period. Total computed excess rainfall was 169.1 mm. In order to minimize the risk of crop failure due to lack of rain in the region, it is advisable that irrigation schedule is planned at 30 % risk level.

n 30 % risk level may increase the irrigation losses but
ailure.

2.2.3 Development of Regression Relationships

(1) In the study by **Patel and Shete (2008a)** 45 years (1961ï 2005) data of 42 raingauge stations in Sabarkantha district of north Gujarat Region were used to predict consecutive dayøs rainfall from one day rainfall for given recurrence interval from 1 to 50 years. The recurrence interval (return period) was calculated using Gringortenøs plotting position. Models were developed from the first 30 years and were validated for the rest of the 15 years. From the study carried out it was evident that the polynomial regression models best fitted to the given data with coefficient of correlation ranging from 0.858 to 0.999 with negligible RMSE. For a recurrence interval of 50 years, the maximum rainfall expected in 1 day & 2, 3, 4, 5 and 6 consecutive days was 818 mm, 1,162 mm, 1,462 mm, 1,628 mm, 1,761 mm and 1,835 mm respectively. For the Sabarkantha district of north Gujarat region, one can use the models provided in the study to predict 2ï 6 consecutive days rainfall from one day rainfall at a given recurrence interval accurately for the design of various hydrologic structures.

(2) Annual one day maximum rainfall and two to five consecutive dayøs maximum rainfall corresponding to a return period of 2 to 100 years has been conducted for Accra, Ghana by **Kwaku and Duke (2007)**. Three commonly used probability distributions; normal, lognormal and gamma distributions were tested to determine the best fit probability distribution that described the annual one day maximum and two to five consecutive daysô maximum rainfall series by comparing with the Chiï square value. The results revealed that the logï normal distribution was the best fit probability distribution for one day annual maximum as well as two to five consecutive daysômaximum rainfall for the region. Based on the best fit probability distribution a maximum of 84.05 mm in 1 day, 91.60 mm in 2 days, 100.40 mm in 3 days, 105.67 mm in 4 days and 109.47 mm in 5 days was expected to occur at Accra every two years. Similarly a maximum rainfall of 230.97 mm, 240.49, 272.77 mm, 292.07 mm and 296.54 mm was expected to occur in 1 day, 2, 3, 4 and 5 days respectively every 100 years. The results from the study could be used as a rough guide by engineers and

...ign and construction of drainage systems in the Accra ...ge has been identified as one of the major factors causing flooding in Accra.

(3) **Nadar et al. (2007)** predicted drainage coefficient using Gumbelôs probability analysis theory. The area considered under study was Devgadhbaria rain gauge station in Panchmahals district. The daily rainfall data from 1961ï 2005 were taken into consideration. Maximum rainfall of various consecutive days e.g. one day, two days, three days and so on for each year under consideration were computed. The maximum amount of rainfall at different probability levels was studied by model studies using Curve Expert 1.3 software. The drainage coï efficient at different probability levels were computed using Gumbelôs probability distribution, which comes out to be maximum for 1ï day maximum rainfall and minimum for 7ï days maximum rainfall considered for any of the probability levels. The minimum drainage coï efficient for the area taken under study was 71.893 mm / day at 60% probability level and the maximum drainage coï efficient was 368.771 mm / day at 80% probability level.

2.2.4 Characteristics of Climate Data

Determining statistical parameters in general
Trends related to temperature
Trends related to rainfall
Trends related to other parameters

Determining statistical parameters in general

(1) **Clarke (2010)** discussed four areas where, statistical methods were misused in reporting results of hydroï climatological research. They were: (i) the use of the same data set both to suggest a hypothesis (commonly of trend over time) and to test it; (ii) failure to use an appropriate significance level for tests in which a number of hypotheses were tested, even when the data sets used were mutually uncorrelated; (iii) failure to account for spatial correlations between variables, whether these were explanatory or response variables; and (iv) exaggerated importance given to statistical tests of significance, in particular to the 5% and 1% significance levels.

nents in climatic series were treated as nonï stationary model and Bayesian statistics were combined through Carlo procedure by **Kottegoda et al. (2007)**. Gibbs sampling was used in the Monte Carlo application. Monthly series of river flow, rainfall and temperature from northern Italy were used. Some late temperature rises were noted, otherwise there were no systematic increases or decreases in the series. Changes in periodicity were also of a random nature. From the results it was also possible to compare these properties between different locations and climatic indicators.

(3) In this twoï part series, the **ASCE (2000a)** investigated the role of artificial neural networks (ANNs) in hydrology. ANNs are gaining popularity, as was evidenced by the increasing number of papers on this topic appearing in hydrology journals, especially over the last decade. In terms of hydrologic applications, this modeling tool is still in its nascent stages. The practicing hydrologic community is just becoming aware of the potential of ANNs as an alternative modeling tool. This paper was intended to serve as an introduction to ANNs for hydrologists. Apart from descriptions of various aspects of ANNs and some guidelines on their usage, the paper offered a brief comparison of the nature of ANNs and other modeling philosophies in hydrology. A discussion on the strengths and limitations of ANNs brought out the similarities they had with other modeling approaches, such as the physical model.

Trends related to temperature

(1) The temporal and spatial characteristics of trends in extreme indices over Korea between 1971 and 2010 were investigated by **Im et al. (2010)** using daily minimum (Tmin) and maximum (Tmax) temperatures and precipitation data from a regional climate projection at 20 km grid spacing. Five temperatureï based indices and five precipitationï based indices were selected to comprehensively consider the frequency, intensity, and persistence of extreme events. In addition, Mannï Kendall tests were used to detect the statistical significance of trends in these indices. For validation during the reference period (1971ï 2000), the model reasonably simulated the temporal and spatial pattern of the trend. The model captured observed direction and magnitude well in various types of extremes. Indices based on Tmin showed a considerable change towards warmer climate

sed on Tmax did not reveal any distinct trend, implying of Tmin and Tmax to global warming. Indices of the frequency and intensity of heavy precipitation showed a significant increase, whereas the duration of dry and wet consecutive days showed no change. For future projections, the temperatureï based indices exhibited a much more significant and consistent trend than the precipitationï based indices, with statistical significance at the 95% confidence level for all indices. The frequency and intensity of heavy precipitation were projected to increase in the 21st century, continuing the trend of the reference climate. Although the future projected changes in the duration of consecutive dry and wet days were not statistically significant, the signal became more pronounced with respect to the reference simulation.

(2) The daily rainfall and temperature data 1969ï 2000 of Jhansi were analyzed to know seasonal and annual variability. Three distinct crop growth seasons kharif (26ï 40 SMW), rabi (42ï 15 SMW) and summer (16ï 25 SMW) were characterized for seasonal trends by **Singh et al. (2009b).** The stable rainfall period was worked out. The annual and Kharif rainfall showed a decrease in recent decade (1984ï 1993). Trend analysis on rainfall reflected a decrease of 0.89 and 1.12 mm per year in annual and kharif season during past 35 years whereas no such specific trend was observed for rabi and summer seasons. The temperature variability was small indicating only minor year to year variations. However during recent decade, the minimum temperature showed an increase of 0.05^0 C and 0.13^0 C per year during annual and kharif season.

(3) According to **Haris et al. (2008)** climatic variability combining with humanï induced emission of greenhouse gases resulted in an increase of global mean temperature which in turn, lead to higher evaporative demand and accelerated the hydrological cycle. In changing climatic scenarios variable rainfall characteristics directly affected ecosystem, agricultural practices and water resource management. In the present study, the changing trends of rainfall, temperature and potential evapotranspiration (PET) were investigated for monthly and annual basis for some centers of Bihar in Eastern India. The results showed that the highest and lowest average rainfall was observed at Pusa during July and December months respectively to the tune of 324.52 mm and 3.80 mm and coefficient of variation ranges from 0.53 to 2.08 for Pusan and from 0.38 to

r (Bihar agroecological zone IIIA), increasing trend in all months, although this increase was significant for April to June only. In majority of the cases except during January and Aprilï June, maximum and minimum temperatures showed an increasing trend, potential evapotranspiration showed a decreasing trend in all months except during Julyï October. At Pusa (Bihar agroecologcial zone I), an increase in minimum temperature and rainfall and decrease in maximum temperature and PET was observed. Four months (Julyï October) out of 12 showed a downward trend in rainfall but upward trend for the rest of months and annual rainfall. However, this increase was significant for April, November and December and decrease was significant for March and September months. Maximum temperature showed decreasing trend from Januaryï June and annually but from Julyï December and increasing trend was observed. In general, minimum temperature showed an increasing trend and this was significant for all of the cases except during March. During first six months (Januaryï June) potential evapotranspiration observed an increasing trend while decreasing trend in remaining six months, however annual PET showed a decreasing trend.

Trends related to rainfall

(1) Annual, seasonal and monthly rainfall trends from 1961 to 2006 period were analysed in the study by **Rio et al. (2010)** applying various statistical tools to data from 553 Spanish weather stations. The magnitude of the trends was derived from the slopes of the regression lines using the least squares method, while the statistical significance was determined using the nonï parametric Mannï Kendall test. Geostatistical interpolation techniques were applied to generate rainfall trend surfaces. Combining classic trends tests and spatially interpolated precipitation permits the spatioï temporal visualization of detected trends. Updated trends revealed that rainfall is generally decreasing in January, February, March, April, and June. Around 61, 44 and 12% of the whole territory was evidencing significant negative trends in February, June and March, respectively. Significant precipitation decreases are also noted in more than 28% of Spain in summer and winter. On the contrary, rainfall was significantly increasing in October in more than 21% of Spain and areas mainly located in northï western areas. May, August, September and autumn also showed significant positive trends in the period 1961ï 2006, although the percentages

ative trends. Finally, the annual precipitation was 1% of the territory.

(2) The daily rainfall data of Akola for last 36 (1971ï 2006) years were analyzed by **Tupe et al. (2010)** to study its variability. The mean annual rainfall was 790 mm with 27 % variability. The contribution from winter, summer, pre monsoon, monsoon and post monsoon periods to total rainfall was 2.48, 3.09, 81.55, 9.23 and 3.65 %. Each standard meteorological week (SMW) from 24th to 40th received a rainfall of above 20 mm, indicating the crop growing period from June 3rd week to October 1st week. The monthly mean rainfall was observed to be 11.8, 144, 195.7, 209.7, 115.1 and 53.2 mm for May, June, July, August, September and October respectively.

(3) In order to investigate the behaviour of climatic and hydrological variables, several statistical and stochastic techniques were currently applied to time series. A statistical analysis of annual and seasonal precipitation was performed over 109 cumulated rainfall series with more than 50 years of data observed in a region of Southern Italy (Calabria) by **Caloiero et al. (2009)**. Trend analyses had been made by using both nonparametric (Mannï Kendall test) and parametric (linear regression analysis) procedures. The long historical series of monthly rainfall data employed in this work had been previously processed through a preï whitening (PW) technique in order to reduce the autocorrelation of rainfall series and its effects on outcomes of trend detection. The application of the above mentioned procedures had shown a decreasing trend for annual and winterï autumn rainfall and an increasing trend for summer precipitation. Moreover the Mannï Whitney test was used to identify the possible change points in the data. The higher percentages of rainfall series showed possible year changes during decade 1960ï 1970 for almost all of the temporal aggregation rainfall.

Trends related to other parameters

(1) Changes in sunshine duration in association with total cloud amount, rainy days and good visibility days over India were examined by **Jaswal (2009)** for 1970ï 2006. Climatologically, annual total sunshine duration over west Rajasthan and adjoining Gujarat was more than 3100 hours which is ideal for harnessing solar energy over these regions. The trend analysis indicated significant decrease in

he country for all months (except June) and the place in January (ï 0.44 hour / decade) followed by decade). Seasonally, decline in sunshine hours was highest in winter and post monsoon (4 % per decade) and lowest in monsoon (3 % per decade). Decadal variations indicated maximum decrease in sunshine over the Indoï Gangetic plains and south peninsula during 1990ï 1999. Spatially, the decreasing trends in sunshine hours are highest in Indoï Gangetic plains and south peninsula while regions over Rajasthan and Gujarat had lowest decrease. Out of 40 stations under study, the maximum decrease in sunshine occurred at New Delhi (winter at 13 % per decade and post monsoon at 10 % per decade) and Varanasi (summer and monsoon at 7 % per decade). Correlation analysis of sunshine duration with total cloud amount, rainy days and good visibility days indicated regional and seasonal variations in factors explaining the long term trends in sunshine duration over the country.

(2) A stochastic model for weekly water deficit series, using 28 years climatological data, under climatic condition of S.K.Nagar was been developed by **Deora and Singh (2009)**. The turning point test and Kendallõs rank correlation test were applied for detecting the trend. Correlogram technique was used to detect the periodicity, which was then analyzed by Fourier series method. Significant harmonics were also identified. The statistical properties of the generated water deficit series were compared with observed series. The developed model was validated by predicting two years ahead and compared with the observed water deficit series, the test results indicated the high degree of model fitness. The developed model may be used for representing the timeï based structure of the water deficit time series.

(3) The subject of trend detection in hydrologic data has received a great deal of attention lately, especially in connection with the anticipated changes in global climate. However, climatic variability, which is reflected in hydrologic data, can adversely affect trend test results. The scaling hypothesis has been recently proposed for modeling such variability in hydrologic data. The Mannï Kendall test, which is widely used to detect trends in hydrologic data, was modified to account for the effect of scaling by **Hamed (2008)**. Exact expressions for the mean and variance of the test statistic were derived under the scaling hypothesis, and the normal distribution was shown to remain a reasonable

e for estimating the modified variance from observed e modified test was applied to a group of 57 worldwide total annual river flow time series from the database of the Global Runoff Data Centre in Koblenz, Germany, that were shown in an earlier study to exhibit significant trends in annual maximum flow. The results showed a considerable reduction in the number of stations with significant trends when the effect of scaling was taken into account. These results indicated that the evidence of real trends in hydrologic data was even weaker than suggested by earlier studies, although highly significant increasing trends seemed to be more common than negative ones. It was also shown that admitting scaling in the modified test helped to avoid discrepancies found in some previous studies, such as the existence of significant opposite trends in neighboring stations, or in different segments of the same time series.

2.2.5 Regionalization Based on Spatial and Temporal Behaviour of Rainfall

(1) **Cheval et al. (2011)** contributed to better understanding of the precipitation data, analyzing several measurement errors in Romania. Based on the influence of wind speed, solid precipitation rate, and wetting losses, the monthly amounts registered at 159 weather stations through 1961ï 2006 were adjusted. The results emphasized distinct temporal and spatial distributions of the adjusted magnitude. In general, the correction factors increased with altitude and they had high values in the cold season, as they highly depended on wind speed and solid precipitation percentage. In Romania, bias corrections increased monthly precipitation by less than 10% from June to September, by 10ï 20% in the transition months, and by higher values during the winter.

(2) The study by **Deniz et al. (2010**) investigated the spatial variability of the continentality, oceanity and aridity indices in Turkey. Four indices were calculated using the climatic data from 229 meteorological stations in Turkey. The nature of the indices expressed general climatic features such as continentality, marine influences and aridity. The climatic indices used were the Johansson Continentality (JC) Index, the Kerner Oceanity Index (KOI), the De Martonne Aridity Index (IDM) and the Pinna Combinative (PV) Index. Furthermore, aridity characteristics in Turkey were examined using the two

990 and 1991ï 2006). To assess the temperature and urkey, the climatic indices were calculated by using monthly temperature and precipitation for the period 1960ï 2006. According to the results of the KOI, marine climates characteristics were dominant in the Black Sea region than in its Aegean and Mediterranean region. The JC index was used for the climatic classification between continental and oceanic climates. The continental effect was found across 25% of the country. The maximum continentality with a score of 71.5 was found in the eastern Anatolia. Furthermore, semiï dry areas were increasing in the 1991ï 2006 period compared to 1960ï 1990. A significant correlation was found between the values of the JC index and the KOI. The JC index gave reasonable results for Turkey. The continental effect was found across 25% of the country. The analysis may be of benefit for the explanation of landscape characteristics and the rational utilization of water resources, agriculture and energy scenarios for the region in many areas of Turkey.

(3) The analysis carried out by **Wickramagamage (2010)** was based on monthly means of rainfall at a dense network of gauging stations in Sri Lanka. The mean monthly values of rainfall at 646 stations were used as variables to characterize the individual stations. These variables showed a significant correlation among most of them. The highest correlations were found between months within the same meteorological season, with one exception. The exception was that of October which was a higher correlation with months of southwest monsoon (SWM) than with the interï monsoon (IM) months. The IM months and November had moderate values of correlation with the months of SWM. All three months of northeast monsoon (NEM) were strongly correlated and form a clearly defined group. This pattern of correlation explained the spatial distribution of rainfall of the 12 months. The strongly correlated months had a similar spatial pattern. This indicated that the number of distinct spatial modes of rainfall was less than 12. To discover these modes, principal component analysis (PCA) and factor analysis (FA) were applied on the data set. Of the two ordination methods, FA produced more easily interpretable results than PCA. The factor solution identified four spatiotemporal rainfall modesï weak southwest (SW) mode (Marchï April), strong SW mode (Mayï October), strong NEM mode (Decemberï

e (November). These modes have strong similarity to s created using the original data of the same periods.

2.2.6 Design Storm from Rainfall Depths

(1) The objective of the study by **Lu and Yamamoto (2008)** was to develop a new method for deriving statistical distribution of maximum discharge from the distribution of annual maximum daily rainfall by using a random cascade model. This model was used to probabilistically downscale daily rainfall into hyetographs in which the daily rainfall was randomly generated according to its probabilistic distribution. Then maximum discharge was calculated from downscaled hyetograph by means of a rainfallï runoff model. Finally, the distribution of maximum discharge was derived numerically. This technique was applied to the Doki River Basin, a small basin in Japan, where the influence of human activities was limited. The observed annual maximum discharge data from 1976 to 1998 were used to verify the calculated distribution of maximum discharge. It was shown that the distribution of maximum discharge was well reproduced.

(2) Information about the incidence of heaviest 1, 2 and 3ï day rainfall events and their spatial patterns over the Indian region were useful for different hydrological analysis and design purposes. Keeping this in view, **Mandal et al. (2005)** prepared spatial patterns maps of heaviest 1, 2 and 3ï day rainfall over the contiguous Indian region using 643 long period (1901ï 1991) rainfall stations data uniformly distributed over the country. Catalogue of exceptionally heavy falls of rain in 1, 2 and 3ï day duration were presented in tabular form and their meteorological causes had been briefly discussed. Trend analysis had been attempted to know whether there was any increasing or decreasing trends in the extreme 1, 2 and 3ï day rainfall over the Indian region.

(3) The hydrological studies including the design flood studies for the major projects in Gujarat were carried out due to 1973 unprecedented floods occurred in the major rivers, namely, the Banas, the Sabarmati, the Mahi, the Narmada, the Tapi and the Damanganga flowing through the Gujarat State. This necessitated the revision of design flood studies carried out in the past. Keeping the devastating effects of the floods in view, an attempt was made by **Mistry (1988)** to bring out the facts which necessitated the revision of design flood, the problems arising out

he design flood and the points required to be analysed es for planning the river valley development keeping in view the experience gained from the existing reservoirs and the modern methods available due to advancement made in the techinal as well as meterological spheres.

2.2.7 Drought Analysis

(1) **Mavromatis (2010)** presented a methodology for making use of drought indices in climate change impact assessment studies. To achieve this goal: (1) linear relationships between drought indices and satellite soil moisture information, derived from the ERS scatterometer [Soil Water Index, (SWI)] for the years 1992ï 2000, were developed by employing [analysis of covariance (ANCOVA)] and (2) the vulnerability of soil water content to climate change was assessed using regional climate model (RCM) projections. Several drought indices were evaluated for their abilities to monitor SWI, on a monthly basis, at nine locations in Greece. The original Palmer Drought Severity Index (Origï PDSI) and its selfï calibrated version (SCï PDSI) correlated best with SWI in three stations each and precipitation in two. The degree of agreement, however, varied substantially among the sites. Seasonality had a significant effect on the relationship between the SWI and the two afore mentioned drought indices (Origï PDSI, SCï PDSI), presenting a bimodal pattern that fluctuated markedly during the year. ANCOVA had proved to be a useful method for measuring the agreement between SWI and the drought indices (r^2 ranged from 46.2% to 79.9%), implying that drought indices were an important information source for detecting and monitoring drought. 11 different RCM runs were compared for their abilities to reproduce present climate mean and variability of temperature and precipitation. Origï PDSI was not sensitive to the much warmer future climate change scenarios constructed and, therefore, was not suggested for climate change impacts assessment studies. SCï PDSI, on the other hand, it had the potential to be used; however, its responses depended on the time period on which the climate characteristics and duration factors were computed from.

(2) Droughts are an inevitable consequence of meteorological variability, and the design of water resource infrastructure and management strategies to mitigate

ssment of the risk. Crucial characteristics of droughts ensities, durations, and severities. According to **Wong et al. (2010)** these variables were typically correlated and copulas provided a versatile means to model their dependence structure. In Australia, for example, drought severity was associated with the Elï Niño Southern Oscillation. Data from two rainfall districts in New South Wales, one on the east and the other on the west of the Great Dividing Range, were considered. These rainfall data were categorized into three states, Elï Niño, Neutral, and Laï Niña, according to the prevailing Southern Oscillation Index. Gumbel Hougaard copulas and *t*–copulas were fitted to the droughts in the three states. The copula parameters were estimated separately for each state, and the differences were analyzed. The goodnessï ofï fit of the Gumbelï Hougaard and *t*ï copulas were compared, and the limitations of the two copula models were discussed. The times between drought events were also analyzed according to the Elï Niño Southern Oscillation state they occur in. The fitted copulas were used to estimate annual recurrence intervals of at least one of the three variables, and of all three variables, exceeding critical values taking into account of the mixture of states.

(3) **Chen et al. (2009)** investigated historical trends of meteorological drought in Taiwan by means of longterm precipitation records. Information on local climate change over the last century was also presented. Monthly and daily precipitation data for roughly 100 years, collected by 22 weather stations, were used as the study database. Meteorological droughts of different levels of severity were represented by the standardized precipitation index (SPI) at a threeï monthly time scale. Additionally, changeï point detection was used to identify meteorological drought trends in the SPI series. Results of the analysis indicate that the incidence of meteorological drought has decreased in northeastern Taiwan since around 1960, and increased in central and southern Taiwan. Longï term daily precipitation series show an increasing trend for dry days all over Taiwan. Finally, frequency analysis was performed to obtain further information on trends of return periods of drought characteristics.

d Agriculture

Onset and withdrawal of monsoon

Evapotranspiration rate

Dry spell analysis for crop planning

Crop planning

Climate classification

(1) The work by **Khan et al. (2010)** dealt with the climates of Pakistan. It was based on the study and analysis of the data regarding temperature, rainfall, number of rainy days, humidity, wind speed and direction, pressure, evapotranspiration, sunshine, and also with the classification of climates. The factors bringing variation in the climates of Pakistan were latitudinal location, proximity to sea level, rough topography, continentility, marine influence in the extreme south, vegetation cover, and soil contents. On the basis of temperature, Pakistan had been classified into five regions i.e. hot, warm, mild, cool, and cold. The southern parts of Pakistan had high temperature (28^{o}C at Hyderabad) that decreased toward north upto 10^{o}C at Astore. Four rainfall regions had been identified i.e. arid, semiï arid, sub humid, and humid. The rainfall concentration decreased from 171.4 cm at Murree in the north to 3.4 cm at Nokkundi in the south. The eastern part of Pakistan received heavy rains during summer, from southwesterly currents, called monsoon, whereas the western parts had high rains in winter, from southwesterly winds, called western disturbances. The extreme north of the country had heavy rains from local thunderstorms caused by convectional uplifting of air parcel due to local heating. Pakistan experienced four rainy seasons i.e. winter rainfall, preï monsoon rainfall, monsoon rainfall, and post monsoon rainfall. The winter and monsoon were the moistest seasons, while the other two constituted the driest seasons of the country. The highest annual number of rainy days was 91.3 at Murree in the north, while it decreased to 4 at Nokkundi in the south. The relative humidity of Pakistan was above 70 % at Makran coast and less than 40 % in southwestern Balochistan, and in the extreme north, while the rest of Pakistan was 40 % to 70 %. The lower latitudes of the country along with coastal belt had a recorded wind speed of above 6 knots, while it decreased to 2 knots in the northern mountainous region. The

outhwestern Balochistan recorded low pressure in igh pressure developed over Himalayas in winter. The Makran coast and parts of Balochistan and Sind had sunshine duration above 8 h / day, which reduced to 7 h / day toward northern mountainous region. Most of the plain had evapotranspiration above 3mm, while it decreased to 2 mm in highland. Due to its subï tropical location, Pakistan had two main seasons i.e. summer and winter. The summer season of the country lasted for seven months in plain and for four months in highland, while the winter season varies for five months in plain and seven months in highland. These two main seasons of Pakistan were further subï divided into four subï seasons i.e. cold, hot, monsoon, and warm. The cold season varied from midï November to mid April, hot season from mid April to June, and monsoon season from July to mid September and warm season from mid September to mid November. On the basis of distribution and variation of weather elements, Pakistan could be divided into five macro regions, which were further subï divided into 18 meso and 46 micro climatic types.

(2) Long term monthly and annual averages of mean temperature were regressed against corresponding elevation data. A good correlation was observed between annual mean temperature and elevation. These monthly spatial variation of mean temperatures was used for computation of spatial potential based on Thornwaite and Mather method (1957). Different agroclimatic indices were worked out using climatic parameters by **Goswami (2008)**. The values refered to the agroclimatic indices which expressed the relationship between climate and agricultural production in quantitative terms. The information collected on the climatic characteristics had been integrated with information on present land use practices and AWC and soil information to characterize the climate. The study tried to demonstrate the use of new tools to characterize the agroclimate in hilly areas of north eastern Region of India.

(3) **Peel et al. (2007)** produced a new global map of climate using the Köppenï Geiger system based on a large global data set of longï term monthly precipitation and temperature station time series. Climatic variables used in the Köppenï Geiger system were calculated at each station and interpolated between stations using a two dimensional (latitude and longitude) thin plate spline with tension onto a 0.1°×0.1° grid for each continent. A problem in dealing with sites

...ssified into one climate type by the Köppenï Geiger ...utcomes on a continent by continent basis was also ...ost common climate type by land area is BWh (14.2%, Hot desert) followed by Aw (11.5%, Tropical savannah). The updated world Köppenï Geiger climate map is freely available electronically.

Onset and withdrawal of monsoon

(1) Asian summer monsoon is the predominant climate system in Myanmar and nearly 90% of total rainfalls are from summer monsoon. The timing of monsoon onset is of importance to the agricultural sector and water replenishment. However, there is a lack of systematic method to detect the climatological monsoon onset dates of Myanmar. The climatology of the summer monsoon onset over Myanmar was defined by **Htway and Matsumoto (2011)** using the mean pentad precipitation data of 29 stations from 1968 to 2000. As a result, the climatological monsoon onset dates over Myanmar were on 18th May (the middle date of pentad number 28) in the southern and central Myanmar and on 28th May (the middle date of pentad number 30) in the northern Myanmar. These climatological onset dates in two areas of Myanmar were confirmed by examining seven meteorological parameters of the observed station data and ERA40 reï analysis data during the period between 21st April and 9th June.

(2) Studies were undertaken to identify the quantum and distribution of rainfall with the frequency of dry spell occurrence during monsoon at Giridih, Jharkhand state, India by **Banik and Sharma (2009)**. Rainfall at different confidence levels was calculated using mixed gamma distribution. The normal onset of monsoon at Giridih was 24th standard meteorological week (SMW) and the mean monsoon rainfall was 1112 mm. If monsoon onsets was two weeks earlier (22nd SMW) than the normal (24th SMW), the total monsoonal rainfall was more than the normal with increased number of dry spells. The coefficient of variation of June and September rainfall was very high. Moisture availability index (MAI) indicated possibility of rice cultivation from 25th SMW and the flowering stage of rice completed within 39th SMW (normal withdraw of monsoon). Thus to minimize crop failure, conventional cultivation of 135 $\pm$ 10 days rice could be replaced by 95 $\pm$ 10 days one, particularly in upland (without bund, direct seeded rice) and medium land (low bund land) situation.

et over Kerala (MOK) marks the beginning of the rainy sociated with the MOK, significant transitions of large scale atmospheric and oceanic circulation patterns are observed over the Asiaï Pacific region. A new method for the objective identification of MOK, based on large scale circulation features and rainfall over Kerala, was discussed by **Pai and Nair (2009)**. Further, a set of empirical models based on the principal component regression (PCR) technique was developed for the prediction of the date of MOK by keeping in mind the IMDôs operational forecasting service requirements. Predictors for the models were derived using correlation analysis from the thermal, convective and circulation patterns. Only five predictors pertaining to the second half of April were used in the first model (Modelï 1) so that the prediction of MOK can be prepared by the end of April itself. The second model (Modelï 2) used four additional predictors pertaining up to the first half of May along with two predictors used in the Modelï 1 for update prediction at the end of the first half of May. To develop each of the PCR models, Principal Components Analysis (PCA) of the respective predictor data was carried out followed by regression analysis of first two principal components (PCs) with the date of MOK. Both these models showed good skill in predicting the date of MOK during the independent test period of 1997ï 2007. The root mean square error (RMSE) of the predictions from both the models during the independent test period was about four days which was nearly half the RMSE of the predictions based on climatology.

Evapotranspiration rate

(1) The study by **Tripathi and Chintamanie (2010)** analyzed the weather data [X_1 as cloud cover (okta), X_2 as minimum temperature (^oC), X_3 as maximum temperature (^oC), X_4 as wind velocity (km/day), X_5 as wind direction (^{o}), X_6 as maximum RH (%) and X_7 as minimum RH (%)] collected at Roorkee during 2006 & 2007. Result showed that the pan evaporation equal to USWB pan could be calculated using the regression equation;

$$\begin{aligned} Ep_{avg}(\text{mm/day}) = 1.55 + 0.05X_1 + 0.13X_2 + 0.09X_3 + 0.37X_4 - 0.022X_5 \\ - 0.034X_6 - 0.032X_7 \end{aligned} \quad (2.1)$$

...nteith could be made comparable to Modified Penman ... providing some adjustment factor or developing fresh Kc values for its own use.

(2) The Penmanï Monteith (P.M.) equation with its new definition of reference crop evapotranspiration (ETo) was recommended by FAO as the standard method of crop water requirement calculation. The ETo component of the CROPWAT model, which was based on the P.M. equation, was examined for sensitivity to errors in input data under the environment of a semiï humid sub tropic region of Bangladesh by **Ali et al. (2009).** The results showed that the ETo estimates were most sensitive to maximum temperature and least sensitive to minimum temperature. The order of sensitivity noticed was maximum temperature > relative humidity > sunshine duration > wind speed > minimum temperature. The sensitivity coefficients showed seasonal variation. The model parameters óAngstromôs coefficientô showed sensitivity to errors in single or pair values. The implications of sensitivity to ETo estimates and in selecting appropriate method for ETo estimation in a dataï short environment were discussed.

(3) Long term changes of reference evapotranspiration and crop water requirements with climate can have a great effect on agricultural production as well as water resources management. The objective of the research by **Li et al. (2008)** was to analysis the effect of climate change and variability on reference evapotranspiration crop water requirements. Based on the historical meteorology data Penmanï Monteith equation and approaches recommended by FAO reference evapotranspiration (ETo) and crop water requirements which derived by ETo times crop coefficients, were calculated, and its change trends and causes were analyzed also for winter wheat and maize in Hebei Province, China during 1965ï 1999. The results showed that reference evapotranspiration and crop water requirement have decreased with time. The main reason for the decreasing of ETo and crop water requirements was the reducing of sunshine hours and wind speeds.

Dry spell analysis for crop planning

(1) According to **Patel and Shete (2010)** Indian agriculture solely depends on the distribution pattern and amount of rainfall. Analysis based on average annual

icting the start of rains, wet and dry spells for deciding bserved that probabilities of a particular day being wet or dry assist in planning agricultural activities for a region. For the present study Markov models of zero, first and second orders are utilized to predict the probabilities of wet and dry days using Instat climatic guide. The analysis is based on rainfall data of 45 years (1961-2005) obtained from 42 raingauge stations in Sabarkantha district of Gujarat, India. The optimum order of the Markov Chain for the wet and dry spells for Sabarkantha District are analyzed using Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC). From the results it is found that generally the most parsimonious models are those of first order (winter) or zero order (summer). Overall, the BIC yields less ambiguous results than the AIC, and thus, a higher level of model confidence is achieved when using the BIC as the model-order selection criteria. It is found that the zero-order model is superior to the first and second order models in representing the probabilities of dry spell length of 7, 10 and 14 days in Sabarkantha district, Gujarat, India. Markov type models can assist in analyzing the occurrence of wet and dry spells for crop planning and water resources management.

(2) The study of the temporalï spatial variability of dry sequences and the probability of their occurrence are particularly important in understanding the impact of climate change on droughts. **Llano and Penalba (2011)** analysed the different properties of dry sequences, focussing on extreme condition, analysing their degree of spatial coherence, and their temporal variability. For the study, daily precipitation data were used for the period 1961ï 2000 throughout Argentina. The region north of 40 ^{0}S was divided in two from the meridian of 63 ^{0}W with highly differentiated 'dry' properties. The eastern region was more homogeneous where mean dry sequences last less than six days and long sequences of about 60 days. The Andean region showed a marked eastï west gradient in any of the above properties, with extreme values of over 10 days (mean sequences) and 150 days (the longest sequences). At the seasonal level the above properties reflected a differential pattern according to the time of year under study. In the case of summer, when the dry sequences were more harmful to crops, the maximum duration in the Pampa region could extend to about 25 days. Owing to the problems that dry sequences of over 30 days could produce in the different

...n the above findings, the temporalï spatial variability ...bility over the years, together with a progressive decrease in the occurrence of such events, was found. The study of extreme dry events provided useful tools that could be applied to different hydrological and agricultural needs.

(3) The aim of the study by **Mathlouthi and Lebdi (2009)** was to derive operation rules for small reservoirs during dry events. The approach was illustrated by the case study of Ghézala Dam, located in the north of Tunisia. The following data were available: daily rainfall for the period from 1968 to 2005 and hydrological data from 1985 to 2002. As a first step, events of dry periods were analysed, according to a predetermined threshold. A dry event was considered to consist of a series of dry days separated by rainfall events, each defined as an uninterrupted series of rainfall days comprising at least one day with precipitation exceeding a threshold of 4 mm. A specific procedure was followed to generate synthetic sequences of dry and wet events, of lengths corresponding to a hydrological year. These data were routed through a simple rainfallï runoff model to obtain synthetic streamflow series. Each generated data set was subject to deterministic optimization using incremental dynamic programming (IDP). Operation rules were derived by means of multiple regression analysis, and appeared to perform most satisfactorily for different predetermined levels of available reservoir storage. The practical utility of these rules was demonstrated for simulated dry, intermediate and wet years, respectively.

Crop planning

(1) Based on the result of an experiment conducted for three years from 1997ï 1999 during Kharif, under rainfed conditions, a model was generated by **Patil and Puttanna (2009)** for relating crop coefficient of ragi with time at Bangalore. The peak value of crop coefficient was found to be 1.02 on 66th day after sowing. The multiple regression equation was also generated based on the accumulated values of actual evapotranspiration (AET), growing degree days (GDD) and bright hours of Sunshine (BHS) from sowing to physiological maturity, using the field experimental data for the period 1998ï 2005. This multiple regression equation could be applied to forecast the yield of finger millet under rainfed conditions. This model was validated for the crop grown during Kharif 2005.

pping systems across the state of Kerala as the index lining while increasing in index of nonï foodgrain crops as mentioned by **Rao et al. (2008a)**. It was also evident that there was a change in climate as rainfall during the southwest monsoon was declining and temperature rise was projected in tune with global warming. The occurrence of floods and droughts as evident in 2007 (floods due to excess monsoon rainfall by 41% against normal) and summer 2004 (drought due to significant rainfall from November, 2006 to May 2004), adversely affected food crops like paddy and plantation crops production to a considerable extent. Deforestation, shift in cropping systems, decline in wetlands and depletion of surface water resources and groundwater may aggravate the intensity of floods and droughts in excess and deficit rainfall events. The frequency of weather abnormalities was likely to be high as projected across the country. At the same time, climate change/ variability may lead to shift in crop boundaries which were thermosensitive and aversely affected crop production to a considerable extent, reflecting on Stateõs economy. It was more so across mid and high ranges of kerala, where thermosensitive crops were grown.

(3) The long term rainfall data for Sali rice season (June ï November) of Jaintia Hills district, Meghalaya had been analysed to estimate expected weekly rainfall at various probability levels by **Goswami et al. (2008)**. Based on expected rainfall at 50 and 75 % probability levels and water requirement, a crop calendar for Sali rice had been prepared for the district. The calendar was assumed to be applicable for the whole district irrespective of terrain differences as rice was mostly grown in comparatively plain lands in bunded condition. 22nd to 24th meteorological weeks had been suggested best for sowing / transplanting to avoid any kind of water stress during the critical growth periods. Amount of water required to maintain at least 5 cm of standing water in the field up to the dough stage had also been calculated.

CHAPTER 3

STUDY AREA

3.1 GENERAL

Gujarat, has an area of 1,96,077 km² with a coast line of 1,600 km, most of which lies on the Kathiawar peninsula and a population of 6,03,83,682 as per the 2011 census data. The state is bordered by Rajasthan to the north, Maharashtra to the south, Madhya Pradesh to the east and the Arabian Sea as well as the Pakistani province of Sindh on the west (Map 1.2). Its capital is Gandhinagar, while its largest city is Ahmedabad.

3.2 STUDY AREA

Gujarat is divided into eight agroclimatic zones as mentioned in chapter 1 (Map 1.3 and Table 1.1). North Gujarat agroclimatic zone is selected amongst all the eight agroclimatic zones for the present study (Map 1.3). North Gujarat agroclimatic zone is partly or fully spread over seven districts namely Ahmedabad, Banaskantha, Gandhinagar, Kheda, Mehsana, Patan and Sabarkantha (Table 1.1). There are 48 talukas under the study area as given in Table 3.1. It covers 12 % (196.12 lac ha) geographical and 21 % (94.99 lac ha) cultivated area of the State.

nder Study

		Taluka	Taluka under study
1	Ahmedabad	Ahmedabad	Ahmedabad
2		Barvala	Dascroi
3		Bavla	Mandal
4		Daskroi	Sanand
5		Dhandhuka	Viramgam
6		Dholka	
7		Mandal	
8		Rampur	
9		Ranpura	
10		Sanand	
11		Viramgam	
12	Banaskantha	Amirgadh	Deesa
13		Bhabharnava	Dhanera
14		Danta	Palanpur
15		Dantiwada	Wadgam
16		Deesa	
17		Dhanera	
18		Diodar	
19		Kankrej	
20		Palanpur	
21		Tharad	
22		Wadgam	
23		Vav	
24	Gandhinagar	Dehgam	Dehgam
25		Gandhingar	Gandhingar
26		Kalol	Kalol
27		Mansa	Mansa
28	Kheda	Balasinor	Balasinor
29		Kapadwanj	Kapadwanj
30		Kathlal	Kathlal
31		Kheda	Kheda
32		Mahudha	Mahudha
33		Matar	Mehmdabad
34		Mehmdabad	Nadiad
35		Nadiad	Thasra
36		Thasra	Virpur
37		Virpur	
38	Mehsana	Bechraji	Bechraji
39		Kadi	Kadi
40		Kheralu	Kheralu
41		Mehsana	Mehsana
42		Satlasana	Satlasana
43		Unjha	Unjha
44		Vadnagar	Vadnagar
45		Vijapur	Vijapur
46		Visnagar	Visnagar

		Chanasma	Patan
		Harij	Radhanpur
		Patan	Santalpur
		Radhanpur	Sidhpur
51		Sami	
52		Santalpur	
53		Sidhpur	
54		Bayad	Bayad
55		Bhiloda	Bhiloda
56		Dhansura	Dhansura
57		Himatnagar	Himatnagar
58		Idar	Idar
59		Khedbramha	Khedbramha
60	Sabarkantha	Malpur	Malpur
61		Meghraj	Meghraj
62		Modasa	Modasa
63		Prantij	Prantij
64		Talod	Talod
65		Vadali	Vadali
66		Vijaynagar	Vijaynagar

Ahmedabad District

Ahmedabad is located at 23.00º N and 72.58º E. Ahmedabad is the largest city in Gujarat. It is the seventh largest city and seventh largest metropolitan area of India. The city spans an area of 205 km^2.

Ahmedabad experiences extreme climate. There is great difference between the temperatures of days and nights. Summers start from the month of March and end by June. Winters are cool and dry and period includes the month of November to February. Monsoons are from July to September. The annual rainfall varies between 85 mm to 1,549 mm for a period from 1961 to 2008.

Banaskantha District

The Banaskantha district is situated between the parallels of latitude 23.81° N and 24.70° N and the meridians of longitude 71.10° E and 73.00° E. The area covered by the district is 10,757 km^2. The rank of the district is 4^{th} in area of the State. It is in the north western part of the Gujarat State.The district is surrounded by Rajasthan state to the north, Sabarkantha district to the east, Patan district to the southï east and Kachchh district to the west.

The climate of this district is characterized by a hot summer and dryness in the non rainy seasons. The cold season from December to February is followed by

...ch to May. The south-west monsoon season is from ...er and November form the post monsoon season. The ...een 214 mm to 1,801 mm for a period from 1961 to 2008.

Gandhinagar District

The district extends from 20.00º N to 23.36º N latitude and 71.10ºE to 72.66ºE longitude and has an area of 2,163.48 sq km. Gandhinagar district is located in central portion of Gujarat state, surrounded by Mehsana district to the north, Sabarkantha district to the northï east, Ahmedabad district to the south & west and Kheda to the southï east.

In Gandhinagar district, the region has extreme climate with mean maximum temperature of 45^{o} C and mean minimum temperature of 9^{o} C. The annual rainfall varies between 144 mm to 1,469 mm for a period from 1961 to 2008.

Kheda District

Kheda is located at 22.75° N and 72.68° E. It has an average elevation of 21 m. It has a population of 2,024,216 of which 20.08% were urban as of 2001. It covers an area of 3,943 km^2. Kheda city is the administrative headquarters of the district. The district has over 600 villages. It is bounded by the districts of Gandhinagar and Sabarkantha to the north, Panchmahal to the east, Ahmedabad to the west, and Anand and Vadodara to the south.

The climate of the Kheda district is characterized by a hot summer and general dryness except during the southï west monsoon. The period from March to May is one of continuous increase in temperature. The weather is intensely hot in summer and particularly in the month of May the day temperature reaches 43^{0} C or even above. January is generally the coldest month when temperature goes down to 8^{0} C to 9^{0} C during nights. The annual rainfall varies from 103 mm to 1,992 mm for a period from 1961 to 2008.

The Mehsana district has an area of 4376.38 km^2. The forest area is of 50.22 km^2, the irrigated area is of 1930.79 km^2 and unirrigated area accounts for 1467.67 km^2. Mehsana district is surrounded by Banaskantha district to the north, Sabarkantha district to the east, Gandhinagar district to the southï east, Ahmedabad to the southï west and Patan district to the west.

The climate of the Mehsana district is moderate with mean daily maximum temperature of 41º C and the mean daily minimum temperature of 11º C. The annual rainfall varies between 36 mm to 2,603 mm for a period from 1961 to 2008.

Patan District

The Patan District has an area of 5,742.59 km^2. The forest area is of 438.36 km^2, the irrigated area is of 1,012.62 km^2 and unirrigated area accounts for 2,966.41 km^2. The district is surrounded by Banaskantha district to the north, Mehsana district to the east, Surendranagar district to the south and Kachchh district to the west.

The climate of this district is characterized by a hot summer and general dryness in the major part of the year. Summer is very hot and winter is too cold. The cold season is from December to February. After February there is rapid increase in the temperature. May is the hottest month. The mean daily maximum temperature is about 41^0 C and the minimum is about 8^0 C. After October both the day and night temperature decreases at a rapid rate. January is the coldest month. The annual rainfall varies between 59 mm to 1,713 mm for a period from 1961 to 2008.

Sabarkantha District

The Sabarkantha district is the part of Gujarat plains and lies between 72º 43' to 73º 39' E and 23º 03' to 24º 30' N, covering an area of 7,259.60 km^2. It is surrounded by Banaskantha and Mehsana districts in the west; Ahmedabad, Gandhinagar, Kheda and Panchmahals districts in the south and Sirohi, Udaipur and Dungarpur districts (Rajasthan) in the north and east.

tha district is characterized by a hot summer with n the monsoon season. The annual rainfall varies between 45 mm to 2,462 mm for a period from 1961 to 2008.

3.2.1 Agriculture Scenario

North Gujarat is described as arid and semi arid region with high temperatures and limited growth period (LGP) of less than 100 days. The rainy season being short (Julyï August), the biggest problem in both agriculture and daily life is water. The water is very precious due to scarce and bad quality of ground water. The high temperatures, sandy soils, scarce water and high wind velocity combined together make very precarious agricultural situation in the region that often leads to water stress during postï anthesis and grain development period in Kharif crops. Contrarily, high temperatures, both during seeding and maturity, are the main yieldï limiting factors in Rabi crops. The summer and spring crops are feasible only where water is available. As such the selection of crop depends primarily on quantum and distribution of rainfall, water availability, appropriate temperature window and such other natural resources.

Agriculture is highly diversified in the region. Pearl millet is the most dominant crop followed by cotton, rapeseed, mustard, wheat, castor, guar, mungbean, maize, sesamum and cumin. Isabgol is the main source of natural fibre. The productivity of castor, potato, guar, cotton and wheat have evinsaged significant enhancement. All the technological revolutions in seed production of cotton inclusive of Hybrid cotton technology and BT Cotton Technology belong to north Gujarat.

3.2.2 Water Resources

North Gujarat constitutes 23 percent area of Gujarat state where 34 percent of population lives. The biggest problem in agriculture and domestic life is ñWaterò for drinking and irrigation. Average rainfall of the whole region is 600 mm. It varies a lot and is the highest (around 900 mm) in eastern part of north Gujarat. It reduces as one proceeds towards west. The agricultural situations in north Gujarat are marked by erratic rains in quantum and space that often leads to ally in less rain endowed areas like Banaskantha, atan.

Despite proportion of irrigated area of cultivated land in north Gujarat is more (49%) than Gujarat (32%) yet it faces severe scarcity of water availability as compared to other regions of Gujarat. Major source of irrigation is ground water. Dug wells and tube wells are the major source of irrigation and consummately cover over 88 % of the irrigation resources as compared to 80% irrigation water supply through wells in Gujarat. Only 15 % of the rainfall percolates in the soil there by storing over 225 crore cubic meters of rain water annually as ground water. The rest flows away as runoff every year creating lot of soil erosion and depletion of soil nutrition. The withdrawal of ground water is 350 crore cubic meters per annum thereby creating an average annual deficit of ground water as 125 crore cubic meters. Surface water availability per capita in north Gujarat is 124 cubic meters per year as compared to 735 and 274 cubic meters per year in South & Central Gujarat and Saurashtra, respectively. Thus north Gujarat is the most stigmatic for the over withdrawal of ground water with water lift in many talukas particularly in Mehsana district having approached critical level of over 500 m. Due to over withdrawal of ground water, ground water table has been going down by 2 to 4 meters per year. As such the digging of the wells is not advisable in such dark zones. The energy required for pumping water is also enormous and generally motor horse power required is 50 hp.

3.2.3 Soil Resources

The north Gujarat can be divided into two major parts (i) with loamy sandy soil and has rainfall of around 700 mm that encompases Mehsana, Gandhinagar and Sabarkanth districts having pearlmillet or cotton based cropping system and (ii) with sandy soil having lesser average rainfall (450 mm) spread over the remaining land. The salinity problem is menacing and the ingression has been intimidating at a rate of 0.5 km/year due to which the fertile lands are becoming unproductive.

Soils of north Gujarat exhibit considerable variability in their characteristics and productivity. The soils are shallow to very depp (> 30 m), moderate to excessively drained and gently sloping. The typical aridity of the region leads to level of organic carbon (< 0.5%) in soil. Most of these g/ha), low to medium P_2O_5 (12ï 54 kg/ha) and medium a), which reflects poor soil fertility culminating in lower productivity. Most of the soils are also deficient in sultphur (< 10 mg/kg), iron (< 5 mg/kg) and zinc (< 0.5 mg/kg). The status of manganese (> 10 mg/kg) and copper (> 0.4 mg/kg) is adequate in soils of all the districts. High infiltration rate and low water holding capacity are the major production constraints.

3.2.4 Cropping Pattern

Agriculture in north Gujarat predominantly hovers around nonï food crop economy with local preference for crops like castor, groundnut, spices, cotton, tobacco, vegetables and fruits. The region is fast catapulting into ñOil Bowlò with more than 25% area i.e 7.8 lac ha under oilseeds.

In north Gujarat pearlmillet is the most dominant crop (20%), followed by cotton (12%), rape seed and mustard (12%), wheat (9%), castor (9%), Guar (7%), mungbean (6%), maize (5%), sesame (4%) and cumin (4%). Pearl millet covers around 59.2 percent of the area under pearlmillet in Gujarat (9.26 lac ha). Mustard, castor and guar have lot of industrial utility and are predominantly grown in north Gujarat occupying 73.7, 96.2 and 98.4 % of the acreage under those crops in the state, respectively. Similarly mung, bean, cumin, moth bean, potato, isabgol and fennel are also predominantly grown in north Gujarat constituting 84.0, 48.0, 90.0, 76.6, 92.2 and 86.2 percent of the area under respective crop in the State, respectively.

CHAPTER 4

ATA COLLECTION

4.1 GENERAL

To facilitate achieving the objectives of the study the climate data i.e. minimum and maximum temperatures, relative humidity, wind speed, sunshine hours and rainfall are collected. For agricultural analysis, data regarding onset of monsoon and crop details are collected. For water resources project analysis data of the major and minor irrigation schemes in north Gujarat region are obtained.

4.2 COLLECTION OF DATA

For planning the irrigation activities and water resources projects in the area data regarding long term climate parameters, soil analysis and crop data are necessary. Above mentioned data are collected from various Government and private agencies. The various data collected and source of data are enlisted as follows:

4.2.1 Climate Data

Climate data comprises of major five variables namely, minimum & maximum temperatures, relative humidity, bright sunshine hours and wind speed. These five basic climate dataset are the minimum requirement for planning of any water resources or agricultural planning. The above mentioned climate parameters are available from the meteorological stations established in and around the area.

Meteorological Data:

Source:

1. India Meteorological Department, Pune.
2. Sardar Krushinagar Agriculture University, Dantiwada, Banaskantha.

Data:

(1) Rainfall.

(2) Evaporation.

(5) Average relative humidity.

(6) Sunshine hours.

(7) Dew point temperature.

The weekly climate data i.e. minimum and maximum temperatures, averagerelative humidity, wind speed, sunshine hours and rainfall are collected from IMD, Pune. Details of climate stations are presented in Table 4.1.

Table 4.1 Details of Climate Stations Available for the Study

Station Name	Latitude N	Longitude E	Altitude m	From	To
Ahmedabad	22°04'00"	72°38'00"	55	1969	2005
Deesa	24°15'30"	72°10'20"	136	1969	2005
Idar	23°50'40"	73°00'30"	219	1969	2005
VallabhVidhyanagar	22°34'00"	72°56'00"	44	1969	2005
Gandhinagar	23°13'00"	72°42'00"	82	1973	1978
Sardar Krushinagar	24°19'10"	72°20'15"	572	1982	2008

As the climate stations are very few in the region the 28 years of available data are also utilized. But 6 years of available weekly data of Gandhinagar has not been considered for the study. Thus there are 5 climate stations available. The sample data for Ahmedabad climate station are represented in Fig. 4.1.

In order to improve the analysis involving only rainfall data, raingauge networks wherein only daily rainfall data are measured, are considered. These daily rainfall dataset are obtained from State Water Data Centre (SWDC), Gandhinagar.

The rainfall data for the entire north Gujarat region comprising of 7 districts viz. Ahmedabad, Banaskantha, Gandhinagar, Kheda, Mehsana, Patan and Sabarkantha are collected. There are 167 raingauge stations established in these 7 districts. The details are presented in Table 4.2 below. The data contains missing records from few days to several years. The data availability is from 1961 onwards.

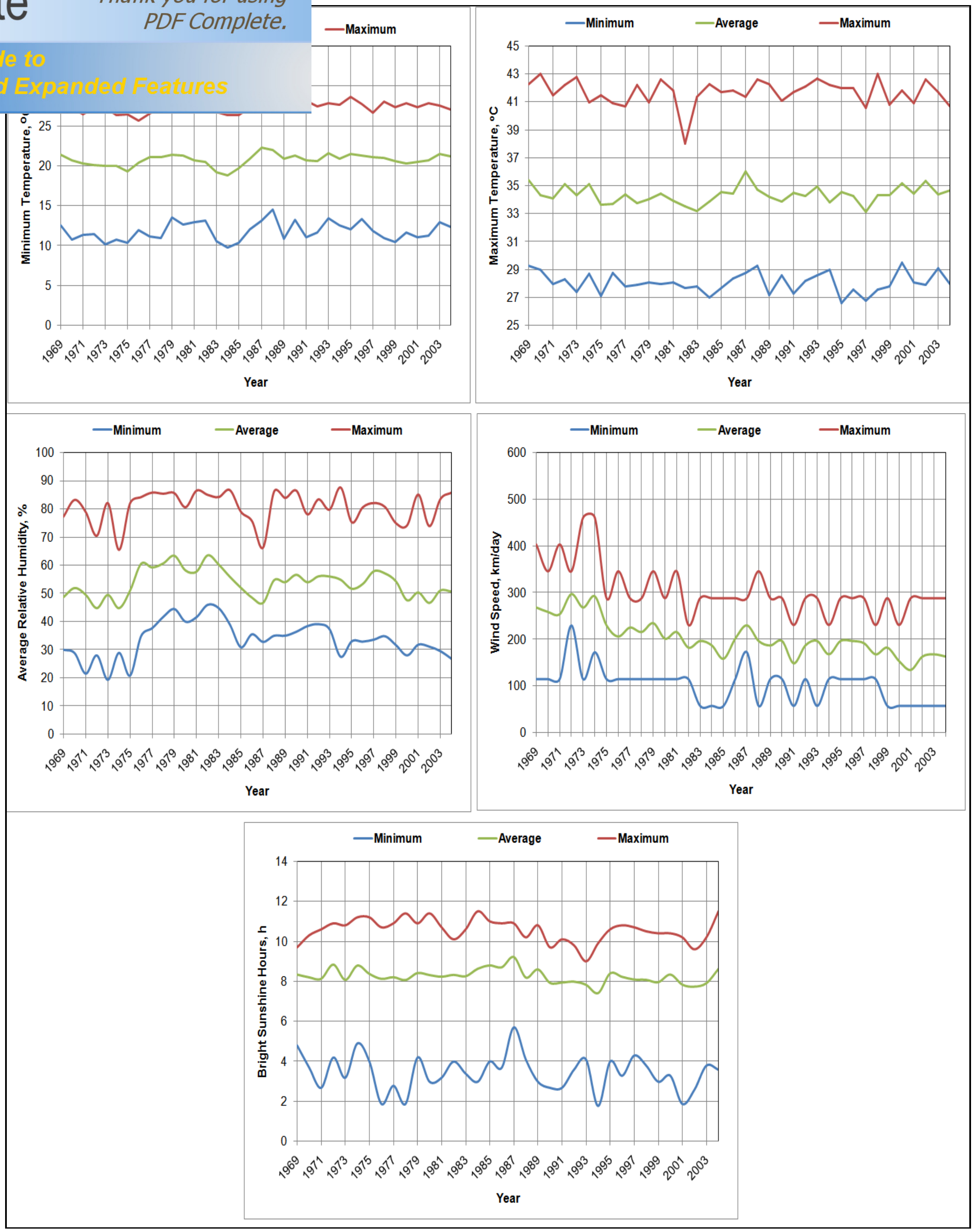


Fig. 4.1 Meteorological data for Ahmedabad climate station.

tations Situated in North Gujarat Region

			District	Latitude N	Longitude E	From	To	Years
[illegible]	[illegible]	[illegible]	Ahmedabad	22°04'00"	72°38'00"	1961	2005	45
2	Aslali	Dascroi	Ahmedabad	22°55'00"	72°35'40"	1961	2005	45
3	Bagodra	Dholka	Ahmedabad	22°38'30"	72°12'10"	1969	2005	37
4	Bareja	Dascroi	Ahmedabad	22°50'50"	72°35'30"	1961	2005	45
5	Barejadi	Dascroi	Ahmedabad	22°53'40"	72°40'30"	1962	2005	44
6	Bavla	Bavla	Ahmedabad	22°49'40"	72°22'40"	1966	2005	40
7	Bhankoda	Viramnagar	Ahmedabad	23°16'40"	72°09'30"	1967	2005	39
8	Chandola	Dascroi	Ahmedabad	22°59'20"	72°36'30"	1962	2005	44
9	Changodar	Dholka	Ahmedabad	22°55'40"	72°26'50"	1966	2005	40
10	Dehgam	Dehgam	Ahmedabad	23°10'00"	72°49'30"	1962	2005	44
11	Dhandhuka	Dhandhuka	Ahmedabad	22°23'00"	71°59'20"	1961	2005	45
12	Dholera	Dhandhuka	Ahmedabad	22°14'30"	72°14'10"	1961	2002	42
13	Dholka	Dholka	Ahmedabad	22°43'40"	72°26'30"	1961	2005	45
14	Mandal (A)	Mandal	Ahmedabad	23°12'00"	71°50'00"	2001	2005	5
15	Mithapur	Dholka	Ahmedabad	22°36'50"	72°07'30"	1970	1998	29
16	Nal Lake	Sanand	Ahmedabad	22°49'10"	72°03'50"	1970	2005	36
17	Sadra	Dehgam	Ahmedabad	23°20'20"	72°46'20"	1967	1998	32
18	Sanand	Sanand	Ahmedabad	22°59'20"	72°23'00"	1967	2005	39
19	Sitapur	Viramnagar	Ahmedabad	23°27'20"	71°50'40"	1967	2005	39
20	Wasai	Dascroi	Ahmedabad	22°51'30"	72°32'40"	1971	2005	35
21	Viramgam	Viramnagar	Ahmedabad	23°07'20"	72°02'50"	1962	2005	44
22	Warna	Dholka	Ahmedabad	22°30'00"	72°24'10"	1967	2005	39
23	Ambaji	Danta	Banaskantha	24°20'10"	72°51'00"	1971	2005	35
24	Amirgadh	Palanpur	Banaskantha	24°24'50"	72°38'50"	1967	2005	39
25	Balundra	Palanpur	Banaskantha	24°21'22"	72°32'02"	1998	2005	8
26	Bapla	Dhanera	Banaskantha	24°34'04"	72°13'12"	1965	2005	41
27	Bhabhar	Bhabhar	Banaskantha	24°03'55"	71°36'00"	2000	2005	6
28	Bhilda	Danta	Banaskantha	24°31'05"	72°25'05"	2000	2005	6
29	Bhildi	Bhildi	Banaskantha	24°11'34"	72°00'39"	1999	2000	2
30	Chandisar	Palanpur	Banaskantha	24°13'55"	72°18'40"	1969	2005	37
31	Chitrasani	Palanpur	Banaskantha	24°16'00"	72°30'00"	1967	2005	39
32	Danta	Danta	Banaskantha	24°11'36"	72°45'45"	1961	2005	45
33	Dantiwada	Dhanera	Banaskantha	24°19'10"	72°20'15"	1964	2005	42
34	Deesa	Deesa	Banaskantha	24°15'30"	72°10'20"	1961	2005	45
35	Deodar	Deodar	Banaskantha	24°06'30"	71°46'10"	1962	2005	44
36	Dhanera	Dhanera	Banaskantha	24°30'40"	72°01'45"	1961	2005	45
37	Gadh	Palanpur	Banaskantha	24°07'17"	72°15'31"	1971	2005	35
38	Hadad	Danta	Banaskantha	24°15'45"	72°58'30"	1968	2005	38
39	Hathindra	Palanpur	Banaskantha	24°13'35"	72°35'55"	1971	1999	29
40	Jhajham	Santalpur	Banaskantha	23°56'50"	71°20'05"	1967	2005	39
41	Junisarotri	Palanpur	Banaskantha	24°21'40"	72°32'45"	1971	2005	35
42	Kankrej	Shihori	Banaskantha	24°02'10"	71°56'36"	1962	1977	16
43	Kanodar	Palanpur	Banaskantha	24°05'20"	72°24'10"	1993	2005	13
44	Kansari	Deesa	Banaskantha	24°19'40"	72°08'05"	1981	2005	25
45	Wadgam	Wadgam	Banaskantha	24°04'21"	72°29'35"	1961	2005	45
46	Khara	Palanpur	Banaskantha	24°22'25"	72°26'45"	1971	1992	22
47	Mandal	Dhanera	Banaskantha	24°34'00"	72°14'00"	1993	1998	6
48	Marwada	Palanpur	Banaskantha	24°21'55"	72°21'05"	1971	1992	22
49	Mavsari	Wav	Banaskantha	24°36'50"	71°21'55"	1964	2005	42
50	Mukteshwar	Wadgam	Banaskantha	24°02'21"	72°37'51"	1984	2005	22
51	Naroli	Tharad	Banaskantha	24°37'15"	71°38'25"	1964	2005	42
52	Nava	Deesa	Banaskantha	24°07'49"	72°10'17"	1971	2005	35
53	Navavas	Danta	Banaskantha	23°59'55"	72°42'16"	2000	2005	6
54	Palanpur	Palanpur	Banaskantha	24°10'14"	72°26'10"	1962	2005	44
55	Panthawada	Dhanera	Banaskantha	24°29'20"	72°18'05"	1967	2005	39
56	Paswadal	Palanpur	Banaskantha	23°59'00"	72°25'00"	1970	1998	29

			Banaskantha	23°58'50"	72°31'50"	2000	2005	6
			Banaskantha	23°50'00"	71°36'19"	1961	2005	45
			Banaskantha	24°18'08"	72°30'44"	1971	1992	22
			Banaskantha	24°13'13"	72°14'51"	1973	2005	33
61	Ratanpur	Palanpur	Banaskantha	24°09'20"	72°28'15"	1999	2005	7
62	Samau	Palanpur	Banaskantha	24°05'16"	72°06'00"	1971	2000	30
63	Sanali Ashram	Danta	Banaskantha	24°12'20"	72°57'30"	1970	2000	31
64	Santalpur	Santalpur	Banaskantha	23°45'52"	71°10'05"	1961	2005	45
65	Sipu Dam	Dantiwada	Banaskantha	24°23'30"	72°18'10"	1999	2005	7
66	Suigam	Wav	Banaskantha	24°08'00"	71°22'00"	1967	2005	39
67	Tharad	Tharad	Banaskantha	24°23'30"	71°37'20"	1961	2005	45
68	Umbari	Kankarej	Banaskantha	24°03'10"	72°00'15"	2000	2005	6
69	Varahi	Santalpur	Banaskantha	23°47'35"	71°26'30"	1961	1998	38
70	Virampur	Palanpur	Banaskantha	24°16'10"	72°39'42"	1971	1992	22
71	Wav	Wav	Banaskantha	24°21'55"	71°31'30"	1962	2005	44
72	Zerda	Deesa	Banaskantha	24°22'10"	72°03'23"	1998	2005	8
73	Gandhinagar	Gandhinagar	Gandhinagar	23°13'00"	72°42'00"	1974	2005	32
74	Mansa	Mansa	Gandhinagar	23°25'30"	72°42'00"	1967	2005	39
75	Raipur weir	Dehgam	Gandhinagar	23°06'30"	72°43'45"	1971	2005	35
76	Sevalia	Thasara	Kheda	22°48'16"	73°21'29"	1983	2001	19
77	Balasinor	Balasinor	Kheda	22°57'25"	73°15'13"	1961	2005	45
78	Betawada	Kapadwanj	Kheda	23°05'08"	73°03'20"	1999	2005	7
79	Bilodra	Nadida	Kheda	22°44'45"	72°52'34"	1968	2005	38
80	Dakor	Thasara	Kheda	22°45'10"	73°08'50"	1974	2005	32
81	Kapadwanj	Kapadwanj	Kheda	23°02'00"	73°04'30"	1968	2005	38
82	Kathlal	Kapadwanj	Kheda	22°54'50"	72°59'10"	1969	2005	37
83	Kheda	Kheda	Kheda	22°45'00"	72°41'10"	1967	2005	39
84	Limbasi	Matar	Kheda	22°36'40"	72°37'30"	1973	2005	33
85	Mahemdabad	Mahemdabad	Kheda	22°49'30"	72°45'30"	1969	2005	37
86	Mahij	Mahemdabad	Kheda	22°52'30"	72°39'05"	1967	2005	39
87	Mahisa	Maudha	Kheda	22°51'20"	73°03'40"	1971	2005	35
88	Mahudha	Nadiad	Kheda	22°49'20"	72°56'30"	1967	2005	39
89	Matar	Matar	Kheda	22°42'20"	72°39'40"	1993	2005	13
90	Nadiad	Nadiad	Kheda	22°41'40"	72°52'10"	1970	2005	36
91	Pinglaj	Kheda	Kheda	22°48'50"	72°36'20"	1962	2005	44
92	Rasikpura	Kheda	Kheda	22°42'10"	72°31'10"	1967	2005	39
93	Savli tank	Balasinor	Kheda	22°57'40"	73°06'50"	1965	2005	41
94	Sayat tank	Nadiad	Kheda	22°47'00"	73°05'00"	1967	2005	39
95	Thasara	Thasara	Kheda	22°47'40"	73°12'50"	1998	2005	8
96	Vadol	Kapadwanj	Kheda	22°58'30"	73°12'00"	1968	2005	38
97	Vaghroli Tank	Thasara	Kheda	22°53'00"	73°17'30"	1968	1987	20
98	Kalol	Kalol	Mehsana	23°15'00"	72°29'40"	1961	2005	45
99	Ambaliyasan	Mehsana	Mehsana	23°27'30"	72°27'00"	1970	2003	34
100	Baspa	Sami	Mehsana	23°43'35"	71°40'35"	1981	2003	23
101	Becharaji	Becahraji	Mehsana	23°32'40"	72°06'30"	1961	1961	1
102	Dharoi	Kheralu	Mehsana	24°00'00"	72°51'15"	1962	2004	43
103	Dhinoj	Chansma	Mehsana	23°39'40"	72°16'50"	1964	2003	40
104	Kadi	Kadi	Mehsana	23°18'00"	72°22'10"	1962	2005	44
105	Katosan	Mehsana	Mehsana	23°27'00"	72°13'00"	1937	2003	67
106	Khandosan	Visnagar	Mehsana	23°43'09"	72°27'39"	1993	2003	11
107	Kheralu	Kheralu	Mehsana	23°53'10"	72°37'20"	1967	1998	32
108	Mehsana	Mehsana	Mehsana	23°36'30"	72°24'40"	1961	1999	39
109	Ransipur	Vijapur	Mehsana	23°44'10"	72°48'00"	1967	2005	39
110	Ranuj	Patan	Mehsana	23°45'40"	72°13'50"	1970	2003	34
111	Red Laxmi	Vadnagar	Mehsana	23°49'20"	72°41'20"	2001	2003	3
112	Sudasana	Kheralu	Mehsana	23°49'30"	72°48'30"	1967	1998	32
113	Taranga hill	Kheralu	Mehsana	23°58'00"	72°45'30"	1967	1998	32
114	Thol	Kadi	Mehsana	23°07'40"	72°22'40"	1972	2005	34
115	Unjha	Unjha	Mehsana	23°48'15"	72°23'45"	1965	2003	39
116	Vijapur	Vijapur	Mehsana	23°33'30"	72°45'15"	1967	2005	39

			Mehsana	23°42'00"	72°33'15"	1961	2000	40
			Patan	23°51'21"	72°06'58"	1961	2005	45
			Patan	23°42'50"	72°06'50"	1962	2003	42
			Patan	23°42'00"	71°56'45"	1962	2003	42
121	Raphu	Sami	Patan	23°36'25"	71°34'15"	1973	2003	31
122	Sami	Sami	Patan	23°41'30"	71°49'00"	1962	2003	42
123	Sidhpur	Sidhpur	Patan	23°54'35"	72°21'30"	1961	2003	43
124	Wagdod	Patan	Patan	23°59'16"	72°09'15"	1971	2003	33
125	Ziliya	Chanasma	Patan	23°41'45"	72°11'00"	1999	2003	5
126	Ambaliyara	Bayad	Sabarkantha	23°13'00"	73°02'30"	1999	2005	7
127	Anior	Malpur	Sabarkantha	23°20'00"	73°23'20"	1981	2005	25
128	Badoli	Idar	Sabarkantha	23°49'30"	73°04'20"	1968	2005	38
129	Bayad	Bayad	Sabarkantha	23°14'00"	73°14'00"	1962	2005	44
130	Bhempoda	Malpur	Sabarkantha	23°19'42"	73°25'54"	1982	2005	24
131	Bhiloda	Bhiloda	Sabarkantha	23°46'10"	73°24'45"	1961	2005	45
132	Chandop	Idar	Sabarkantha	23°55'40"	72°51'00"	1970	1998	29
133	Chhapara weir	Vijaynagar	Sabarkantha	24°02'10"	73°10'30"	1973	2003	31
134	Dantral	Khedbrhma	Sabarkantha	24°18'45"	73°02'30"	1996	2005	10
135	Derol	Himatnagar	Sabarkantha	23°35'20"	72°48'30"	1988	2005	18
136	Gunva	Khedbrahma	Sabarkantha	24°18'40"	73°02'20"	1970	1995	26
137	Himatnagar	Himatnagar	Sabarkantha	23°36'00"	72°57'50"	1967	2005	39
138	Idar	Idar	Sabarkantha	23°50'40"	73°00'30"	1967	2005	39
139	Kabola	Modasa	Sabarkantha	23°31'10"	73°13'03"	1999	2005	7
140	Khandiol	Himatnagar	Sabarkantha	23°43'10"	73°02'31"	1982	2005	24
141	Khedbrahma	Khedbrhma	Sabarkantha	24°02'08"	73°02'03"	1967	2005	39
142	Kheroj	Khedbrhma	Sabarkantha	24°14'50"	73°01'00"	1982	1998	17
143	Kundlacampo	Vijaynagar	Sabarkantha	23°58'45"	73°13'10"	1970	2004	35
144	Lalpur	Himatnagar	Sabarkantha	23°37'10"	72°55'45"	1981	2004	24
145	Limla dam	Prantij	Sabarkantha	23°24'00"	72°53'20"	1971	2005	35
146	Maghodi	Malpur	Sabarkantha	23°16'00"	73°24'00"	1961	1998	38
147	Malpur	Malpur	Sabarkantha	23°21'40"	73°31'08"	1962	2005	44
148	Mankadi	Bhiloda	Sabarkantha	23°42'00"	73°13'10"	1987	2005	19
149	Medhasan	Modasa	Sabarkantha	23°32'20"	73°16'30"	1991	2001	11
150	Meghraj	Meghraj	Sabarkantha	23°30'30"	73°30'40"	1961	2005	45
151	Modasa	Modasa	Sabarkantha	23°27'45"	73°17'40"	1961	2005	45
152	Pal	Vijaynagar	Sabarkantha	23°58'02"	73°17'00"	1963	2004	42
153	Parsodacampo	Vijaynagar	Sabarkantha	24°02'10"	73°11'45"	1970	1998	29
154	Posina	Khedbrahma	Sabarkantha	24°22'30"	73°02'10"	1970	1993	24
155	Prantij	Prantij	Sabarkantha	23°25'50"	72°54'00"	1967	2005	39
156	Rahiol	Modasa	Sabarkantha	23°24'10"	73°13'35"	1981	1998	18
157	Rellawada	Meghraj	Sabarkantha	23°37'20"	73°28'25"	1981	2005	25
158	Sabli	Idar	Sabarkantha	23°43'00"	73°08'00"	1969	2004	36
159	Sathamba	Bayad	Sabarkantha	23°10'10"	73°19'40"	1961	2005	45
160	Shamlaji	Bhiloda	Sabarkantha	23°40'41"	73°21'58"	1964	2005	42
161	Titoi	Modasa	Sabarkantha	23°36'40"	73°22'20"	1971	2002	32
162	Vadgam	Modasa	Sabarkantha	23°20'10"	73°10'30"	1961	2005	45
163	Vajepur	Vijaynagar	Sabarkantha	23°59'32"	73°09'45"	1998	2005	8
164	Vanej	Vijaynagar	Sabarkantha	23°58'40"	73°18'30"	2001	2005	5
165	Vijaynagar	Vijaynagar	Sabarkantha	24°00'20"	73°21'40"	1967	2005	39
166	Virpur	Idar	Sabarkantha	23°47'00"	72°56'30"	1968	2005	38
167	Volva	Modasa	Sabarkantha	23°28'52"	73°19'41"	1982	2005	24

Out of 167 raingauge stations, 132 are situated in north Gujarat agroclimatic zone and are highlighted in Table 4.2. For performing any hydrological analysis atleast more than 35 years data are required. Hence only those raingauge stations having more than 35 years of rainfall data are considered. Table 4.3 gives the details of raingauge stations considered for the study in north Gujarat hlighted station contains missing records ranging from

Table 4.3 Details of 73 Raingauge Stations in North Gujarat Agroclimatic Zone

Sr. No.	Name of station	Taluka	District	Latitude N	Longitude E	Data available	
						From	To
1	Aslali	Dascroi	Ahmedabad	22°55'00"	72°35'40"	1961	2008
2	Bareja	Dascroi		22°50'50"	72°35'30"	1971	2008
3	Barejadi	Dascroi		22°53'40"	72°40'30"	1971	2005
4	Chandola	Dascroi		22°59'20"	72°36'30"	1971	2008
5	Dehgam	Dehgam		23°10'00"	72°49'30"	1962	2006
6	Nal Lake	Sanand		22°49'10"	72°03'50"	1970	2008
7	Sanand	Sanand		22°59'20"	72°23'00"	1967	2008
8	Wasai	Dascroi		22°51'30"	72°32'40"	1971	2008
9	Ambaji	Danta	Banaskantha	24°20'10"	72°51'00"	1971	2008
10	Amirgadh	Palanpur		24°24'50"	72°38'50"	1967	2008
11	Bapla	Dhanera		24°34'04"	72°13'12"	1965	2008
12	Chandisar	Palanpur		24°13'55"	72°18'40"	1969	2008
13	Chitrasani	Palanpur		24°16'00"	72°30'00"	1967	2008
14	Danta	Danta		24°11'36"	72°45'45"	1961	2008
15	Dantiwada	Dhanera		24°19'10"	72°20'15"	1964	2008
16	Deesa	Deesa		24°15'30"	72°10'20"	1961	2008
17	Dhanera	Dhanera		24°30'40"	72°01'45"	1961	2008
18	Gadh	Palanpur		24°07'17"	72°15'31"	1971	2008
19	Hadad	Danta		24°15'45"	72°58'30"	1968	2008
20	Junisarotri	Palanpur		24°21'40"	72°32'45"	1971	2008
21	Nava	Deesa		24°07'49"	72°10'17"	1971	2006
22	Palanpur	Palanpur		24°10'14"	72°26'10"	1962	2008
23	Panthawada	Dhanera		24°29'20"	72°18'05"	1967	2008
24	Sanali Ashram	Danta		24°12'20"	72°57'30"	1970	2004
25	Wadgam	Wadgam		24°04'21"	72°29'35"	1961	2008
26	Mansa	Mansa	Gandhinagar	23°25'30"	72°42'00"	1967	2008
27	Raipur weir	Dehgam		23°06'30"	72°43'45"	1971	2008
28	Balasinor	Balasinor	Kheda	22°57'25"	73°15'13"	1961	2008
29	Dakor	Thasara		22°45'10"	73°08'50"	1974	2008
30	Kapadwanj	Kapadwanj		23°02'00"	73°04'30"	1968	2008
31	Kathlal	Kapadwanj		22°54'50"	72°59'10"	1969	2008
32	Kheda	Kheda		22°45'00"	72°41'10"	1967	2008
33	Mahemdabad	Mahemdabad		22°49'30"	72°45'30"	1967	2008
34	Mahisa	Maudha		22°51'20"	73°03'40"	1970	2005
35	Nadiad	Nadiad		22°41'40"	72°52'10"	1965	2008
36	Pinglaj	Kheda		22°48'50"	72°36'20"	1967	2005
37	Savli tank	Balasinor		22°57'40"	73°06'50"	1968	2008
38	Vadol	Kapadwanj		22°58'30"	73°12'00"	1970	2005
39	Vaghroli Tank	Thasara		22°53'00"	73°17'30"	1973	2008
40	Ambaliyasan	Mehsana	Mehsana	23°27'30"	72°27'00"	1970	2008
41	Kalol	Kalol		23°15'00"	72°29'40"	1961	2008
42	Dharoi	Kheralu		24°00'00"	72°51'15"	1968	2008
43	Kadi	Kadi		23°18'00"	72°22'10"	1962	2006
44	Katosan	Mehsana		23°27'00"	72°13'00"	1967	2008
45	Kheralu	Kheralu		23°53'10"	72°37'20"	1967	2008

[illegible]	[illegible]	[illegible]		23°36'30"	72°24'40"	1961	2005
[illegible]	[illegible]	[illegible]		23°44'10"	72°48'00"	1967	2005
[illegible]	[illegible]	[illegible]		23°07'40"	72°22'40"	1972	2008
[illegible]	[illegible]	[illegible]		23°48'15"	72°23'45"	1965	2003
50	Vijapur	Vijapur		23°33'30"	72°45'15"	1967	2008
51	Visanagar	Visnagar		23°42'00"	72°33'15"	1961	2008
52	Patan	Patan		23°51'21"	72°06'58"	1961	2008
53	Sidhpur	Sidhpur	Patan	23°54'35"	72°21'30"	1961	2008
54	Wagdod	Patan		23°59'16"	72°09'15"	1971	2005
55	Badoli	Idar		23°49'30"	73°04'20"	1968	2008
56	Bayad	Bayad		23°14'00"	73°14'00"	1962	2008
57	Bhiloda	Bhiloda		23°46'10"	73°24'45"	1961	2008
58	Dantral	Khedbrahma		24°18'45"	73°02'30"	1970	2008
59	Himatnagar	Himatnagar		23°36'00"	72°57'50"	1967	2008
60	Idar	Idar		23°50'40"	73°00'30"	1967	2008
61	Khedbrahma	Khedbrahma		24°02'08"	73°02'03"	1967	2008
62	Kundlacampo	Vijaynagar		23°58'45"	73°13'10"	1970	2004
63	Limla dam	Prantij		23°24'00"	72°53'20"	1971	2008
64	Malpur	Malpur	Sabarkantha	23°21'40"	73°31'08"	1962	2008
65	Meghraj	Meghraj		23°30'30"	73°30'40"	1961	2008
66	Modasa	Modasa		23°27'45"	73°17'40"	1961	2008
67	Pal	Vijaynagar		23°58'02"	73°17'00"	1961	2005
68	Prantij	Prantij		23°25'50"	72°54'00"	1967	2008
69	Sabli	Idar		23°43'00"	73°08'00"	1969	2004
70	Shamlaji	Bhiloda		23°40'41"	73°21'58"	1964	2005
71	Vadgam	Modasa		23°20'10"	73°10'30"	1961	2008
72	Vijaynagar	Vijaynagar		24°00'20"	73°21'40"	1967	2008
73	Virpur	Idar		23°47'00"	72°56'30"	1970	2005

The maximum and minimum annual rainfall during the study period (1961 to 2008) for the above raingauge stations are presented districtwise in Figs. 4.2 to 4.8.

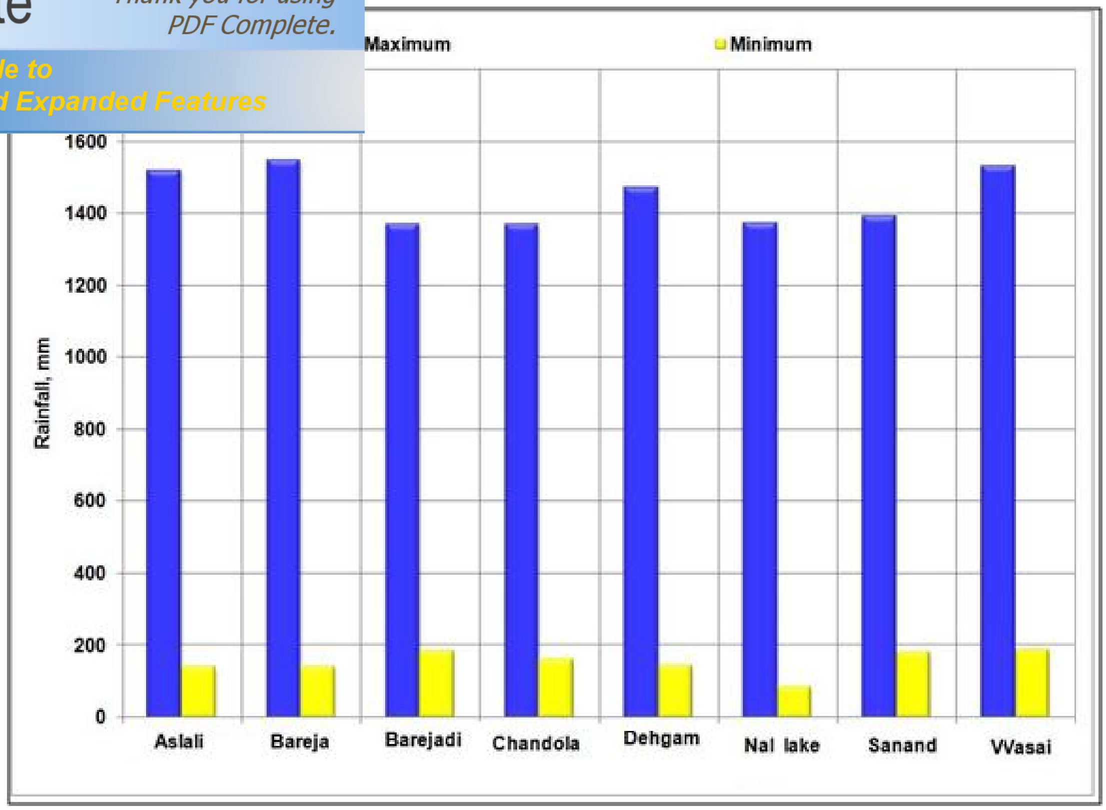


Fig. 4.2 Annual rainfall for the raingauge stations in Ahmedabad district

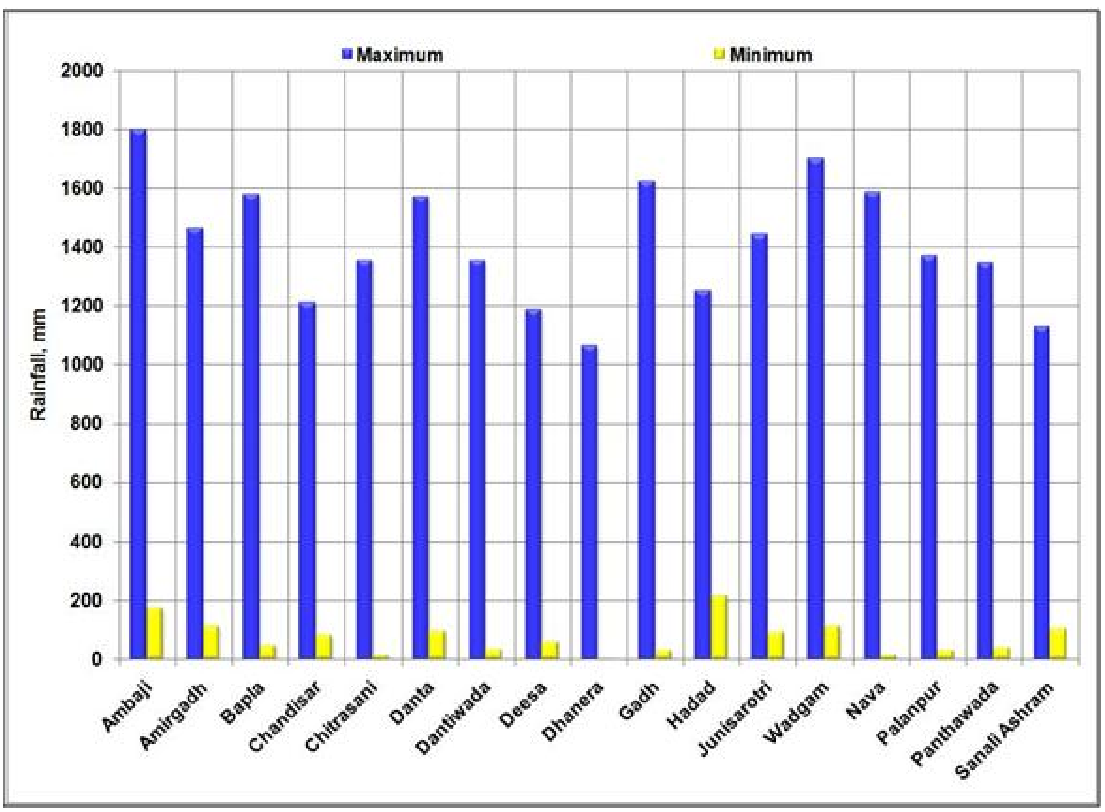


Fig. 4.3 Annual rainfall for the raingauge stations in Banaskantha district

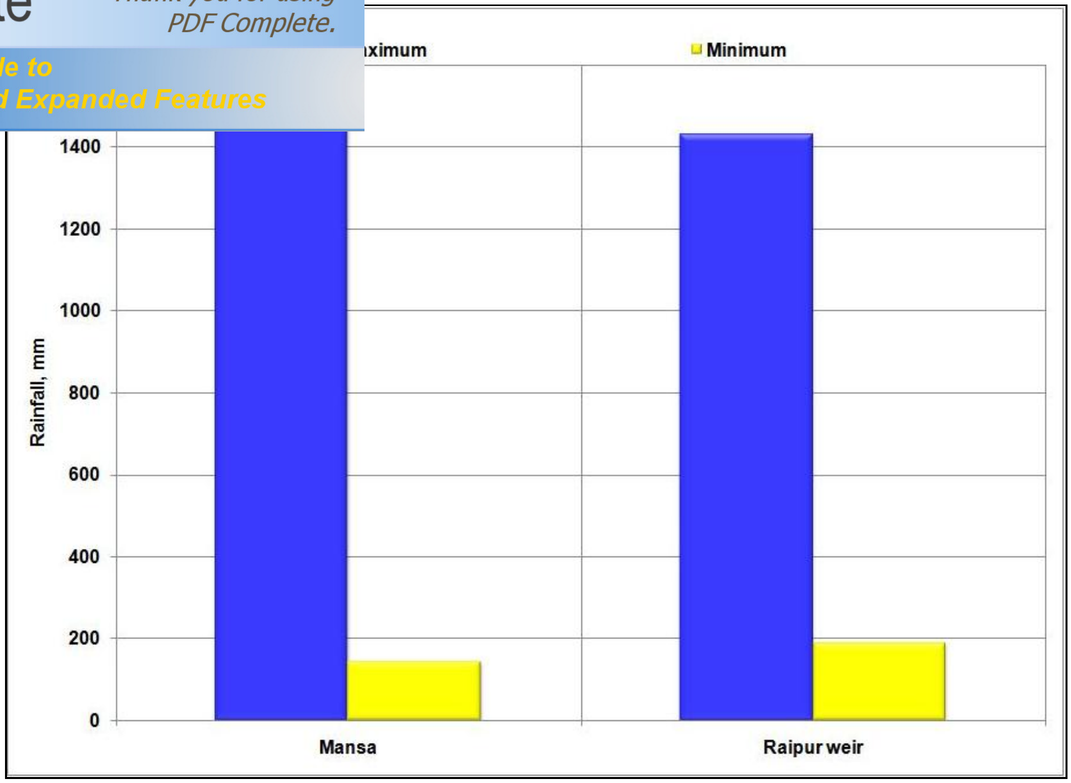


Fig. 4.4 Annual rainfall for the raingauge stations in Gandhinagar district

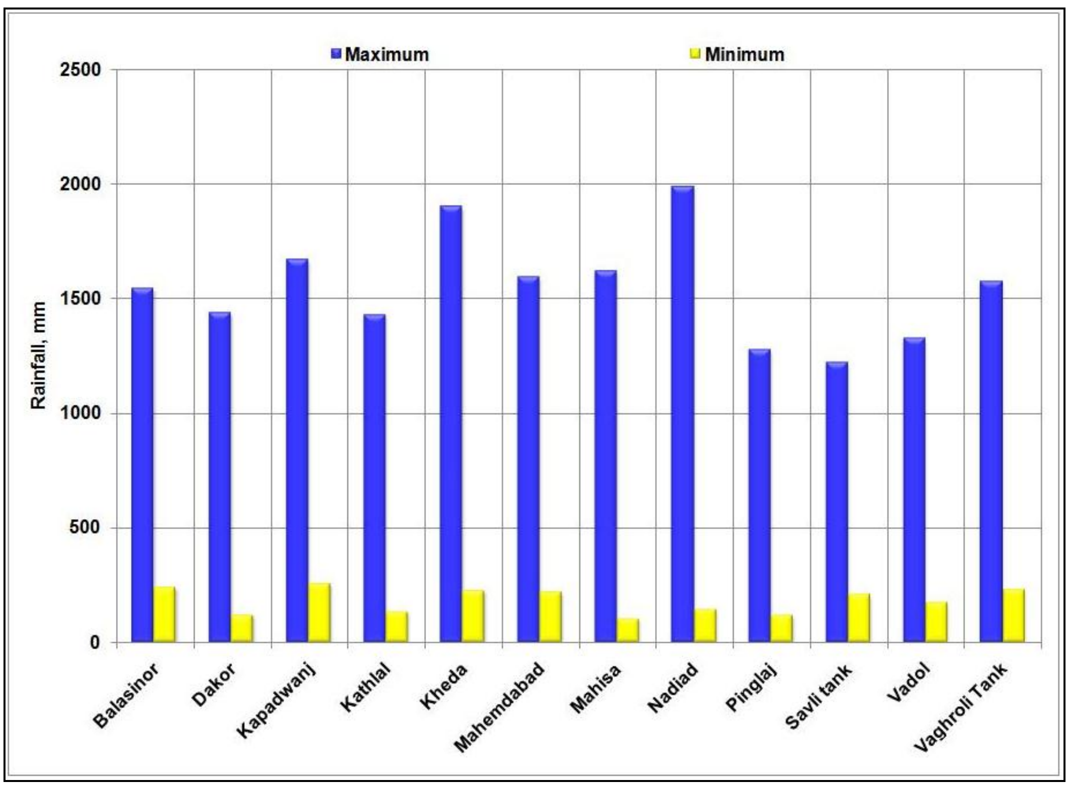


Fig. 4.5 Annual rainfall for the raingauge stations in Kheda district

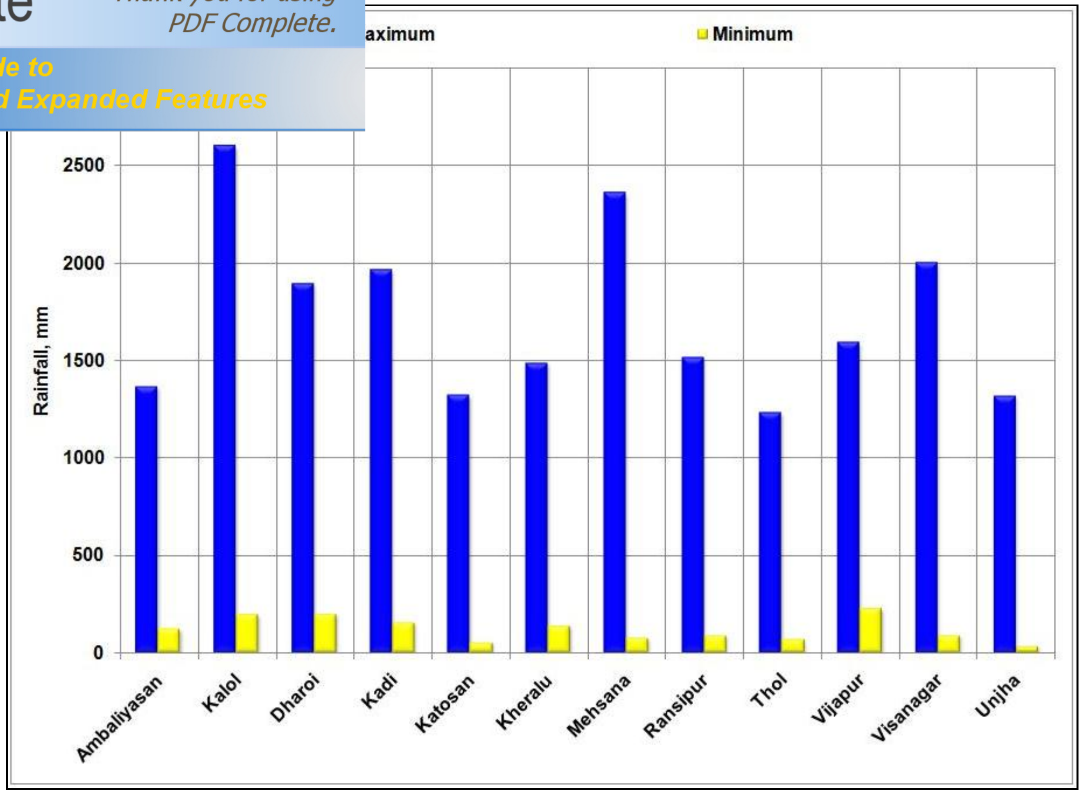


Fig. 4.6 Annual rainfall for the raingauge stations in Mehsana district

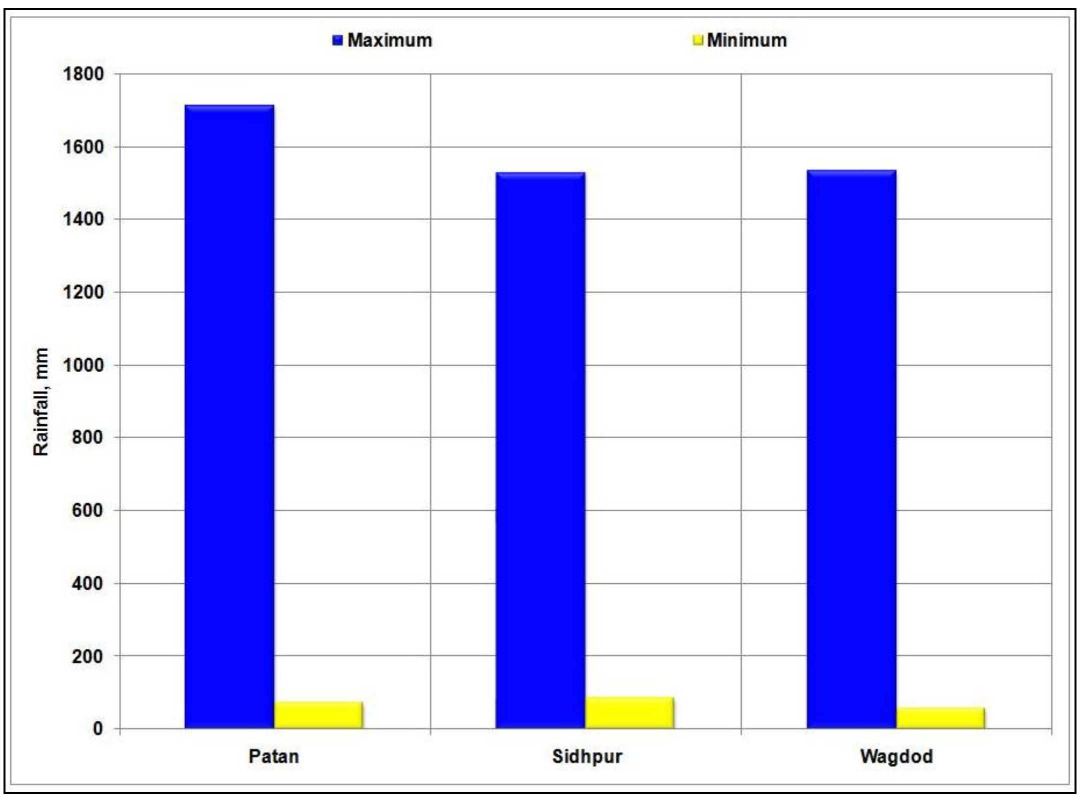


Fig. 4.7 Annual rainfall for the raingauge stations in Patan district

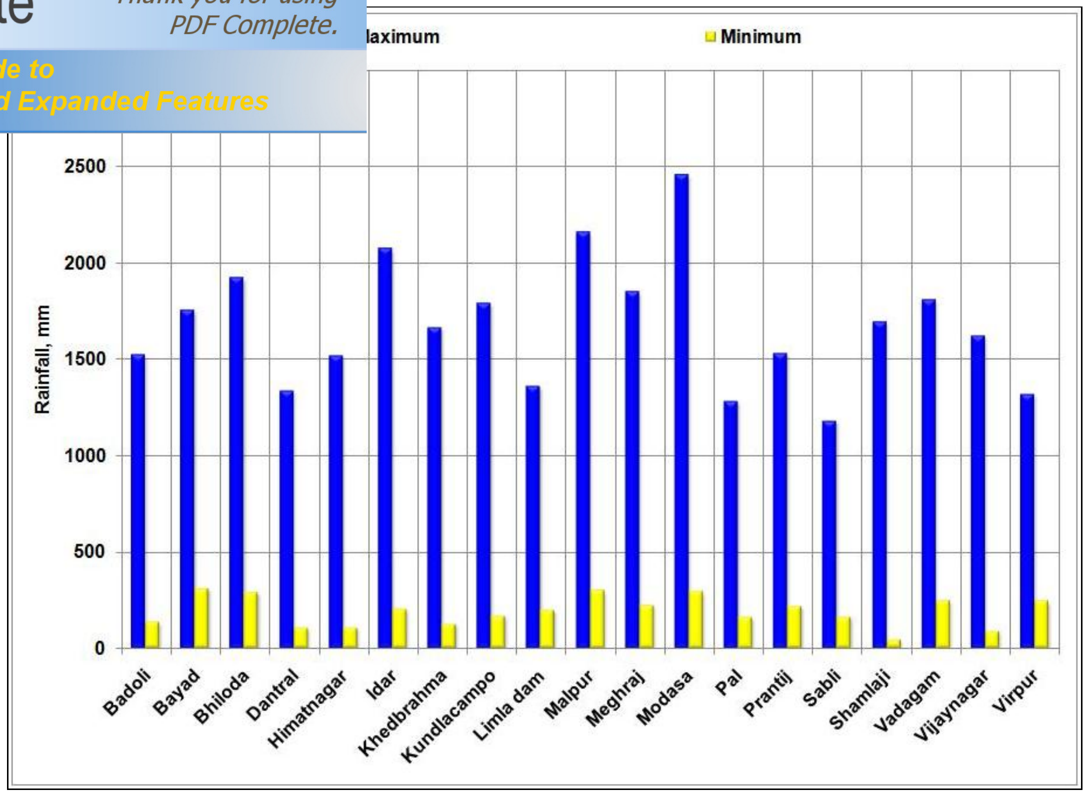


Fig. 4.8 Annual rainfall for the raingauge stations in Sabarkantha district

4.2.2 Details of Water Resources Projects

The north Gujarat region consists of major, medium and minor irrigation projects. There are 7 major irrigation schemes as given in Table 4.4.

Table 4.4 Major Irrigation Schemes in North Gujarat Region

Sr. No.	Scheme name	District
1	Dantiwada	Banaskantha
2	Dharoi	Mehsana
3	Fatehwadi	Ahmedabad
4	Hathmati	Sabarkantha
5	Meshwo	Sabarkantha
6	Sipu	Banaskantha
7	Vatrak	Sabarkantha

The details of each major irrigation schemes are obtained from Central Design Organization (CDO), Gandhinagar. From the catchment area details obtained for these schemes it was observed except for Hathmati reservoir, the other six catchment area included the adjoining state of Rajasthan. As the catchment area of Hathmati reservoir entirely lies in Gujarat State, for the present study it is n analysis the details of which are presented as below.

nment area is given in Plate 1.

Location	Vill: Fatepur, Ta: Bhiloda, Dist: Sabarkantha
Purpose	Irrigation & flood control
River	Hathmati
Area of catchment	595 km^2
Mean annual runoff in the catchment	123 Mm^3
Mean annual rainfall	864 mm
Year of commencement of construction work	1959
Year of completion	1971
Dam :	
Type	Earthen
Maximum height above the lowest point of foundation	23.62 m
Length at the top of the dam	933 m
Total Volume Content:	
Earthwork	1.2 Mm^3
Spillway Details:	
Type	Waste weir
Length	241 m
Energy dissipater	Stilling basin apron
Maximum discharge	2943 m^3/s
Type, Nos. and size of gate	Ungated
Reservoir:	
Area at full reservoir level	32.36 Km^2
Gross storage capacity	161 Mm^3

153 Mm^3

Area under submergence

a) Forest : NIL b) Waste land : NA c) Culturable : 3750 ha

No. of villages under submergence 14 partial ,6 full

(Source: http://guj–nwrws.gujarat.gov.in)

4.2.3 Soil Type Data

The general properties of soil in the study area were mentioned in Chapter 3. For the analysis of onset of monsoon, the soil moisture holding capacity data are required. The characteristics of the top soil found in the study area are obtained from various soil survey reports, prepared by various soil survey divisions in the state, as mentioned below. These are indicative values which are obtained by conducting borehole log test. These values are then analyzed for top 0.25 m soil layer for the study for all the raingauge stations and presented in Table 4.5.

Source:

1. November 2000, Land Irrigability appraisal report for the area under the command of Hadmatiya Reservoir Project , Taluka: Dantiwada, District : Banaskantha, Soil survey division, Ahmadabad, Narmada Water resources and water supply department, Govt. of Gujarat.
2. July 1998, Land Irrigability appraisal report for the area under the command of Mahdevpura water Resources Project , Taluka: Kapadwanj, District : Kheda, S.E., Soils, Drainage & Reclamation Circle, Vadodara, Narmada Water resources and water supply department, Govt. of Gujarat.
3. May 1993, Land Irrigability appraisal report for the area under the command of Kadiyara water resources project, District : Sabarkantha, S.E. Soils, Drainage & Reclamation Circle, Vadodara, Narmada & Water Resources Department, Govt. of Gujarat.
4. December 2000, Land Irrigability appraisal report for the area under the command of Kharicut Irrigation Scheme, Taluka : City, District : Ahmedabad, Soils Survey Division, Ahmedabad, Narmada Water resources and water supply department, Govt. of Gujarat.

Irrigability appraisal report for the area under the Water Resources Project, Taluka : Danta, District: Banaskantha, S.E. Soils and Drainage and Reclamation Circle, Vadodara, Narmada Water resources and water supply department, Govt. of Gujarat.

6. August 1988, 3 Decades of Soil Survey Organisation, S.E. Soils and Drainage and Reclamation Circle, Vadodara, Narmada Water resources and water supply department, Govt. of Gujarat.
7. Land Irrigability Appraisal Report for the area under the command of Sipu Reservoir Project, Taluka : Dantiwada, District : Banaskantha, Soils Survey Division, Ahmedabad, Narmada Water resources and water supply department, Govt. of Gujarat.
8. August 1998, Detailed Soil Survey Report for the Area under the command of Balaram Water Resources Project, Taluka : Palanpur, District : Banaskantha, S.E. Soils and Drainage and Reclamation Circle, Vadodara, Narmada Water resources and water supply department, Govt. of Gujarat.
9. October 2000, Land Irrigability Appraisal Report for the area under the command of Sipu Reservoir Project, Taluka : Dantiwada, District : Banaskantha, Soils Survey Division, Ahmedabad, Narmada Water resources and water supply department, Govt. of Gujarat.
10. November 1990, Mahadevpura water resources project, Taluka: Kapadwanj, District : Kheda, S.E. Soils and Drainage and Reclamation Circle, Vadodara, Narmada Water resources and water supply department, Govt. of Gujarat.
11. November 1990, Revised detailed soil survey report for the area under the command of varanasi irrigation scheme, Taluka: Kapadwanj, District : Kheda, S.E. Soils and Drainage and Reclamation Circle, Vadodara, Narmada Water resources and water supply department, Govt. of Gujarat.
12. March 1988, Detailed soil survey report of Galab Irrigation Scheme, Taluka: Thasara and Kapadwanj, District : Kheda, S.E. Soils and Drainage and Reclamation Circle, Vadodara, Narmada Water resources and water supply department, Govt. of Gujarat.
13. May 1994, Land Irrigability appraisal report for the area under the command of Vadgam Water Resources Project, Taluka : Modasa, District: Sabarkantha, S.E. Soils and Drainage and Reclamation Circle, Vadodara, Narmada & Water Resources Department, Govt. of Gujarat.

Report for the Area under the Command of Rolla
ka : Megharaj, District: Sabarkantha, S.E. Soils and Drainage and Reclamation Circle, Vadodara, Narmada & Water Resources Department, Govt. of Gujarat.

15. November 1979, Soil Survey Report for the Area under the Command of Hathmati Reservoir Project, District : Sabarkantha, Soils Survey Division, (W.R.I.), Ahmedabad, Govt. of Gujarat.
16. Soil Survey Report for the Area under the Command of Watrak Irrigation Scheme, Taluka: Malpur, District : Sabarkantha, Soils Survey Division, Ahmedabad, Govt. of Gujarat.
17. January 2001, Land Irrigability Appraisal Report for the Area under the Extended Command of Sabarmati Reservoir Project, Volume I, S.E. Soils and Drainage and Reclamation Circle, Vadodara, Narmada Water Resources and Water Supply Department, Govt. of Gujarat.
18. March 2006, Land Irrigability Appraisal Report for the Area under the Command of Mukteshwar Water Resources Project, Taluka: Wadgam, District: Banaskantha, Soil Survey Division : Gandhinagar, Soils, Drainage & Reclamation circle, Vadodara, Narmada Water Resources Water Supply and Kalpsar Department, Govt. of Gujarat.
19. May 1994, Land Irrigability Appraisal Report for the Area under the Command of Pal Water Resources Project, Taluka: Vijaynagar, District: Sabarkantha, Soils, Drainage & Reclamation circle, Vadodara, Narmada & Water Resources Department, Govt. of Gujarat.
20. May 1993, Detailed Soil Survey Report for the area under the command of Chandrana Water Resources Project, District : Sabarkantha, S.E., Soils , Drainage & Reclamation, Vadodara, Narmada & Water Resources Department, Govt. of Gujarat.

Vater (TAW) in the 0.25 m Soil Profile

		Station	Depth, mm/0.25 m soil depth
1	Ahmedabad	Aslali	37
2		Bareja	31
3		Barejadi	40
4		Chandola	40
5		Dehgam	37
6		Sanand	40
7		Nal Lake	40
8		Wasai	40
9	Banaskantha	Ambaji	40
10		amirgadh	25
11		Bapla	30
12		Chandisar	25
13		Chitrasani	25
14		Danta	40
15		Dantiwada	30
16		Deesa	30
17		Dhanera	30
18		Gadh	25
19		Hadad	40
20		Junisarotri	25
21		Nava	30
22		Palanpur	25
23		Panthawada	30
24		Sanali Ashram	40
25		Wadgam	30
26	Gandhinagar	mansa	40
27		Raipur weir	37
28	Kheda	Balasinor	37
29		Dakor	37
30		Kapadwanj	37
31		Kathlal	37
32		Kheda	37
33		Mahemdabad	37
34		Mahisa	37
35		Nadiad	37
36		Pinglaj	37
37		Savli tank	37
38		Vadol	37
39		Vaghroli Tank	37
40	Mehsana	Ambaliyasan	40
41		Kalol	40
42		Dharoi	40
43		Kadi	40
44		Katosan	40
45		Kheralu	40
46		Mehsana	40
47		Ransipur	40
48		Thol	40
49		Unjha	30
50		Vijapur	40
51		Visanagar	40
52	Patan	Patan	40
53		Sidhpur	25
54		Wagdod	40

		Badoli	31
		Bayad	37
		Bhiloda	32
58	Sabarkantha	Dantral	30
59		Himmatnagar	30
60		Idar	31
61		Khedbhrama	37
62		Kundlacampo	37
63		Limla dam	27
64		Malpur	32
65		Meghraj	32
66		Modasa	32
67		Pal	37
68		Prantij	27
69		Sabli	31
70		Shamlaji	32
71		Vadgam	32
72		Vijaynagar	37
73		Virpur	31

4.2.4 Crop Data

The details regarding the cropping pattern and major crops grown in the study area are obtained from the following sources.

1. Department of Agriculture, Krishi Bhavan, Gandhinagar.
2. Sardar Krushinagar Agriculture University, Dantiwada, Banaskantha.
   Anand Agriculture University, Anand.

The details of crop, crop length period, crop growth stages of certain major crops considered for the analysis are presented in Table 4.6 to 4.10.

Table 4.6 Details of Pearl Millet with Effective Root Zone Depth of 30 cm

Name of variety	Date of sowing	Length of growing period, days	Crop development stages		Critical growth stages	
			Stage	Days	Stage	Days
GHB 558	On set of monsoon (June 3^{rd} week to July 1^{st} week)	90ï 100	1. Emergence	04ï 05	1.Tillering	30
GHB 538			2. Seedling	15ï 30	2. Flowering	50
GHB 577			3.Tillering	30ï 35	3. Milking	70
			4. Panicle initiation	45ï 50	4. Soft dough	80
			5. Flowering	50ï 60		
			6. Milking	65ï 75		
			7. Soft dough	75ï 85		
			8. Dry husk	85ï 100		

with Effective Root Zone Depth of 50 cm

Name of variety	Date of sowing	of growing period, days	Crop development stages		Critical growth stages	
			Stage	Days	Stage	Days
GM 4	Onset of monsoon (June 3rd week to July 1st week)	85ï 90	1. Emergence	5	1. Knee high	30
Narmada Moti		85ï 90	2. Seedling	15ï 25	2.Tasseling	45
GM 6		75ï 80	3. Knee high	25ï 30	3. Silking	55
			4. Tasseling	45ï 50	4. Milky	70
			5. Silking	57ï 60		
			6. Milky	65ï 70		
			7. Grain development	70ï 75		
			8. Dry husk	75ï 80		

Table 4.8 Details of Groundnut with Effective Root Zone Depth of 45 cm

Name of variety	Date of sowing	Length of growing period, days	Crop development stages		Critical growth stages	
			Stage	Days	Stage	Days
GG 2	Onset of monsoon (June 3rd week to July 2nd week)	100-110	1. Emergence	7-10	1. Flowering	30-45
GG 5			2. Branching	15-35	2. Peg formation	31-51
GG 7			3. Flowering	30-45	3. Pod formation	40-60
GG 20	Onset of monsoon (June 2nd week to end of June)	120-130	4. Peg formation	31-51	4.Pod development	50-90
GG 10			5. Pod formation	40-60		
GG 11			6. Pod development	50-90		
GG 12						

Table 4.9 Details of Cotton with Effective Root Zone Depth of 75 cm

Name of variety	Date of sowing	Length of growing Period, days	Crop development stages		Critical growth stages	
			Stage	Days	Stage	Days
Rainfed Cotton						
GC 11	On set of monsoon (June 3rd week to July 3rd week)	230ï 250	1. Germination	04ï 05	1. Branching	50
GC 13			2. Seedling	30ï 40	2. Square	85
GC 21			3. Branching	40ï 60	3. Flowering	95
GC 23			4. Square	85	3. Boll formation	120
			5. Flower	95		
			5. Boll formation	120		
			6. Boll bursting	160		
			7. First peaking	180		
Irrigated Cotton						
Govt approved Bt cotton	3rd week of May to 1st week of July	180ï 230	1. Germination	04ï 05	1. Branching	40
			2. Seedling	20ï 30	2. Square	60
			3. Branching	30ï 50	3. Flowering	70
			4. Square initiation	60	3. Boll formation	90
			5. Flower initiation	70	6. Boll development	100
			5. Boll formation	90	7. Boll bursting	120
			6. Boll development	100	7. First peaking	140
			7. Boll bursting	120		
			8. First peaking	140		

me with Effective Root Zone Depth of 60 cm

Name of variety	Date of sowing	Length of growing period, days	Crop development stages		Critical growth stages	
			Stage	Days	Stage	Days
GT 1	On set of monsoon (June 3rd week to July 1st week)	85-90	1. Emergence	4	1. Vegetative	25
GT 2		85-90	2. Vegetative	10-30	2. Branching	35
GT 20		90-95	3. Branching	30-40	3. Flowering	50
			4. Flowering	40-60	4. Pod filling	70
Purva 1	Mid August	120	5. Pod filling	60-75		

Table 4.11 Details of Mung Bean with Effective Root Zone Depth of 45 cm

Name of variety	Date of sowing	Length of growing period, days	Crop development stages		Critical growth stages	
			Stage	Days	Stage	Days
K 851	Onset of monsoon (June 3rd week to July 2nd week)	61-68	1. Emergence	4	1. Branching	30
GM 4			2. Branching	25-30	2. Flowering	35-45
			3. Flowering	35-45	3. Pod development	50-55
			4. Pod development			

Table 4.12 Details of Guar with Effective Root Zone Depth of 60 cm

Name of variety	Date of sowing	Length of growing Period, days	Crop development stages		Critical growth stages	
			Stage	Days	Stage	Days
GG 1	2nd week of July to 4th week of July	100-110	1. Emergence	4	1. Branching	25
GG 2		95-100	2. Branching	25	2. Flowering	35-50
			3. Flowering	35-50	3. Pod development	45-60
			4. Pod development	45-60		

CHAPTER 5

METHODOLOGY

5.1 GENERAL

Daily rainfall data for 73 raingauge stations, weekly minimum & maximum temperatures, relative humidities, sunshine hours, dew point temperature and wind speed for greater than or equal to 35 years in the north Gujarat agroclimatic zone are collected from various sources mentioned in the Chapter 4.

Generally, it is observed that the dataset obtained is seldom continuous. For performing the analysis one requires a complete data set. Therefore the missing data have to be filled up using an appropriate method. It is a known fact that the climatic parameters except the rainfall are recorded for all the 365 days on daily basis while rainfall is recorded only when it occurs i.e. for the monsoon period on daily basis. For Gujarat it is observed that 94% of annual rainfall occurs in the monsoon season. From the dataset of rainfall it is observed that for the premonsoon (March to May), postmonsoon (October and November) and winter (December to February) seasons the daily values are zero for more than 98% of years except in some cases of the month of October. Thus for determining missing daily rainfall June to October months are considered. For other climatic parameters all 365 days values are considered. For the parameters other than rainfall the missing dataset is filled in using the linear trend followed by the values obtained from the past.

Hydrologic modeling and water resources assessments depend upon knowledge of the form and amount of rainfall occurring in a region of concern over a time period of interest. Rainfall varies spatially and temporally. It should be understood that both spatial and temporal variations in rainfall are important in hydrologic studies as well as in water resources planning and in agriculture planning.

ssing daily rainfall data the latitudes and longitudes of the different raingauge stations are converted to x and y coï ordinates using the Franson Coord Trans V 2.2. The raingauge stations in and around study area are utilized for forming the groups of stations to compute the missing data using cluster analysis.

Cluster Analysis

Cluster analysis is one of the statistical techniques often used in meteorology and climatology to identify homogeneous climate groups and for climate classification. The aim of the cluster analysis is to group the raingauge stations into clusters for filling in missing data. It is performed by clustering algorithms. All the clustering algorithms follow the basic four steps routine to identify homogeneous groups

(i) Calculation of the specified distance between all the raingauge stations.
(ii) Formation of a new cluster merging from the two closest entries, based on a defined criterion.
(iii) Recalculation of the distance between all the entries, and
(iv) Repetition of steps (ii) and (iii) until all entries merge into one cluster.

Data clustering algorithms can be of different types such as joining (tree clustering), two way joining (block clustering) and kï means clustering. The purpose of this joining algorithm is to join together objects into successively larger clusters, using some measure of similarity or distance. A typical result of this type of clustering is the hierarchical tree. While for other types of analyses the research question of interest is usually expressed in terms of cases (observations) or variables. It turns out that the clustering of both may yield useful results. For example, imagine a study where a researcher has gathered data on different measures of climate parameters (variables) for a sample of tropical climate (cases). The researcher may want to cluster cases (parameters) to detect clusters of parameters with similar characteristics. At the same time, the researcher may want to cluster variables (sub climate category) to detect clusters of measures that appear to tap similar sub climate characteristics. This type of problems uses two way joining algorithms. This method of clustering is very different from the joining (tree clustering) and twoï way joining. Suppose that one oncerning the number of clusters in ones cases or o "tell" the computer to form exactly 3 clusters that are to be as distinct as possible. This is the type of research question that can be addressed by the kï means clustering algorithm. For the present study the joining algorithm is of concern as forming the groups of raingauge stations are required based on the distances. Also one cannot be biased and conclude that some n number of clusters are required for grouping the stations so the kï means will not be useful and the two way joining is out of choice as ones goal for forming the groups is based on the single parameter distance between the stations. Thus for the cluster analysis joining algorithm is appropriate and hence adopted.

Hierarchical tree is a way to investigate grouping in data, simultaneously over a variety of scales, by creating a cluster tree called a dendrogram. The tree is not a single set of clusters, but rather a multiï level hierarchy, where clusters at one level are joined as clusters at the next higher level. Hierarchical tree can be agglomerative ("bottomï up") or divisive ("topï down"). Agglomerative algorithms begin with each element as a separate cluster and merge them into successively larger clusters. Divisive algorithms begin with the whole set and proceed to divide it into successively smaller clusters.

The joining or tree clustering method uses the dissimilarities/similarities or distances between objects when forming the clusters. Similarities are a set of rules that serve as criteria for grouping or separating items. The distances (similarities) can be based on a single dimension or multiple dimensions, with each dimension representing a rule or condition for grouping objects. The most straightforward way of computing distances between objects in a multiï dimensional space is to compute Euclidean distances. If one has a twoï or threeï dimensional space this measure is the actual geometric distance between objects in the space (i.e., as if measured with a ruler). However, the joining algorithm does not "care" whether the distances that are "fed" to it are actual real distances, or some other derived measure of distance that is more meaningful to the researcher; and it is up to the researcher to select the right method for her specific application. There are different distance measures available for clustering which are used in the present study given in Table 5.1.

of Distance Measures for Clustering

	Equation	Remark
Euclidean	$\text{distance}\ (x, y) = \left\{ \sum_i (x_i - y_i)^2 \right\}^{\frac{1}{2}}$	Euclidean distance
Square Euclidean distance (Seuclidean)	$\text{distance}\ (x, y) = \frac{\sum_i (x_i - y_i)^2}{V}$	Each coordinate in the sum of squares is inversely weighted by the sample variance, v, of that coordinate
Mahalanobis distance	$d(\vec{x}, \vec{y}) = \sqrt{\sum_{i=1}^{N} \frac{(x_i - y_i)^2}{\sigma_i^2}},$	Corrects data for different scales and correlations in the variables
City block metric	$\text{distance}(x, y) = \sum_i \lvert x_i - y_i \rvert$	---
Minikowski metric	$d_p(x_i, x_j) = \left(\sum_{K=1}^{d} \lvert x_{i,k} - x_{j,k} \rvert^p \right)^{\frac{1}{p}}$	---
cosine	$angle(P_1, P_2) = \cos^{-1} \frac{\vec{P_1} \cdot \vec{P_2}}{\sqrt{(\vec{P_1} \cdot \vec{P_1})(\vec{P_2} \cdot \vec{P_2})}}$	One minus the cosine of the included angle between points (treated as vectors)
correlation	distance = 1 ï r; where r = Z(x)·Z(y)/n	One minus the sample correlation between points (treated as sequences of values)
Hamming distance	---	The percentage of coordinates that differ
Jaccard	---	One minus the Jaccard coefficient (based on similarity), the percentage of nonzero coordinates that differ
Chebychev distance	$\text{distance}(x, y) = \text{maximum} \lvert x_i - y_i \rvert$	Maximum coordinate difference

When each object represents its own cluster, the distances between those objects are defined by the chosen distance measure. One then needs a linkage or amalgamation (aggregate) rule to determine when two clusters are sufficiently similar to be linked together. There are various possibilities as presented in Table 5.2. For example, link two clusters together when any two objects in the two clusters are closer together than the respective linkage distance.

MATLAB software is used for forming the clusters. Different combinations using the distance measures and linkage rules are evaluated by Cophen coefficient feature available. This measure is used to compare alternative cluster solutions obtained using different combinations of distance measures and linkage rules presented in Tables 5.1 and 5.2. Based on the groups formed using the cluster analysis, further calculations are carried out.

r Determining Clusters

	Remarks
Single	The distance between two clusters is determined by the distance of the two closest objects (nearest neighbors) in the different clusters. This rule will, in a sense, string objects together to form clusters, and the resulting clusters tend to represent long "chains."
Complete	In this method, the distances between clusters are determined by the greatest distance between any two objects in the different clusters (i.e., by the "farthest neighbors"). This method usually performs quite well in cases when the objects actually form naturally distinct "clumps." If the clusters tend to be somehow elongated or of a "chain" type nature, then this method is inappropriate.
Average	In this method, the distance between two clusters is calculated as the average distance between all pairs of objects in the two different clusters. This method is also very efficient when the objects form natural distinct "clumps," however, it performs equally well with elongated, "chain" type clusters. It is also called as unweighted pairï group method using arithmetic averages.
Weighted	This method is identical to the unweighted pairï group average method, except that in the computations, the size of the respective clusters (i.e., the number of objects contained in them) is used as a weight. Thus, this method (rather than the previous method) should be used when the cluster sizes are suspected to be greatly uneven. It is also known as weighted pairï group method using arithmetic averages.
Centroid	The centroid of a cluster is the average point in the multidimensional space defined by the dimensions. In a sense, it is the center of gravity for the respective cluster. In this method, the distance between two clusters is determined as the difference between centroids. It is also called as unweighted pairï group method using the centroid average.
Median	This method is identical to the previous one, except that weighting is introduced into the computations to take into consideration, differences in cluster sizes (i.e., the number of objects contained in them). Thus, when there are (or one suspects there to be) considerable differences in cluster sizes, this method is preferable to the previous one. It is also known as weighted pairï group method using the centroid average.
Ward	This method is distinct from all other methods because it uses an analysis of variance approach to evaluate the distances between clusters. In short, this method attempts to minimize the sum of squares of any two (hypothetical) clusters that can be formed at each step. In general, this method is regarded as very efficient; however, it tends to create clusters of small size.

Though there are number of raingauge stations in the vicinity of the raingauge station where missing data are to be calculated, it happens rarely that there is more than one station where complete data are available, for filling the missing data. An attempt is made to fill the missing data using only one rainguage station and to identify the same. Amongst the different methods available, the artificial neural network (ANN), the closest station and the non linear regression methods are used, as other methods require more than one rainguage station. After forming the groups of the raingauge stations the missing data are calculated using the ANN method, closest station method and non linear regression method.

ted station are to be filled in using the best method tation (CS) and non linear regression (NLR) methods with one raingauge station as input. Different ANN networks such as competitivecascadeï forward backpropagation, Elman backpropagation, feedï forward backpropagation, feedï forward inputï delay backpropagation, generalized regression, Hopfield recurrent, linear layer, perceptron, probabilistic neural and radial basis are explored in case for filling missing data using ANN method. For closest station method the missing data are filled in with the same set of data as present in the nearby raingauge station. While in case for non linear regression method the selected regression equation provides zero value output given the zero value input. This is required for the representation of no rain events. Thus the gamma model as presented in Eq. 5.1 is used for non linear regression models.

Gamma Model: $y = a \cdot (x_m/b)^c \cdot \exp(a/b)$ (5.1)

where,

y = missing rainfall record from the station in question

x_m = rainfall data from the selected station for finding missing record

a, b, c = constants

A nearby raingauge station (having complete data for a period which is found missing in the raingauge station in question) to the raingauge station in question, is selected as an input station. If the nearest station contained the same missing records then the next nearby station containining the complete dataset is selected as input station. When there are more than one nearby stations having complete dataset then the input station is determined based on the higher correlation coefficient value between the input station and the missing data raingauge station. Thus the groups of the raingauge stations are explored for determining the input station.

After determining the input station for filling in missing data of the raingauge station, the set of complete data (100%) in both the input and the raingauge station in question are utilized for model analysis. From these 100% dataset, 70% data are utilized for forecast and model preparation and the remaining 30%

ate the model based on different forecast and model

In order to investigate the best method based on the forecasted events, the categorical or conditional statistics quantifying the skill in the prediction of the occurrence of rain based on the familiar 2 × 2 (yes/no) contingency Table is used. A contingency Table presented in Table 5.3 is a matrix showing the frequencies of predicted and/or observed events, such as "rain" and "no rain". It gives information about the types of errors occurring in the forecast.

Table 5.3 A 2 x 2 Contingency Matrix for Conditional / Categorical Statistics

		Event observed	
		Yes	**No**
Event forecast	**Yes**	A	B
	No	C	D

The value of "A" is the number of event forecasts that correspond to event observations, or the number of hits. Value of "B" is the number of event forecasts that do not correspond to observed events, or the number of false alarms. Value of "C" is the number of noï event forecasts corresponding to observed events, or the number of misses and value of "D" is the number of noï event forecasts corresponding to no events observed, or the number of correct rejections. This 2 x 2 table will be referred in the definitions of a number of performance measures formulated for the 2 x 2 verification problem. For example based on the method for determining missing rainfall, a certain value is obtained which will be referred to the case yes for the event forecasted. Then the next step will be to choose either A or B based on the actual data observed. If the rain actually occurred then A is chosen and if not then B. Thus for the 2 x 2 contingency table the alphabets A, B, C and D will be replaced by the numeric values by categorizing each value obtained. Based on the values obtained Table 5.4 presents the definitions and equations of conditional / categorical statistics for verification of the forecasted values obtained using ANN, CS and NLR methods

Akaike's information criterion (AIC) and Bayesian's Information Criterion (BIC) of selecting the optimum model are considered for selection of the method to be used. Akaike (1974) proposed AIC as a measure of the goodness of fit of an estimated statistical model. It is based on the concept of entropy, in effect offering a relative measure of the information lost when a given model is used to

...be said to describe the tradeoff between bias and ...tion, or that of precision and complexity of the model. The AIC is not a test on the model in the sense of hypothesis testing; rather it is a tool for model selection.

Table 5.4 Details of Conditional / Categorical Statistics

Conditional / categorial statistics	Equation	Limits	Perfect score	Remarks
Bias Score, BIAS	$BIAS = \dfrac{A+B}{A+C}$	0 to infinity	1	A perfect bias score indicates the predicted rainfall area (frequency) is the same as was observed. Value less than one underforecasts rainfall. Value greater than one overforecasts rainfall.
Probability of Detection, POD	$POD = \dfrac{A}{A+C}$	0 to 1	1	The POD is sensitive only to missed events, not false alarms. POD can be increased by issuing a larger number of rain forecasts on the assumption that a greater number will be correct, usually at the cost of more false alarms.
False Alarm Ratio, FAR	$FAR = \dfrac{B}{A+B}$	0 to 1	0	FAR is sensitive only to false predictions, and not to missed events. This score can always be decreased by underforecasting the number of severe events, but only at the cost of more missed events.
Equitable Threat Score, ETS	$ETS = \dfrac{(DxA)-(BxC)}{(B+C)xN+(DxA-BxC)}$	min. value is 1/3	ï	The ETS is a modification to the CSI that takes into account the number correct forecasts of events (hits) that would be expected purely due to chance
Hanssen and Kuipers Score, HK	$HK = \dfrac{DxA-BxC}{(D+B)x(C+A)}$	ï 1 to 1	1	The HK score has the advantage that it is independent of the distribution of events and nonï events in the sample set. Put another way, for measuring the skill of the model, the HK score is appropriate because it does not depend on whether there happened to be more wet or dry days in the sample set (provided the sample set is large enough to yield stable statistics). This is why it is often called the "true skill statistic."

competing models may be ranked according to their e lowest AIC being the best.

1] (5.2)

where k is the no. of parameters, n the no. of observations and RSS is the residual sum of squares given as

$$RSS = \sum_{i=1}^{n} \left(p_i - o_i \right)^2 \tag{5.3}$$

where p_i is the predicted data points and o_i is the observed data points.

In parametric methods, there might be various candidate models with different number of parameters to represent a dataset. The number of parameters in a model plays an important role. The likelihood of the training data is increased when the number of parameters in the model is increased but it might result in overtraining problem, if the number of parameters is too large. In order to overcome this problem, one can use BIC (parametric method) which is also one of the statistical criteria for model selection. The BIC is sometimes also named the Schwarz Criterion or Schwarz Information Criterion (SIC). It is so named because Schwarz (1978) gave a Bayesian argument for adopting it.

$$BIC = n \ln\left(\frac{RSS}{n}\right) + k \ln(n) \tag{5.4}$$

where k is the no. of parameters, n is the no. of observations and RSS is the residual sum of squares.

For validating the model amounts obtained in conjunction to AIC and BIC, two more parameters presented in Table 5.5 will be used, as these are the basic parameters for testing the model amounts.

Table 5.5 Details of Goodness of Fit Parameters for Validating Model Amounts

Goodness of fit parameter	**Equation**	**Remarks**
Root mean square error, RMSE	$RMSE = \left[\sum_{i=1}^{n} \frac{(Oi - pi)^2}{n} \right]^{0.5}$	It is appropriate to quantify the error in terms of the units of the variable. Both RMSE and MAE indicate errors in the model amounts obtained.
Mean absolute error, MAE	$MAE = \frac{1}{n}\left[\sum_{i=1}^{n} \lvert o_i - p_i \rvert \right]$	

The missing sunshine hours are determined using the CROPWAT 8.0 software based on the FAO 56 guidelines. The method is derived from the air temperature (minimum and maximum temperatures) differences which are related to the in a location as an indicator of the fraction of hat reaches the earthös surface. The Hargreavesô radiation formula adjusted and validated at several weather stations, is available in CROPWAT 8.0 and hence used.

For other climatic parameters such as minimum temperature, maximum temperature, relative humidity, wind speed, etc., the missing data are filled in using the SPSS software. Here the data are filled in using linear trend, observed for the study period, for each parameter under consideration.

5.3 PROBABILITY DISTRIBUTION

Probability distribution arises from experiments where the outcome is subjected to chance. The nature of the experiment dictates which probability distribution may be appropriate for modeling the resulting random outcomes. There are two types of probability distributionï continuous and discrete. Using a probability model does not allow one to predict the result of any individual experiment but one can determine the probability that a given outcome will fall inside a specific range of values. The rainfall data is a collection of continuous random variable as it can take on any value within a finite range. The complete daily point rainfall dataset thus obtained is used for the analysis by converting it to consecutive 2, 3, 4, 5, 6, 7 and 10 days rainfall. Fig. 5.1 and 5.2 shows the illustration for determining consecutive 2 and 3 days maximum rainfall total. Similar procedure is adopted for determining consecutive 4, 5, 6, 7 and 10 days maximum rainfall total.

[illegible]	[illegible]	[illegible]	[illegible]	4	5	6	7	8	9	10	11	12	13	14	15
[illegible]	[illegible]	[illegible]	[illegible]	20	56	66	22	15	0	6	10	27	33	5	3
[illegible]	[illegible]		[illegible]5		122		37		6		37		38		
Moving 2 day total	16														
		20													
			25												
				122											
					88										
						37									
							15								
								6							
									16						
										37					
											60				
												38			
													8		
Maximum 2 day total					122										

Fig. 5.1 Illustration for computing consecutive 2 days maximum rainfall.

Date	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Rainfall, mm	1	15	5	20	56	66	22	15	0	6	10	27	33	5	3
		21			142			37			43			41	
Moving 3 day total		21													
			40												
				81											
					142										
						144									
							103								
								37							
									21						
										16					
											43				
												65			
													65		
														41	
Maximum 3 day total						144									

Fig. 5.2 Illustration for computing consecutive 3 days maximum rainfall.

There are numerous continuous probability distributions available. The selection of best fitted probability distribution will be based on AIC and BIC using the maximum likelihood method. The available sixteen continuous probability distributions are checked for the rainfall dataset (1961ï 2008) of north Gujarat agroclimatic zone and are given in Table 5.6.

ability Distributions used in the Present Study

Sr. no.	continuous probability distribution	Probability density function
1	Birnbaumï Saunders	$y = f(x\|\beta,\gamma) = \frac{1}{\sqrt{2\pi}}\exp\left\{-\frac{(\sqrt{x/\beta}-\sqrt{\beta/x})^2}{2\gamma^2}\right\}\left(\frac{(\sqrt{x/\beta}+\sqrt{\beta/x})}{2\gamma x}\right)$
2	Exponential	$y = f(x\|\mu) = \frac{1}{\mu}e^{-\frac{x}{\mu}}$
3	Extreme value	$y = f(x\|\mu,\sigma) = \sigma^{-1}\exp\left(\frac{x-\mu}{\sigma}\right)\exp\left(-\exp\left(\frac{x-\mu}{\sigma}\right)\right)$
4	Gamma	$y = f(x\|a,b) = \frac{1}{b^a\Gamma(a)}x^{a-1}e^{-\frac{x}{b}}$
5	Generalized extreme value	$y = f(x\|k,\mu,\sigma) = \left(\frac{1}{\sigma}\right)\exp\left(-\left(1+k\frac{(x-\mu)}{\sigma}\right)^{-\frac{1}{k}}\right)\left(1+k\frac{(x-\mu)}{\sigma}\right)^{-1-\frac{1}{k}}$
6	Generalized Pareto	$y = f(x\|k,\sigma,\theta) = \left(\frac{1}{\sigma}\right)\left(1+k\frac{(x-\theta)}{\sigma}\right)^{-1-\frac{1}{k}}$
7	Inverse Gaussian	$y = f(x\|\lambda,\mu) = \sqrt{\frac{\lambda}{2\pi x^3}}\exp\left\{-\frac{\lambda}{2\mu^2 x}(x-\mu)^2\right\}$
8	Logistic	$y = f(x\|\sigma,\mu) = \frac{e^{\frac{x-\mu}{\sigma}}}{\sigma\left(1+e^{\frac{x-\mu}{\sigma}}\right)^2}$
9	Logï Logistic	The variable *x* has a loglogistic distribution with location parameter μ and scale parameter $\sigma > 0$ if ln *x* has a logistic distribution with parameters μ and σ.
10	Lognormal	$y = f(x\|\mu,\sigma) = \frac{1}{x\sigma\sqrt{2\pi}}e^{\frac{-(\ln x-\mu)^2}{2\sigma^2}}$
11	Nakagami	$y = f(x\|\omega,\mu) = 2\left(\frac{\mu}{\omega}\right)^{\mu}\frac{1}{\Gamma(\mu)}x^{(2\mu-1)}e^{-\frac{\mu}{\omega}x^2}$
12	Normal	$y = f(x\|\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}}e^{\frac{-(x-\mu)^2}{2\sigma^2}}$
13	Rayleigh	$y = f(x\|b) = \frac{x}{b^2}e^{\left(\frac{-x^2}{2b^2}\right)}$
14	Rician	$y = f(x\|\sigma,s) = I_0\left(\frac{xs}{\sigma^2}\right)\frac{x}{\sigma^2}e^{-\left(\frac{x^2+s^2}{2\sigma^2}\right)}$

		$\ldots) = \frac{\Gamma(\frac{\upsilon+1}{2})}{\sigma\sqrt{\upsilon\pi}\,\Gamma(\frac{\upsilon}{2})}\left[\frac{\upsilon+\left(\frac{x-\mu}{\sigma}\right)^2}{\upsilon}\right]^{-\left(\frac{\upsilon+1}{2}\right)}$
16	Weibull	$y = f(x\mid a,b) = ba^{-b}x^{b-1}e^{-\left(\frac{x}{a}\right)^b} I_{(0,\infty)}(x)$

An effort has been made to determine the best fitted probability distribution for the given rainfall dataset in order to evaluate the rainfall characteristics of the region. The complete daily rainfall dataset obtained is used for the analysis by converting it to consecutive 2, 3, 4, 5, 6, 7 and 10 days rainfall. The backward moving window is used to obtain the consecutive 2, 3, 4, 5, 6, 7 and 10 days rainfall data. 16 different probabilities presented in Table 5.6 are applied to the dataset of one and consecutive 2, 3, 4, 5, 6, 7 & 10 days rainfall.

The AIC for probability distribution fittings is different from the Eq. 5.2 and is given as,

$$\mathrm{AIC} = 2k - 2\mathrm{In}(L) \qquad (5.5)$$

where k is the number of parameters in the statistical model, and L is the maximized value of the likelihood function for the estimated model.

Similarly BIC is an asymptotic result derived under the assumptions that the data distribution is in the exponential family.

The BIC is expressed as:

$$\mathrm{BIC} = -2\ln L + k\ln(n) \qquad (5.6)$$

where n is the number of observations, or equivalently, the sample size; k is the number of free parameters to be estimated and L is the maximized value of the likelihood function for the estimated model.

5.4 DEVELOPMENT OF REGRESSION RELATIONSHIPS

Using the fitted distribution the probability of rainfall and the respective return period will be obtained and regression models will be developed for the rainfall of different amounts applicable for water resources planning which is discussed in the following text.

lationship have been developed

Regression models for one day to ten consecutive days of annual maximum rainfall corresponding to one to 1000 years of return period.

Regression relationships of two to ten consecutive days of maximum annual rainfall with one day annual maximum rainfall.

Regression relationship for the prediction of consecutive days of maximum rainfall from one day maximum rainfall and consecutive days ranging from two to seven and ten.

Based on the fitted distribution, the probability of occurrence of a rainfall denoted by P, whose magnitude is equal to or in excess of a specified magnitude X is obtained. The recurrence interval (return period) T is given by,

$$T = {}^{1}\!/_{P} \qquad (5.7)$$

Thus the rainfall amount for a recurrence interval from 1ï 10 years in steps of 1 year, 15, 20, 25, 50, 75 and 100 years are determined using the best probability distribution fitted to the dataset, for application in drainage coefficient, design of water harvesting system, etc.

The consecutive two to seven and ten days rainfall and the recurrence interval for each of the combinations will be investigated based on the fitted probability. For the development of regression models a dataset consisting of 100 samples are selected. The sample consists of 1ï 65 years in steps of 1 year, 70ï 200 in steps of 5 years, 250ï 500 in step of 50 years, 750 and 1000 years. Out of these 100 values model formulation are carried out using 70% data (70 values) and the remaining 30% data are used to validate the model. The selection of 70 values out of 100 values is a random selection. This selection iteration procedure is carried out 35 times. Thus 35 different random models are developed and the best model based on the goodness of fit parameters is considered.

Regression relationships of two to seven and ten consecutive days of maximum annual rainfall with one day annual maximum rainfall are developed using the same approach.

ameters

Measure of the "goodness of fit" is the coefficient of correlation, r. To explain the meaning of this measure, one has to define the standard deviation, which quantifies the spread of the data around the mean:

$$s_t = \sum_{i=1}^{n} \left(\bar{o} - o_i \right)^2 \tag{5.8}$$

where s_t is the standard deviation, o_i is the observed data points and $\bar{o}$ is the average of the observed data points given by

$$\bar{o} = \frac{1}{n} \sum_{i-1}^{n} o_i \tag{5.9}$$

The quantity s_t considers the spread around a constant line (the mean) as opposed to the spread around the regression model. This is the uncertainty of the dependent variable prior to regression. One also defines the deviation from the fitting curve as

$$s_r = \sum_{i=1}^{n} \left(o_i - p_i \right)^2 \tag{5.10}$$

where s_r is the deviation from the fitting curve, p_i is the predicted data points.

Note the similarity of this expression to the standard error of the estimate given in Eq. 5.9; this quantity likewise measures the spread of the points around the fitting function. Thus, the improvement (or error reduction) due to describing the data in terms of a regression model can be quantified by subtracting the two quantities. Because the magnitude of the quantity is dependent on the scale of the data, this difference is normalized to yield

$$r = \sqrt{\frac{s_t - s_r}{s_t}} \tag{5.11}$$

where r is defined as the coefficient of correlation. As the regression model starts improving describing the data, the correlation coefficient approaches unity. For a perfect fit, the standard error of the estimate will approach $s_r = 0$ and the correlation coefficient will approach $r = 1$.

Legates and McCabe (1999) evaluated the correlation and correlation based measures widely used to examine the goodness of fit of hydrologic and hydroclimatic models. According to them these measures are oversensitive to insensitive to additive and proportional differences ns and observations. Because of these limitations, correlation-based measures can indicate that a model is good predictor, even when it is not. In the present study three basic parameters (the coefficient of determination R^2, the coefficient of Efficiency, E and the Index of Agreement, d) are used for model validation.

Coefficient of determination, R^2

The coefficient of determination is the square of the Pearsonôs Product Moment coefficient of correlation ($R^2 = r^2$) and describes the proportion of the total variance in the observed data that can be explained by the model. It ranges from 0.0 (poor model) to 1.0 (perfect model) and is given by

$$R^2 = \frac{\sum_{i=1}^{n}(o_i - p_i)(p_i - \bar{p})}{\left[\sum_{i=1}^{n}(o_i - \bar{o})^2\right]^{0.5}\left[\sum_{i=1}^{n}(p_i - \bar{p})^2\right]^{0.5}} \qquad (5.12)$$

where o_i and p_i are the observed and predicted data points and $\bar{o}$ and $\bar{p}$ are the mean of the observed and predicted data points.

Coefficient of efficiency, E

Nash and Sutcliffe (1970) defined the Coefficient of Efficiency, which ranges from minus infinity (poor model) to 1.0 (perfect model), as

$$Ej = 1.0 - \frac{\sum_{i=1}^{n}|o_i - p_i|^j}{\sum_{i=1}^{n}|o_i - \bar{o}|^j} \qquad (5.13)$$

where Ej is the coefficient of efficiency. E is the ratio of the Mean Square Error (MAE) to the variance in the observed data, subtracted from unity. For example, if the square of the differences between the model simulations and the observations is as large as the variability in the observed data, then E=0.0 and if it exceeds it, then E<0.0 (i.e., the observed mean is a better predictor than p_i). Thus, a value of zero for the coefficient of efficiency indicates that the observed mean, O, is as good a predictor as the model while negative values indicate that the observed mean is a better predictor than the model (Wilcox et al., 1990). The coefficient of efficiency represents an improvement over the coefficient of determination for model evaluation purposes because it is sensitive to l and modelï simulated means and variances; that is, if ary from 1.0 and 0.0, respectively. Due to the squared differences, however, E is more sensitive to extreme values, as is R^2. The coefficient of efficiency has been widely used to evaluate the performance of hydrologic models (Leavesley et al., 1983). Wilcox et al. (1990) used coefficient of efficiency to evaluate the performance of hydrologic models.

Index of agreement, d

Willmott (1981) sought to overcome the insensitivity of correlationï based measures to differences in the observed and modelï simulated means and variances by developing the Index of Agreement, given by

$$dj = 1.0 - \frac{\sum_{i=1}^{n} \left| o_i - p_i \right|}{\sum_{i=1}^{n} \left(\left| p_i - \overline{o}_i \right| + \left| o_i - \overline{o}_i \right| \right)^j} \qquad (5.14)$$

where dj is the index of agreement. The Index of Agreement varies from 0.0 (poor model) to 1.0 (perfect model) which is similar to the interpretation of the coefficient of determination, R^2. Willmott (1984) argued that the Index of agreement represented the ratio between the MSE and the "potential error". Potential error was defined as the sum of the squared absolute values of the distances from p_i to o to o_i and represents the largest value that can attain for each observation/modelï simulation pair. As with the coefficient of efficiency, the index of agreement represents a decided improvement over the coefficient of determination but also is sensitive to extreme values, owing to the squared differences.

The value of j in the Eq. 5.13 and Eq. 5.14 considered for the present study and as suggested by Willmott (1981) is one. The statistic E1 termed as the modified coefficient of efficiency has the desired properties not inflated by squared values and is commensurate with d1 termed as the modified index of agreement. In addition, it is appropriate to quantify the error in terms of the units of the variable.

Inequality coefficient, U

The inequality coefficient is a simulation statistics related to the RMSE, defined as under

(5.15)

The numerator is the root mean square error. If U=0 then p = o and there is a perfect fit. If U=1, then p Í o and it lacks predicative value.

These measures, or absolute error measures (nonï negative statistics that have no upper bound), include the squareï root of the mean square error or RMSE (RMSE = MSE$^{0.5}$) and the mean absolute error, MAE, presented in Eqs. 5.16 and 5.17 , which describe the difference between the model simulations and observations in the units of the variable. Experience using MAE and RMSE shows that in general, RMSE > MAE for the range of most values. The degree to which RMSE exceeds MAE is an indicator of the extent to which outliers (or variance in the differences between the modeled and observed values) exist in the data. (Legates and McCabe, 1999).

$$RMSE = \left[\sum_{i=1}^{n} \frac{(Oi - pi)^2}{n} \right]^{0.5} \quad (5.16)$$

$$MAE = \frac{1}{n} \left[\sum_{i=1}^{n} \left| o_i - p_i \right| \right] \quad (5.17)$$

The models developed present the relationship between the return period and the rainfall of different amount of interest applicable for water resources planning. For agricultural planning particularly for determining the drainage coefficients for the study area it is assumed that 15 % of the rainfall infiltrates into the soil and the remaining 85 % constitutes the runoff (Source: Technical Advisory Report 2009, Sardar Krushinagar Dantiwada Agriculture University). The drainage coefficients is computed for the study area based on the models developed.

5.5 CHARACTERISTICS OF CLIMATIC DATA

Analysis related to the numerical values is the basis of statistical analysis. The statistical analysis of all the climatic parameters is performed to determine the general characteristics of the data. The available daily data for each climate parameter is thus converted to different time scales such as weekly, decadal, nual for further analysis. For monsoon period June,

er months are considered.

Rainfall Data

Rainfall is a variable parameter with respect to time and location. Any type of analysis based on the past record would not represent the climate accurately unless the length of the record is adequate. Mockus (1960) presented an equation for evaluating the adequacy of the length of record for a given level of significance

$$N = (4.3 t_{10} \log R)^2 + 6 \qquad (5.18)$$

where,

N = minimum acceptable length of records,

t_{10} = Student's t value at 90% significance level and (N – 6) degrees of freedom,

R = Ratio of 100 years maximum event to 2 years maximum event

The Mockus equation is a nonlinear equation with unknown N on both sides of equal sign. The calculation of the minimum acceptable length of record is possible through an iterative search through the Eq. 5.18.

The above equation parameters are modified by determining the R value above using the fitted distribution values obtained for respective raingauge stations. The length obtained using the modified equation will be compared with the Mockus equation.

$$N = (4.3 t_{10} \log R_{mod})^2 + 6 \qquad (5.19)$$

where,

N = minimum acceptable length of records,

t_{10} = Student's t value at 90% significance level and (N – 6) degrees of freedom,

R_{mod} = Ratio of 100 years maximum event to 2 years maximum event for the fitted distribution

Coefficient of variation, C_v

$$C_v = \sigma / \bar{X} \qquad (5.20)$$

where σ = the standard deviation and

$\bar{X}$ = the mean of the data points.

of rainfall. This measure is indicative of dependability percentage. The threshold levels for C_V for any interpretation are presented in Table 5.7.

Table 5.7 Threshold Values for Coefficient of Variation

Timescale	**Threshold value**
Daily	< 250 %
Weekly	< 150%
Monthly	<100%
Seasonal	<50 %
Yearly	<25%

If C_V is within the threshold limits of variability, it is considered that the rainfall is dependable (Singh et al. 2004b).

The symmetry of the rainfall distribution curve is measured as its skewness and given as

$$skewness = \frac{M_3^2}{\nu^3} \qquad (5.21)$$

where M_3 is the third moment about mean and 3 is the variance.

The peakedness or flatness of the rainfall distribution curve is observed through its kurtosis

$$kurtosis = \frac{M_4}{\nu^2} \qquad (5.22)$$

where M_4 is the fourth moment about mean.

In order to study the heterogeneity of rainfall amounts over an area, a modified version of Oliver's (1980) Precipitation Concentration Index (PCI) is used. This index is described as

$$PCI = \frac{\sum_{i=1}^{12} P_i^2}{\left(\sum_{i=1}^{12} P_i\right)^2} x100 \qquad (5.23)$$

where P_i is the rainfall amount of the i^{th} month and annually calculated for each of the raingauge stations. The PCI denotes uniformity of monthly distribution in a year over a particular station or the interannual variability. PCI values below 10 indicate a uniform, monthly rainfall distribution in a year. Values from 11 to 20 denote seasonality and values above 20 correspond to climates with substantial monthly variability (Oliver, 1980).

l climate series of rainfall, minimum and maximum temperatures, minimum and maximum relative humidities, sunshine hours and average wind speed are carried out. Trend in the climate parameter at a particular station is examined by applying the Kendall rank correlation test and the regression analysis.

The Mannï Kendall trend test (Mann, 1945; Kendall, 1975) is based on the correlation between the ranks of a time series and their time order. For a time series X = {x1, x2, . . ., xn}, the test statistic is given by Kendall rank statistic which is computed as

$$S = \sum_{i>j} a_{ij} \tag{5.24}$$

where

$$a_{ij} = \mathrm{sign}(x_i - x_j) = \mathrm{sign}(R_j - R_i) \begin{cases} =1 & x_i < x_j \\ =0 & x_i = x_j \\ =-1 & x_i > x_j \end{cases} \tag{5.25}$$

and R_i and R_j are the ranks of observations x_i and x_j of the time series, respectively.

As can be seen from Eq. 5.25, the test statistic depends only on the ranks of the observations, rather than their actual values, resulting in a distribution free test statistic. This is true because if data were to be transformed to any distribution, the ranks of the observations would remain the same. Distributionï free tests have the advantage that their power and significance are not affected by the actual distribution of the data. Under the assumption that the data are independent and identically distributed, the mean and variance of the S statistic in Eq. 5.24 above are given by (Kendall, 1975) as

$$E(S) = 0 \tag{5.26}$$

and

$$V_0(S) = n(n-1)(2n+5)/18 \tag{5.27}$$

where, n is the number of observations. The existence of tied ranks (equal observations) in the data results in a reduction of the variance of S to become

$$\sum_{j=1}^{mt} t_j(t_j - 1)(2t_j + 5)/18 \qquad (5.28)$$

where,

mt = number of groups of tied ranks, each with t_j tied observations.

Kendall (1975) also shows that the distribution of S tends to normality as the number of observations becomes large. The significance of trends can be tested by comparing the standardized variable U_z in Eq. 5.29 with the standard normal variate z at the desired significance level α, where the subtraction or addition of unity in Eq. 5.29 is a continuity correction.

$$U_z = \begin{cases} = \dfrac{S-1}{\sqrt{V_0^*(S)}} & S > 0 \\ = 0 & S = 0 \\ = \dfrac{S+1}{\sqrt{V_0^*(S)}} & S < 0 \end{cases} \qquad (5.29)$$

When there is an absence of a trend in the data series, the value of U_z lies between the limits $\pm$ 1.64 at the 95% level of confidence.

Regression analysis is conducted with time as the independent variable and annual series of respective climate parameter as the dependent variable. A linear equation,

$$Y = m X + c \qquad (5.30)$$

is fitted by regression. Slope of the regression line, m indicates per year increase or decrease in rainfall. Significance of the slope is tested by determining the tï value with the following equation

$$t = \left| \frac{r\sqrt{N-2}}{\sqrt{1-r^2}} \right| \qquad (5.31)$$

where r is the correlation coefficient between Y and X. The null hypothesis (H_0: Slope, m is not significantly different from zero) is rejected if calculated value of t is more than the tabulated value ($t_{1ï\,\alpha/2}$, degrees of freedom) obtained from the standard, t distribution Tables.

The World is facing severe problems of floods and droughts due to the effect of climate change. Daily predictions and intensity of rainfall would help in planning the measures to be adopted, for overcoming the same. The analysis of concentration of intensity of rainfall also helps in water resources planning. The concentration of rainfall intensity at a particular region will help in identifying the areas of high and low intensities. Then it will facilitate to regulate the flows from high intensity areas towards low intensity ones.

In statistical terms the daily rainfall distribution of its amount and frequencies are generally represented by negative exponential distributions. This is so because, in classifying and tabulating the daily rainfall amounts by length, their frequencies decrease exponentially, starting with the lowest class. Therefore, in a given period and place where many small daily amounts of rainfall occur, few large daily amounts of rainfall are also observed. These sparse large amounts may, however, have a considerable weight, i.e. they represent a notable percentage in the total amount of rainfall at the given place. Consequently, their occurrence in any given year may have a decisive effect on hydrologic input. In order to determine the relative or percentage impact of the different classes of daily rainfall and, especially, to evaluate the weight of the largest amounts in the total amount, the study analyses the accumulated percentage of rainfall Y contributed by the accumulated percentage of days X on which it took place. These percentages are related to positive exponential curves, termed normalized rainfall curves (NRC). Such functions are of the kind

$$Y = a\,X \exp(b\,X) \qquad (5.32)$$

where a and b are constants.

Soman and Kumar (1990) analysed the daily rainfall at 365 Indian stations for the 80 year period, 1901ï 1980. The rainfall data relate to the southï west monsoon season from June to September (122 days), which accounts for the major part of the annual rainfall over most parts of the country. For each of the station the rainï days are arranged in ascending order of rain amount, and the association between the cumulated percentage rain amount (Y) and the cumulated days (X), designated as the normalized rainfall curve, hown that X and Y are related by the equation

$$Y = X \exp\left[-b(100-X)^{c}\right] \quad (5.33)$$

where b and c are empirical constants that depend on the coefficient of variation (C_v) of the rainfall series.

The statistical structure of daily precipitation can be analyzed by the means of concentration curves that relate the accumulated percentage of precipitation Y contributed by the accumulated percentage of rain days X on which it took place, (Martin ï Vide, 2004). These curves are adjustable through exponential functions such as Eq. 5.32. A concentration index (COIN), defined on these curves enables the contrast or concentration of the different daily amounts to be evaluated. COIN is used to represent the distribution and intensity of rainfall. This index, which is supported by exponential curves of the type given by Eq. 5.32, evaluates the differences between the rainfall percentages contributed by the different classes. The present study methodologically attempts to determine the structure of the accumulated rainfall amounts contributed by the accumulated number of rainfall days.

In terms of climatology, the term rain day indicates a day on which a measurable amount of rain i.e 0.1 mm or more has been recorded at any station. This is different from what is known as rainy day by Indian Meteorological Department (IMD) which defines a day with a rain amount of 2.5 mm or more. The relation between these two parameters was dealt with by Soman and Kumar (1990), which will also be studied for the present area.

The present study deals with the detailed study regarding the spatial and temporal distribution of rainfall at 73 raingauge stations having varying rainfall in intensity and amounts. As an example consider a hypothetical raingauge station to understand the methodology for calculating the COIN. The rainfall data are distributed among different classes from 0.1ï 0.9 mm with class interval of 1 and are presented in Table 5.8. The frequencies in each class are obtained from the observed rainfall during the study period and denoted as ni.

From Table 5.8 one can learn that there are total 205 rainy days observed during the study period amounting to 2281.50 mm of rainfall. 14 days were recorded

…nfall representing 5.36 % of total 205 rainy days and … rainfall. Highest frequency of 37 days (i.e 24.88 ï 6.83 … %) was recorded for rainfall amount of 1 to 1.9 mm. Maximum rainiest day is observed in the class of 216.0ï 216.9 with frequency of one. Fig. 5.3 represents a normalized rainfall curve for some Aslali raingauge station.

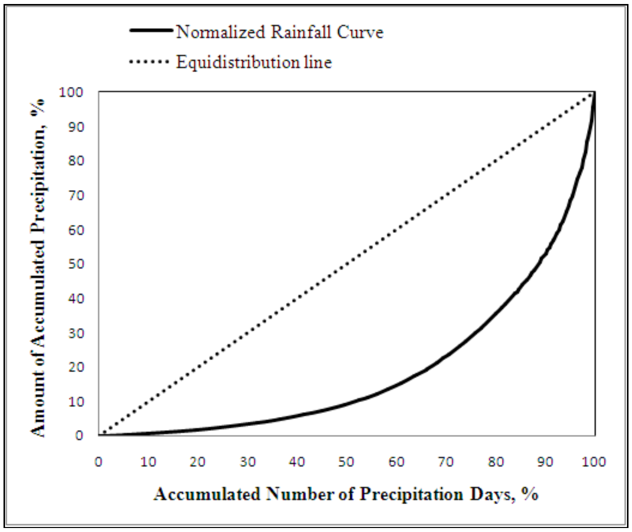


Fig. 5.3 Normalized rainfall curve (NRC) for Aslali raingauge station

Table 5.8 Frequency Distribution, Accumulated Percentage of Rainy Days and Accumulated Percentage of Rainfall Amount for Aslali Raingauge Station

Class	Midpoint	ni	∑ni	Pi	∑Pi	∑ni (%) = X	∑Pi (%) = Y
1	2	3	4	5=2x3	6	7	8
0.10 ï 0.90	0.50	14.00	14.00	7.00	7.00	6.83	0.31
1.00 ï 1.90	1.50	37.00	51.00	55.50	62.50	24.88	2.74
2.00 ï 2.90	2.50	32.00	83.00	80.00	142.50	40.49	6.25
3.00 ï 3.90	3.50	12.00	95.00	42.00	184.50	46.34	8.09
4.00 ï 4.90	4.50	13.00	108.00	58.50	243.00	52.68	10.65
5.00 ï 5.90	5.50	9.00	117.00	49.50	292.50	57.07	12.82
6.00 ï 6.90	6.50	12.00	129.00	78.00	370.50	62.93	16.24
7.00 ï 7.90	7.50	8.00	137.00	60.00	430.50	66.83	18.87
8.00 ï 8.90	8.50	4.00	141.00	34.00	464.50	68.78	20.36
9.00 ï 9.90	9.50	5.00	146.00	47.50	512.00	71.22	22.44
10.00 ï 10.90	10.50	6.00	152.00	63.00	575.00	74.15	25.20
11.00 ï 11.90	11.50	7.00	159.00	80.50	655.50	77.56	28.73
12.00 ï 12.90	12.50	7.00	166.00	87.50	743.00	80.98	32.57
13.00 ï 13.90	13.50	1.00	167.00	13.50	756.50	81.46	33.16
14.00 ï 14.90	14.50	5.00	172.00	72.50	829.00	83.90	36.34
15.00 ï 15.90	15.50	1.00	173.00	15.50	844.50	84.39	37.02
16.00 ï 16.90	16.50	5.00	178.00	82.50	927.00	86.83	40.63
17.00 ï 17.90	17.50	3.00	181.00	52.50	979.50	88.29	42.93
18.00 ï 18.90	18.50	3.00	184.00	55.50	1035.00	89.76	45.36
19.00 ï 19.90	19.50	6.00	190.00	117.00	1152.00	92.68	50.49
20.00 ï 20.90	20.50	3.00	193.00	61.50	1213.50	94.15	53.19
30.00 ï 30.90	30.50	1.00	194.00	30.50	1244.00	94.63	54.53
40.00 ï 40.90	40.50	1.00	195.00	40.50	1284.50	95.12	56.30
50.00 ï 50.90	50.50	2.00	197.00	101.00	1385.50	96.10	60.73
66.00 ï 66.90	66.50	2.00	199.00	133.00	1518.50	97.07	66.56

[illegible]	[illegible]	[illegible]00	200.00	67.50	1586.00	97.56	69.52
[illegible]	[illegible]	[illegible]00	201.00	92.50	1678.50	98.05	73.57
[illegible]	[illegible]	[illegible]00	202.00	99.50	1778.00	98.54	77.93
[illegible]	[illegible]	[illegible]00	203.00	116.50	1894.50	99.02	83.04
170.00 ï 170.90	170.50	1.00	204.00	170.50	2065.00	99.51	90.51
216.00 ï 216.90	216.50	1.00	205.00	216.50	2281.50	100.00	100.00
	Total	**205.00**		**2281.50**	**29136.00**	**2407.81**	**1277.06**

Now for a NRC, a bisector of a quadrant is termed as an equidistribution line representing an ideal case, having the perfect distribution of the daily rainfall. The concentration (or daily irregularity) can be considered to be a function of the relative separation of the equidistribution line. For comparing the raingauge stations consider another raingauge station named Pal.

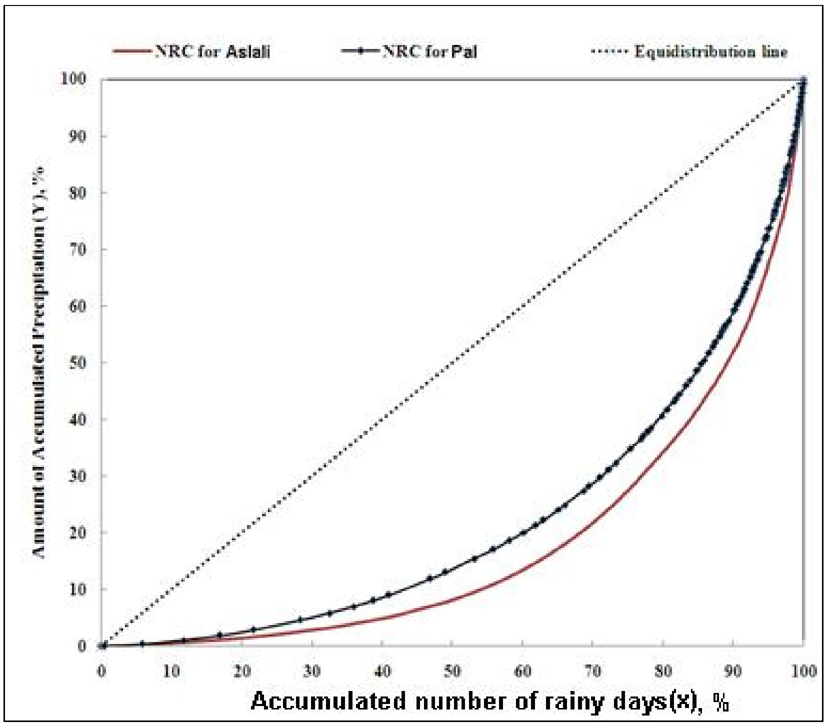


Fig. 5.4 Normalized rainfall curve (NRC) for Pal and Aslali raingauge stations

From Fig. 5.4, it can be said that Aslali stationó polygonal line represents a region with greater concentration or irregularity than that of Pal. Also comparing total amount of the rainfall for 10% of the rainiest days, it is 41% and 47.91% of the total amount of the rainfall in case of Pal and Aslali respectively. Also comparing total amount of the rainfall for 70% of the rainiest days it is 95 % and 96.93 % of the total amount of the rainfall in case of Pal and Aslali respectively Thus in general it can be concluded that at Aslali for any given percentage of the rainiest days a higher percentage of the total annual rainfall amount occurs compared to the percentage of the total annual rainfall amount at Pal for the

the rainiest days. The above mentioned polygonal line ... tration curve or Lorenz curve, widely used in many areas (Martin-Vide, 2004).

The area enclosed by the bisector of the quadrant is denoted as S and the polygonal line provides a measure of concentration, because the greater the area, the greater is the concentration. The Gini concentration index will serve to quantify it and is defined by

$$\text{Gini index} = 2S/10,000 \tag{5.34}$$

The concentration curve of the Aslali station is presented in Fig. 5.3. Now the aboveï mentioned method can be improved by substituting the polygonal lines by the exponential curves of the type given in Eq. (5.32). The determination of constants a and b, by means of the leastï squares method, is as follows:

$$\ln a = \frac{\sum X_i^2 \sum \ln Y_i + \sum X_i \sum X_i \ln X_i - \sum X_i^2 \sum \ln X_i - \sum X_i \sum X_i \sum X_i \ln Y_i}{N\sum X_i^2 - \left(\sum X_i\right)^2} \tag{5.35}$$

$$b = \frac{N\sum X_i \ln Y_i + \sum X_i \sum \ln X_i - N\sum X_i \ln X_i - \sum X_i \sum \ln Y_i}{N\sum X_i^2 - \left(\sum X_i\right)^2} \tag{5.36}$$

After determining the constants, the definite integral of the exponential curve between 0 and 100 represents the area A' under the curve

$$A' = \left[\frac{a}{b} e^{bx}\left(x - \frac{1}{b}\right)\right]_0^{100} \tag{5.37}$$

The area between the equidistribution line and polygonal line is Sôand the area between the equidistribution line and X = 100 is the difference between 10,000/2 and A'.

Thus $$S' = \frac{10,000}{2} - A' \tag{5.38}$$

From this value, daily rainfall concentration index, which resembles that of Gini index, can be defined as

COIN = 2Sô10,000 or simply COIN = Sô5,000 (5.39)

JDY PERIOD

ogic project related with irrigation, hydropower or flood control, it is necessary to determine the areal and time distribution of the greatest rainfall associated with a rainstorm and to evaluate the average depth of rainfall over a specified area during the storm. The specified area for such a hydrologic project is the natural drainage basin which is called a river catchment. By definition, a design storm of a catchment is an estimate of the highest rainfall of a specified recurrence interval over the catchment which is accepted for use in determining the spillway design flood.

Three types of design storms are commonly used for deriving spillway design floods: (i) Standard Project Storm (SPS), (ii) Probable Maximum Storm (PMS) or Probable Maximum Precipitation (PMP), and (iii) Frequency based storms.

The Standard Project Storm (SPS) is the most severe rainstorm that has actually occurred over the catchment during the period of available records. It is used in the design of all water projects where not much risk is involved and economic considerations are taken into account. The probable maximum storm, also called the probable maximum precipitation (PMP), over a river basin refers to that amount of rainfall depth that is close to the physical upper limit for a given duration over a particular drainage area. WMO (1986) defines PMP as the greatest depth of precipitation for a given duration that is physically possible over a particular area and geographical location at a certain time of the year. Estimates of PMP are required for calculating the resulting probable maximum flood (PMF) hydrograph which is the design flood for spillways of large dams, where no risk of failure can be accepted. An estimate of PMP is made either by a statistical method in which a very large return period value of rainfall depth is calculated or by the physical method in which major historical rainstorms are moisture maximized. It is generally determined from the greatest storm rainfall depths associated with severe rainstorms and from increasing this rainfall in accordance with meteorologically possible increases in the atmospheric factors that contribute to storm rainfall. A design flood can be estimated using a frequency based method or rainfall runoff method. The former involves a frequency analysis of longï term streamflow data at a site of interest. When such data are not available, then a frequency analysis of rainfall data is performed and

...noff model to get the design flood. The rainfall runoff ...conceptual, or physically based. On the other hand, regional frequency analysis can also be employed to obtain the design flood. The index method is one of the most popular regional frequency analysis methods.

The derivation of design storm rainfall for a drainage catchment requires use of long period rainfall data and other meteorological data for stations in and around the catchment. The index and catchment area maps are required to identify the number of raingauge stations in and around the catchment area. A detailed hydrometeorological study for the catchment of the Hathmati major irrigation project and Guhai Medium Irrigation Project in north Gujarat region are carried out to provide estimates of the design storm rainfalls for different return periods and the Probable Maximum Precipitation (PMP) likely to be experienced by the catchment using rainfall data for the period 1961 to 2008. The PMP rain depths are used to check the adequacy of the current spillway capacity of the dams constructed. The results of this study are useful for assessing the flood behaviour of a river as well as in many hydrologic design problems or are useful in evaluating the existing hydraulic structures and the effect of climate change if any.

Runoff in the catchment is mainly generated from rainfall occurring in the catchment during June to September. The assessment of total rainfall over the catchment during the individual months and the year as a whole is of vital importance to determine the net availability of water that runs off into the river. Mean monthly, seasonal and annual rainfall and number of rainy days over the catchment upto the dam site have been estimated by Theissen polygon method.

An attempt has been made to determine the highest areal rainfalls for the whole catchment for 1 to 5 days durations. For this purpose the daily rainfall data of the stations in the catchments are analyzed for the period 1961 to 2008 and for each year one heaviest rainstorm that was sustained for 3 to 5 days is selected.

Storm selection

For determining design storm depths, only pertinent storms are selected for analysis. The storm selection is facilitated by a detailed meteorologic study of major storms in the region of the project watershed. As a guideline, a value of 2.5

watersheds in semiarid regions, and a value of 5 cm gions . Only the storms with a daily rainfall equal to or greater than the threshold value are selected for further analysis. Sometimes a heavy storm may be preceded or followed by another storm just short of the threshold value. If the total rainfall depth of the two storms on 2 days equals or exceeds the 2 day threshold value, then both storms are included in the analysis.

After obtaining a suitable severe rainstorm data base, the following four methods are generally used for estimation of the SPS or PMP design storm rainfall

(i) Depthï Duration analysis

(ii) Depthï Areaï Duration analysis

(iii) Storm transposition

(iv) Statistical method

The main objective of these methods is to estimate the highest rainfall that might occur over the catchment. In estimating the PMP, the highest observed rainfall is maximized for a moisture maximization factor (MMF). For the present study the depthï duration method and statistical method are considered for estimating the highest rainfall. In case of statistical method, for different return periods from 2 to 100 years using annual maximum rainfall series of the catchment by applying the methodology given in sections 5.3 and 5.4, the one day and consecutive 1 to 5 daysômaximum rainfalls are determined.

Depth duration method

Frequency of occurrence of 48 (from 1961 to 2008) heavy rainspells which affected the catchment are observed. Daily aerial rainfall during each of these 48 rainstorms are worked out and among them 10 severe rainstorms are considered for further analysis. The maximum point rainfalls for 1 to 5 days durations for these 10 severe rainstorms will be used to determine the isohyetal maps. With a view to obtaining the highest areal rain depths for different durations over the catchment, the areal average rain depths are plotted against their duration. Such a curve is called the depthï duration (DD) curve. The curve enveloping all such curves is then drawn. The enveloping curve gives design storm rainfall for different durations over the catchment.

ximization is to determine the amount of increase in rainfall of a storm due to physically possible alterations in the meteorological factors producing the storm. The physical factors can be distinguished as

1. Mechanisms causing atmospheric moisture to precipitate and
2. The moisture content of the air mass responsible for the storm.

In general, it is difficult to manipulate physical mechanisms for increased precipitation or increase mechanical efficiency of a storm. In practice, storm maximization therefore is not carried out in this way. Furthermore, the mechanisms producing intense rainfall can be reasonably assumed to be highly efficient and may likely be near maximum efficiency. Storms are therefore, maximized for moisture content of the air mass.

The PMP for different durations over an area is derived by maximizing the highest rainfalls obtained for major historical rainstorms that have occurred over the area. This maximization consists of simply multiplying the highest rainfall values by the moisture maximization factor (MMF). The MMF is a ratio of the highest amount of moisture recorded in the study area during the period when the storm occurred to the amount of moisture recorded during the storm. The objective of maximization is to determine the physical upper limit of rainfall which would result if the moisture available to the storm is maximum. Obviously, the most important factor in the moisture maximization is the estimation of moisture or precipitable water available in the atmosphere.

The MMF therefore is determined on the basis of 12ï hour or 24ï hour maximum persisting storm and the maximum ever recorded persisting dew point for the area. Both storm and maximum dew points are reduced pseudoï adiabatically to the 1000 mb level by means of Fig. 5.5 so that dew points obtained at different elevations are comparable. Figure 5.6 gives values of precipitable water (mm) between 1000 mb surface and various pressure levels up to 200 mb in a saturated pseudoï adiabatic atmosphere as a function of the 1000 mb dew point.

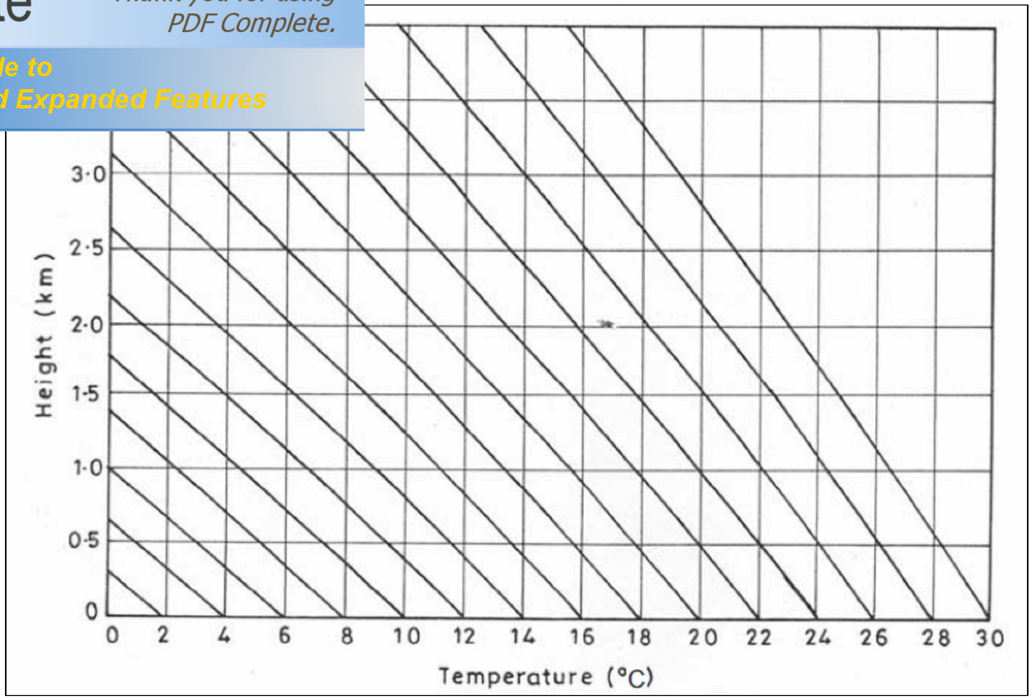


Fig. 5.5 Pseudoï adiabatic diagram for dew point reduction to 1000 mb.

Storm dew point and maximum dew point

Because the storm occurs for several hours, it is desirable to compute the most persistent value of the dew point from observations made at regular intervals of time. In practice, the highest storm dew point persisting over 12 hours or 24 hours is used; this could also be an average value over that time period.

The maximum dew point is obtained from an analysis of historical data. The calendar period of 15 days during which the storm has occurred is marked. The dew point data corresponding to this period is gathered for each of 25 to 30 years. The highest persisting dew point of each year for the selected period is noted. Then the highest of these dew point values is chosen for storm maximization.

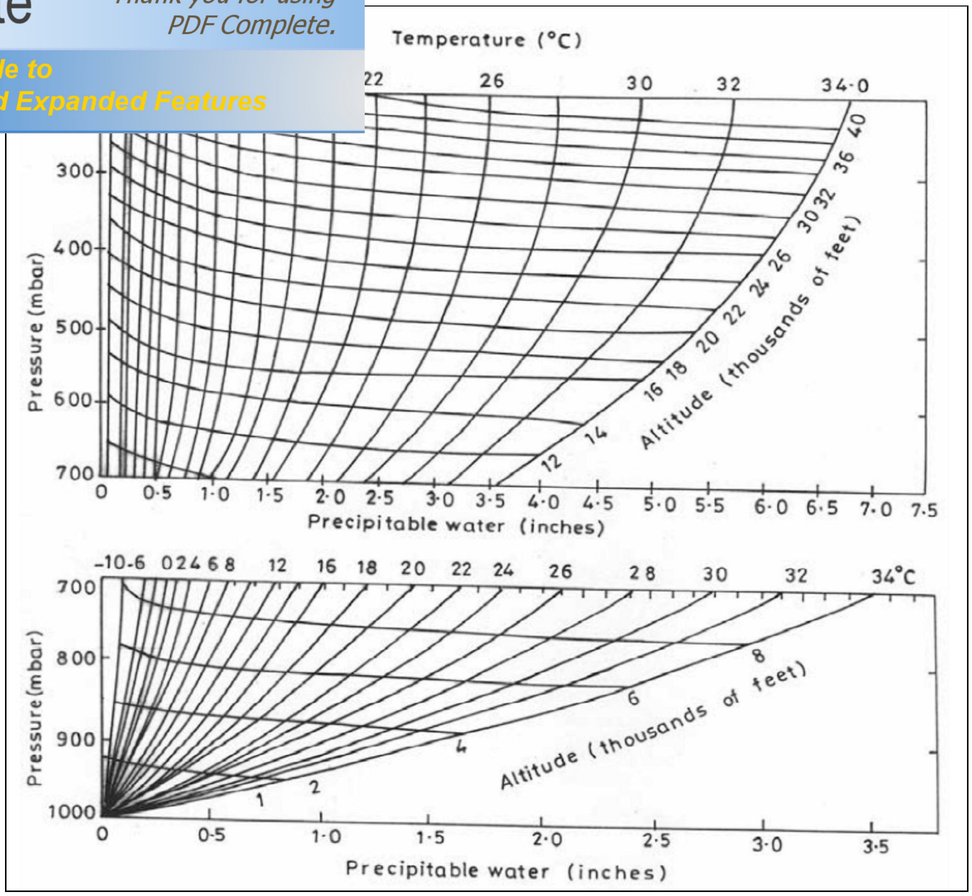


Fig. 5.6 Precipitable water above 1000 mb assuming saturation with pseudo adiabatic lapse rate for the indicated surface temperature.

Moisture adjustment

The standard project storm depths, obtained from depth duration analysis, are multiplied by moisture adjustment factor (MAF). The MAF is defined as the ratio of the precipitable water corresponding to the maximum dew point, W_M, to the precipitable water corresponding to the storm dew point, W_s

$$MAF = \frac{W_M}{W_s} \qquad (5.40)$$

Thus multiplying the MAF and the rainfall depths obtained from the depthï areaï duration the PMP for 1 to 5 days are estimated.

Comparison between physical and statistical methods

The annual maximum catchment rain depths for the 48 year period for 1 to 5 daysôduration are subjected to the best fitted distribution. The maximum rainfall depths for the different return periods are determined by the frequency factor n obtained by the hydrometerological study is then ncy factor method and the return period close to the value obtained by the hydrometerological study is identified. Thus the study compares the statistical and hydrometerological analysis for finding the design storm for a catchment in consideration.

5.8 DROUGHT ANALYSIS

Drought indicates water scarcity resulted due to insufficient precipitation, high evapotranspiration, and over-exploitation of water resources or combination of these parameters. Drought indices are important elements of drought monitoring and assessment since they simplify complex interrelationships between many climate and climate related parameters. There are various methods and indices for drought analysis which identify and classify drought based on the parameters used to determine it. Along the various indices proposed for characterization of meteorological drought two are widely accepted and used according to Tsakiris and Vangelis (2005) namely the Palmer's Drought Severity Index (PDSI) and the standardized precipitation index (SPI). The PDSI uses precipitation evaporation and soil moisture conditions as key determinants. PDSI is useful for drought assessment but not sensitive enough for being used in monitoring of drought. While the SPI is using precipitation as the only determinant describing the water deficit and effective for monitoring drought. The SPI is a relatively new drought index based only on precipitation. It is an index based on the probability of precipitation for any time scale.

The SPI was formulated by Mckee et al. in 1993. The purpose of SPI is to assign a single numeric value to the precipitation that can be compared across regions with markedly different climates. Many researchers have studied the SPI considering it to be fitted to normal distribution by converting it to standard normal variate. For the present study the best fitted distribution are identified and the data are then converted to the standard normal variable. Fig. 5.7 shows the diagrammatic representation of the proposed methodology.

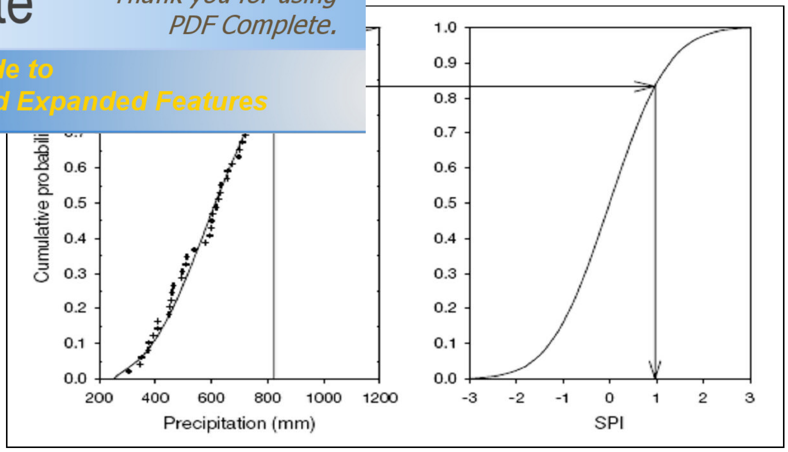


Fig.5.7 Diagrammatic representation of equiprobability transformation from a fitted distribution to the standard normal distribution for determining SPI

The monthly time scale totals are used. Instead of 3 month time scale a 4 month time scale is used as the south west monsoon in India is for 4 months from June to September. The monthly data are then converted to 4, 12 and 24 months totals for determining SPI4, SPI12 and SPI24 respectively. Thus for the present study SPI4 is considered for short term or seasonal variation of drought for 4 months period as it reflects shortï term and mediumï term moisture conditions. It is important to compare the 4ï month SPI with longer time scales. A relatively normal 4ï month period could occur in the middle of a longï term drought that would only be visible at longer time scales. Looking at longer time scales would prevent a misinterpretation that any "drought" might be over. For average and long term drought index duration of 12 months and 24 months are studied respectively. A 12ï month SPI is a comparison of the rainfall for 12 consecutive months with the same 12 consecutive months during all the previous years of available data. The SPI at these time scales reflect longï term rainfall patterns. Because these time scales are the cumulative result of shorter periods that may be above or below normal, the longer SPIs tend toward zero unless a specific trend is taking place. SPIs of 24ï month are probably tied to streamflows, reservoir levels, and even groundwater levels at the longer time scales. Evaluations for each station are being determined by the same methodology.

According to Agnew (2000) as per McKeeŝ classification for drought all negative indices (SPI) are taken to indicate the occurrence of drought; this means for 50% of the time, drought is occurring which is not correct. The SPI drought thresholds recommended by Agnew correspond to 5%, 10%, and 20% probabilities. Hence in 10 years and extreme drought only 1 in 20 years. re realistic drought frequency and it corresponds to the employment of the term abnormal occurrence, as used in other branches of environmental science. Therefore the modified SPI classification proposed by Agnew is adopted. Table 5.9 presents the drought intensity classification according to Agnew.

SPI is the ratio of difference between precipitation and mean at a selected period to standard deviation.

$$\text{SPI} = \frac{x_i - \bar{x}}{\mathring{u}} \tag{5.41}$$

where x_i is the precipitation for ith observation, $\bar{x}$ mean of the data set and $\breve{u}$ standard deviation.

Table 5.9 Modified SPI Classifications by Agnew (2000) for Drought

SPI	Probability of occurrence	McKee et al. (1995) drought classes	Modified drought classes by Agnew (2000)
Less than ï 2.00	0.023	Extremely wet	
Less than ï 1.65	0.050		Extremely wet
Less than ï 1.50	0.067	Severely wet	
Less than ï 1.28	0.100		Severely wet
Less than ï 1.00	0.159	Moderately wet	
Less than ï 0.84	0.201		Moderately wet
Less than ï 0.50	0.309		No drought
Less than 0.00	0.500	Mild drought	No drought
Less than ï 0.50	0.309		No drought
Less than ï 0.84	0.201		Moderate drought
Less than ï 1.00	0.159	Moderate drought	
Less than ï 1.28	0.100		Severe drought
Less than ï 1.50	0.067	Severe drought	
Less than ï 1.65	0.050		Extreme drought
Less than ï 2.00	0.023	Extreme drought	

A newer approach for determining the SPI is introduced. Based on the methodology presented in section 5.3 the best distribution is fitted to the rainfall dataset of 4, 12 and 24 months time series. The probabilities are then obtained for the respective rainfall values. The SPI given by Eq. (5.41) is modified as

$$\text{SPI}_{mod} = \frac{X_{ip} - \bar{x}_p}{\sigma_p} \tag{5.42}$$

where

X_{ip} = fitted probability of rainfall at ith observation; $\bar{x}_p$ = mean of probability; σ_p = standard deviation of probability

…AINFED AGRICULTURE

From analysis of the measured historical data it is possible to get some insight into problems related to the amount of crop water requirement available. If planning of water resources development is to be successful, improved estimates of probable rainfall and its characteristics and timing are critical. Strategic management is needed by analyzing the time series, start of rainy season and water balance of the long historical data for the prediction of a season to be a wet or dry. Techniques like Markov chain can be very helpful for estimation of the risk of dry spells. The information can assist farmers in selecting drought resistant varieties, selecting best sowing date by avoiding the period of high risk of long dry spell. Also the farmer is to be aware of supplementary irrigation and sowing strategies.

Prediction and modeling of rainfall is an important problem in atmospheric sciences and agriculture. It is often addressed using statistical learning methods since global circulation and climate change models are inaccurate to capture characteristics of precipitation for a specific location. Problem of modeling precipitation occurrence for a network of rain stations should capture a number of data properties, e.g. spatial dependencies between pairs of rain stations, the temporal (e.g. runï length) distribution of the wet and dry spell lengths, inter annual variability in the number of rainy days per season, etc. A prolonged dry spell following the ñfalse startò of the rains could affect seed germination and consequently lead to crop failure. Thus, a study of the start of the rainy season is very crucial for crop production.

5.9.1 Climate Classification

Hargreaves (1977) reviewed various classifications of climate and definitions of drought and concluded that, although no simple classification can include all the variations, use of some rather simple generalizations would significantly improve the science of agro technology transfer. A more refined breakdown is required for most specific crops. The climate types based upon mean monthly temperatures were proposed and are given in Table 5.10. Each temperature zone was subdivided using seven criteria, relating to adequacy or excess of precipitation

These classifications are given in Table 5.11 where

$$MAI = \frac{P}{ETo} \qquad (5.43)$$

where

P is the amount of rainfall for 75% probability level

ETo is the amount of reference crop evapotranspiration for 75 % probability level.

Table 5.10 Climate Types based on Mean Monthly Temperatures

Climatic type	Criteria
Polar	All months < 10°C
Boreal	1ï 3 months > 10°C
Sub temperate	4ï 5 months > 10°C
Temperate	6ï 9 months > 10°C
Subtropical	10ï 12 months > 10°C
Tropical	All months ≥17°C

Table 5.11 Classification of Climate for Dryland Agricultural Productivity

Criteria	Climate classification	Productivity classification
All months with MAI of 0.00ï 0.33	Very arid	Not suited for rainfed agriculture
1 or 2 months with MAI of 0.34 or above	Arid	Limited suitability for rainfed agriculture
3 or 4 months with MAI of 0.34 or above	Semiarid	Production possible for crops requiring a 3ï 4 month growing season
5 or more consecutive months with MAI of 0.34 or above	Wetï dry	Production possible for crops requiring a good supply of water during 5 or more months
1 or 2 months with MAI above 1.33	Somewhat wet	Natural or artificial drainage required for good production
3 or 5 months with MAI above 1.33	Moderately wet	Good drainage required for normal agricultural production
6 or more months with MAI above 1.33	Very wet	Very good drainage required for normal agricultural production

Evapotranspiration

The FAO expert consultation in 1990 reached unanimous agreement in recommending the Penmanï Monteith approach as the best performing method to estimate evapotranspiration of a reference crop ETo and adopted the estimates for bulk surface and aerodynamic resistance as elaborated by Allen et al. (1989) as standard values for the reference crop. Many studies on various crops have shown, however, that the crop resistance factor, which represents the stomatal behaviour of the crop, is affected by climatic conditions. Solar radiation, air temperature, vapour pressure deficit, day length and wind have all been found to affect the crop resistance in different degrees and directions.

...s for crop surface resistance and crop height required ...oncept of reference evapotranspiration which was redefined as follows:

> Reference evapotranspiration is the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height (12 cm), a fixed crop surface resistance (70 s $m^{ï 1}$) and albedo (0.23), closely resembling the evapotranspiration from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground and with adequate water.

To further standardize the use of the FAO Penmanï Monteith method, studies were undertaken to provide recommendations when limited meteorological data are available. Procedures were developed to estimate values for vapour pressure, solar radiation and wind speed. This allowed the use of the Penmanï Monteith even if only the temperature data are available. This excluded the need to maintain any other empirical ETo estimation method as a standard, and only one method for estimating ETc is presently recommended, which has largely contributed to the transparency and consistency in reference evapotranspiration and crop water requirement studies.

Irrigation & Drainage (I&D) Paper No. 56 (Allen et al., 1998) provides detailed procedures for the calculation of ETo with different time steps, ranging from hours to months, and includes computations by hand with the help of a calculation sheet, or by means of a computer. The Penmanï Monteith method is used for the estimation of the evapotranspiration of a hypothetical reference crop with fixed crop parameters, i.e. ETo. Experimentally determined ratios of ETc/ETo, called crop coefficients (Kc) are used to relate ETc to ETo or

ETc=Kc x ETo (5.44)

This is referred to as the ETc using single crop coefficient.

Difference in leaf anatomy, stomata characteristics, aerodynamic properties and even albedo causes the crop transpiration to differ from the reference crop evapotranspiration under the same climatic conditions. Due to variations in the crop characteristics throughout its growing season, Kc for a given crop changes from sowing till harvest. A review of crop coefficients resulted in an update of Kc values to be applied to the FAO Penmanï Monteith method and procedures to under various climatic conditions and crop height and ps and crop types (Allen et al., 1998) as illustrated in Fig. 5.8 and 5.9.

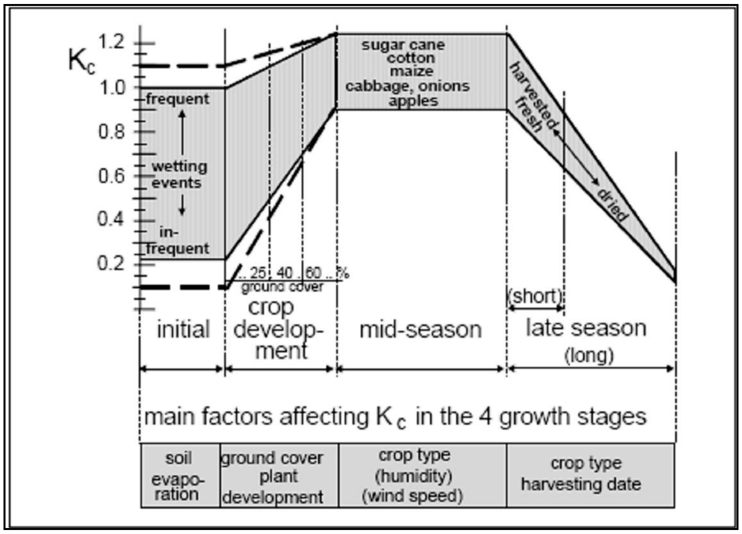


Fig. 5.8 Kc values using FAO Penman Monteith method

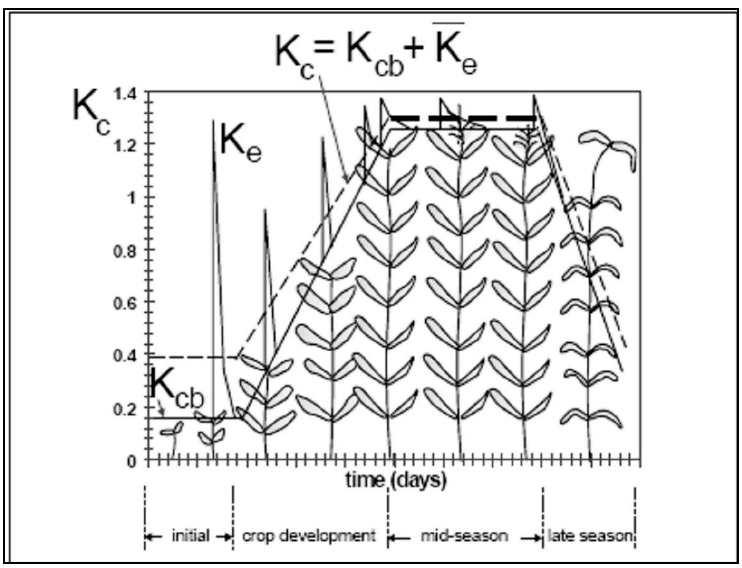


Fig. 5.9 Kc values using dual crop coefficient approach

For more detailed calculations in crop simulation studies, ETc values are needed on a daily basis, requiring a more accurate estimation of crop transpiration and soil evaporation. The effect of specific wetting events on the value Kc and ETc needs to be taken into account for more accurate estimations of ETc. This is done by splitting Kc into two separate coefficients, one for crop transpiration, i.e., the basal crop coefficient (Kcb) representing the transpiration of the crop, and one for soil evaporation, the soil water evaporation coefficient (Ke). Thus, a dual vas introduced for ETc as ETc = (Kcb+Ke) ETo. (Allen

The dual crop coefficient approach is more complicated and more computationally intensive than the single crop coefficient approach. The procedure is conducted on a daily basis and intended for applications using computers. This approach is recommended to be followed when improved estimates for Kc are needed, for example to schedule irrigation for individual fields on a daily basis.

The calculation procedure for ETc using dual crop coefficient approach consists of:

1. Identifying the lengths of crop growth stages, and selecting the corresponding Kcb coefficient;
2. Adjusting the selected Kcb coefficients for climatic conditions during the growth stage;
3. Constructing the basal crop coefficient curve (allowing one to determine Kcb values for any period during the growing period);
4. Determining daily Ke values for surface evaporation; and
5. Calculating ETc as the product of ETo and (Kcb+Ke).

Standard values of revised Kc and Kcb for crop stages initial, midï season and endï season are given in Allen et al. (1998).The concept of dual crop coefficient is taken into consideration but in a different manner by performing the irrigation scheduling, wherein the maximum evapotranspiration rate (ETc = ETm) is obtained by multiplying Kc into ETo, where Kc is considered to be the single crop coefficient. ETc becomes actual evapotranspiration (ETc = ETa) when there are stress conditions due to lack of moisture during rainfed farming. Thus when ETc becomes ETa the Kc value is determined by the ratio of ETa to ETo which is denoted as Kcï adj. Thus Kcï adj is obtained for all such conditions for determining the exact values for rainfed farming.

chain, named after Andrey Markov, is a discreteï time stochastic process with the Markov property. The Markov property means the next state solely depends on the present state and doesn't directly depend on the previous states. There are n numbers of order for preparing Markov models. Considering just two categories of dry and wet is called a zero order Markov chain. A zero order chain is one that has no memory. The fact that yesterday was dry does not affect the chance of rain (wet) today. First order Markov chain consists of four categories of days namely ódry & dryö, ódry & rainö, órain & dryöand órain & rainö A first order chain has only one day of memory. If the chain is first order, then the fact that yesterday was dry may affect (i.e. change the probability) that today is rainy. However, with a first order chain, the extra information that the day before yesterday was also dry does not further change the probability of rain today. With a second order Markov chain the memory extends two days, but no more. And so on.

The modeling approach consists of two stages of analysis. Stage 1: Preparation, Stage 2: Fit the model. Stage 1 summaries the data for the model fitting. As defined by India Meteorological Department, a day with more than 2.5 mm rainfall has been considered as wet and that with less than 2.5 mm rainfall as dry. Stage 2 determines the model probabilities. One has to specify the complexity of the initial model and a previous fitting. Thus the second stage is to fit the model to produce the fitted probabilities. Fig. 5.10 represents the flow chart of the modeling process carried out.

The daily rainfall data are analyzed to determine the observed / actual probabilities. The actual probabilities are determined as

$$\text{Probability of rain} = \frac{\text{Number of rain events observed}}{\text{Total number of events}} \tag{5.45}$$

For example if one has to determine the probability of rain on 15th June for a period of 45 years of analysis. One has to determine the actual no. of rain events observed during the 45 years. Say the number of rain events observed are 32 then the actual probability of rain is 32 / 45 i.e. 71 %. The probability of a day being dry is one minus the probability of rain. 29th February is an exceptional to

of events will not be 45 instead it will be 11 as it occurs
dy period of 45 years.

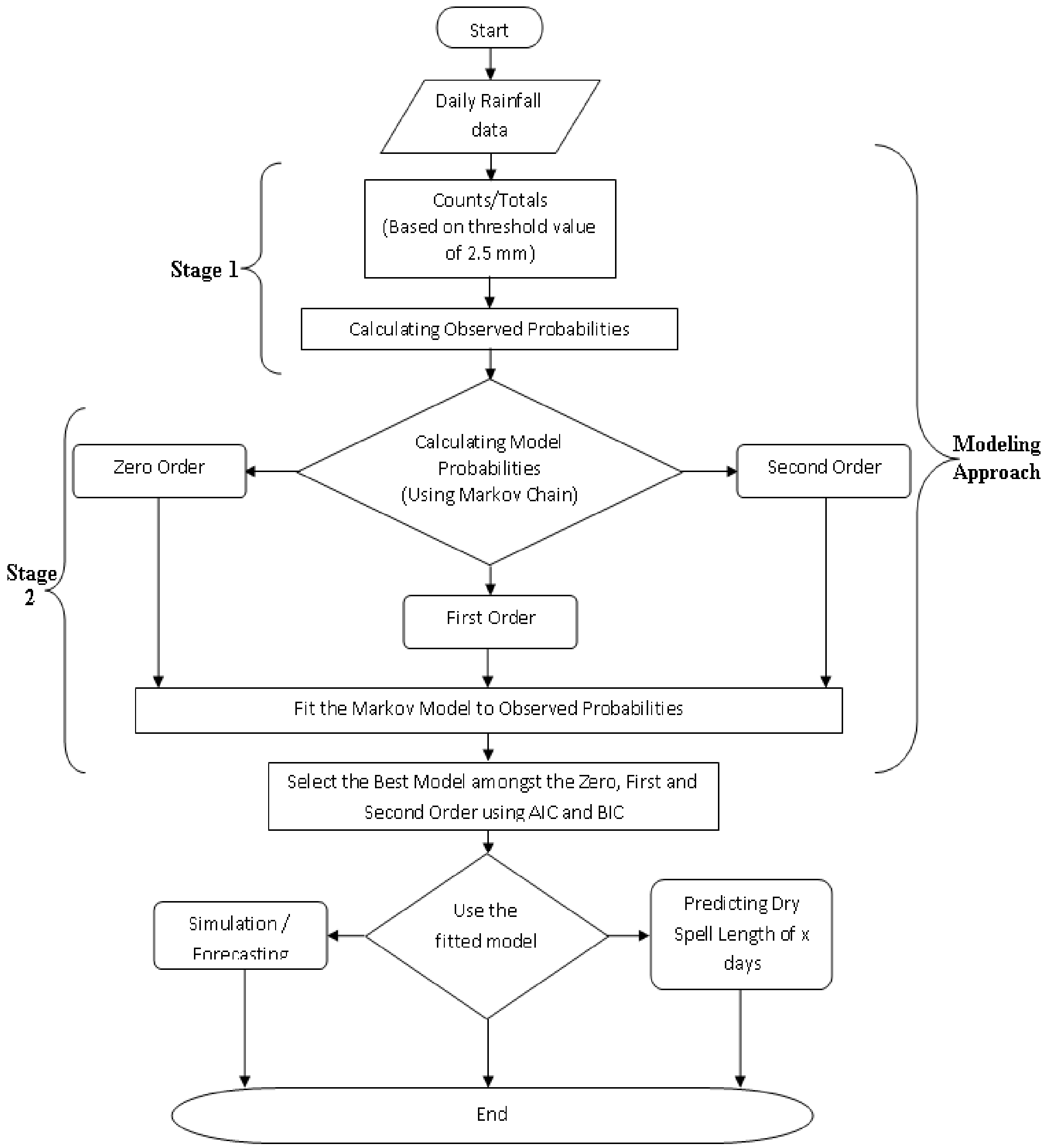


Fig. 5.10 Flowchart of processes carried out in the study

To obtain the optimum order of the Markov chain, Akaike's information criterion (AIC) and Bayesian's Information Criterion (BIC) given by Eq. 5.2 and 5.4 for selecting the optimum model are considered. Further to ensure how much optimum is the model selected the Akaike weights are determined. After determining the optimum order of the model, it is used to determine the probabilities of occurrence of dry spell length from 7 to 14 consecutive days over a period of 30 days. The probabilities thus obtained will be utilized for crop planning in the study area.

ach is applied using 8 mm threshold value. A day with as been considered as wet and that with less than 8 mm rainfall as dry. Rainfall upto 8 mm/day may all lost by evaporation with a dry soil surface and little or no vegetative cover. (Doorenbos and Pruitt, 1977). Therefore this 8 mm threshold value is considered in view of agriculture planning.

5.9.3 Climatic Index (CI)

A study to determine the suitability of crops to be grown at suitable periods of the year based on a proposed ñclimatic indexò considering the availability of water from rainfall as well as the loss of water through evapotranspiration in the rainfed area of north Gujarat agroclimatic zone is carried out.

The water requirement of crop should be less than or equal to the water available from rainfall for a crop to be grown in a particular field. For climatic suitability, the value of crop coefficient (Kc / Kcï adj) obtained from the above methodology should therefore be less than the ratio of two climatic factors effective rainfall and ETo at each stage of crop growth. At a stage of water balance, when the effective rain and crop evapotranspiration are same, the value of Kc is equal to the ratio of two climatic factors namely effective rainfall and ETo. This ratio of two climatic parameters may be termed as climatic index for effective representation of climatic factors in calculation of water balance.

$$CI = Pe/ETo \qquad (5.46)$$

Where
Pe = effective rainfall
ETo = reference evapotranspiration

The effective rainfall is determined based on the irrigation scheduling performed using soil water balance method. The reference evapotranspiration (ETo) is estimated using FAO Penman Monteith method with help of the FAO CropWat 8.0. The weekly values of climatic factors i.e effective rainfall & ETo and climatic index for the 36 years are developed.

The monthly values of the climatic index as the ratio of effective rainfall and ETo are calculated and are analysed to plan for best suited crop and cropping period, for the values of the crop coefficient Kc should be less than or equal to the values growth for optimal crop growth. The 80% dependable is calculated expecting to have it in 4 out of 5 years. Kci is a function of wetting interval, evaporating power of the atmosphere and magnitude of the wetting event during the initial periods and is estimatd from Fig. 5.11 for light to medium (3-10 mm per event) wetting events as suggested by Allen et al. (1998) in FAO Irrigation and Drainage 56.

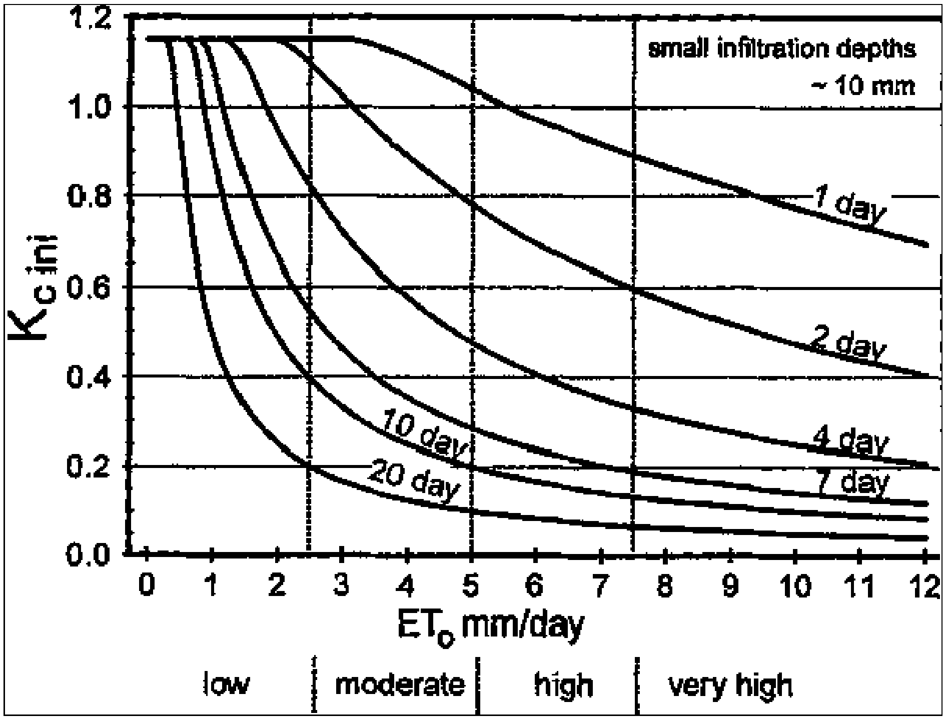


Fig. 5.11 Average Kci as related to the level of ETo and the interval between irrigations and/or significant rain during the initial growth stage for all soil types when wetting events are light to medium (3-10 mm per event)

Once the monthly CI and Kci are obtained then further weekly values of climatic index may be determined and analyzed to plan for best suited crop and cropping period. A CI and Kc curve for all the weeks are drawn out of the average values of CI and Kci for each week.

5.9.4 Crop Period based on Onset and Cessation of Monsoon

At the surface, monsoon onset is recognized as a rapid substantial and sustained increase in rainfall. Over India, monsoon onset occurs initially across the south peninsula in early June, when heavy rains lash south peninsula after the crossï equatorial lowï level jet (LLJ) is established across the Somali coast into the ea. This phenomenon is usually accompanied by the phere shear zone across the Bay of Bengal to the south east Arabian Sea in which a cyclonic vortex may be embedded. By middle of July, monsoon covers the whole country.

Onset criteria

Onset is quantified by the Depth method described by Raes et al. (2004). It considers a cumulative rainfall depth that will bring the top 0.25 m of the soil profile to field capacity during a maximum of 4 days. The corresponding threshold rainfall quantifies the field inspection method by farmers to determine whether conditions are favorable for wet sowing. This is achieved by digging a test hole, usually a day after a rain event. The logic is to allow the rain to reach deeper layers of the soil, forming a recognisable wetting front. The total available soil water (TAW) during the initial stage for annual crops, for the major soils in the study area are used to determine the amount of rainfall required to raise the soil water content from wilting point to field capacity. Since TAW values may vary from one soil type to another an average TAW is considered. A mean threshold value of rainfall is obtained by upgrading the TAW values by 20% to take care of losses by surface runoff, nonï uniform wetting, and soil evaporation. Thus the obtained threshold value of rainfall depth is considered for predicting the onset of monsoon.

For each station, the date having a probability of at least 20% that the root zone has adequate soil moisture is regarded as the date after which the onset criteria apply. The 20% probability level is commonly considered as acceptable when evaluating rainfed agriculture (Kipkorir et al., 2007). If 40 mm depth of water rained in one day the amount of runoff would also be more. So a date with only one day among the 4 days having 40 mm or more rainfall available is not appropriate in view for crop planning. Therefore a search for onset date with a condition of rainy days has to be introduced. Thus atleast 2 out of 4 days must be rainy is applied for searching the onset dates. The date having a probability of at least 20% that the root zone has adequate soil moisture was regarded as the date after which the onset criteria apply. The 20% probability level is commonly considered as acceptable when evaluating rainfed agriculture. (Mugalavai et al. 2008). Starting from the initial search date the onset is taken to be the date on satisfied or exceeded (Stewart, 1990; Kipkorir et al.,

Cessation criteria

Cessation is quantified by considering the date on which the water stress in the root zone of a crop under consideration exceeds a threshold value. For each of the stations and for each of the 48 years of period that daily rainfall data is available the soil water content in the root zone is simulated with help of the soil water balance. The maximum rooting depth for the crop and readily available soil water (RAW) of 50% of TAW is considered in the study. Water stress is assessed by means of the water stress coefficient Ks (Allen et al., 1998). As long as a fraction of RAW remains available in the root zone, there is no water stress and Ks is 1. When water stress occurs, Ks decreases linearly with the soil water content and becomes zero when wilting point is reached. The cessation of the rainy season is assumed when Ks drops below 0.40 within the cessation window. The cessation is taken to be the date on which the criterion was first satisfied or exceeded. If in case during the crop period the threshold value is not observed then the next season crop is considered for the cessation with the same criteria.

Length of growing season

The length of the growing season (days) for a particular year is taken as the difference between the Julian day numbers of the determined onset date and the determined cessation date and of that year.

Statistical analysis

Probabilities of exceedance of the onset dates (specified as julian day numbers) are calculated using the probability distribution function. The 80, 50 and 20% probabilities of exceedance are determined and used as indicators of early, normal and late onset respectively.

Overall information regarding the climate type, dry spell length, climatic index and crop period based on onset and cessation criteria when analysed in correlation with each other will be useful for the planning of irrigation and agricultural activities in the area.

CHAPTER 6

RESULTS AND ANALYSIS

6.1 GENERAL

north Gujarat agroclimatic zone is fully or partly spread over seven districts namely Ahmedabad, Banaskantha, Gandhinagar, Kheda, Mehsana, Patan and Sabarkantha of Gujarat. For the study, 167 raingaguge stations and 5 climate stations situated in and around the north Gujarat agroclimatic zone are selected, various studies are carried out and numerous models are developed. The main objective of the present study is to plan the water resources and irrigation management based on climate parameters. The results obtained and analysis carried out during the study of the north Gujarat agroclimatic zone are presented here.

6.2 MISSING CLIMATE DATA

For determining the nearest input station cluster analysis is applied. Various combinations of distance measures and linkage rules are evaluated using Cophen coefficient. Table 6.1 depicts the results obtained. The square Euclideanï distance measure using averageï linkage rule is found to be the best for forming the clusters as the Cophen coefficient of 0.671 is the highest.

Table 6.1 Cophen Coefficient Value for Various Combinations of Distance Measures and Linkage Rules.

Linkage rule → / Distance measure ↓	Single	Complete	Average	Weighted	Centroid	Median	Ward
Euclidean	0.457	0.643	0.665	0.634	0.658	0.613	0.618
Square Euclidean	0.486	0.633	**0.671**	0.619	0.664	0.613	0.628
Mahalanobis	0.498	0.607	0.607	0.642	0.652	0.664	0.597
Cityblock	0.444	0.607	0.669	0.606	0.640	0.531	0.604
Minkowski	0.457	0.643	0.665	0.634	0.658	0.613	0.618
Cosine	0.605	0.576	0.607	0.605	0.607	0.609	0.604
Correlation	0.522	0.574	0.617	0.655	0.079	0.130	0.042
Hamming	0.100	0.100	0.100	0.100	0.000	0.000	0.000
Jaccard	0.100	0.100	0.100	0.100	0.000	0.000	0.000
Chebychev	0.454	0.613	0.655	0.621	0.657	0.646	0.621

167 raingauge stations in and around the study area. ...e coded from 1 to 167 numbers. Fig. 6.1 presents a part of the whole cluster formed for the analysis. The whole cluster is presented in Plate 2. The input to the raingauge station having missing daily data are determined using the cluster analysis. For example consider station having code No. 52 with missing records, in Fig. 6.1. From Fig. 6.1 it is evident that station 52 is nearer to station 62. Therefore for determining missing records of station 52, the input station selected is the station 62. In many cases it is found that the immediate nearer station also has the missing records. Then for such cases the next nearer station is explored for determining complete records. For example the missing records of station 52 are from 1975 to 1980. As discussed earlier one selects station 62 as the input station for determining missing records. But it is found that the station 62 has 1980 year as missing. Then in this case, the next nearer station 124 is explored and if the station 124 contains 1980 year as missing then either station 29 or 42 is explored till complete set of missing records are filled with the data from such nearer stations. The extent of exploring the outer loops for considering the missing records is limited to 0.5 units of the distance measure statistics obtained as one needs to analyse nearer stations. It is observed that the farthest distance within this limit is within 30 km and nearest is around 4 km. For cases where no such station with all the data is available for the corresponding set of missing records then two different models are developed for different years. For example based on the previous illustration when one finds that station 62 contains 1980 year missing then the model for determining the missing records for the year 1975 to 1979 is developed and for 1980 separate input station i.e. station 124 is used. Thus for determining the missing records of one station two separate models based on the availability of input station are developed. In the present study the total number of raingauge stations containing missing daily data is 47. The total numbers of models developed are 68.

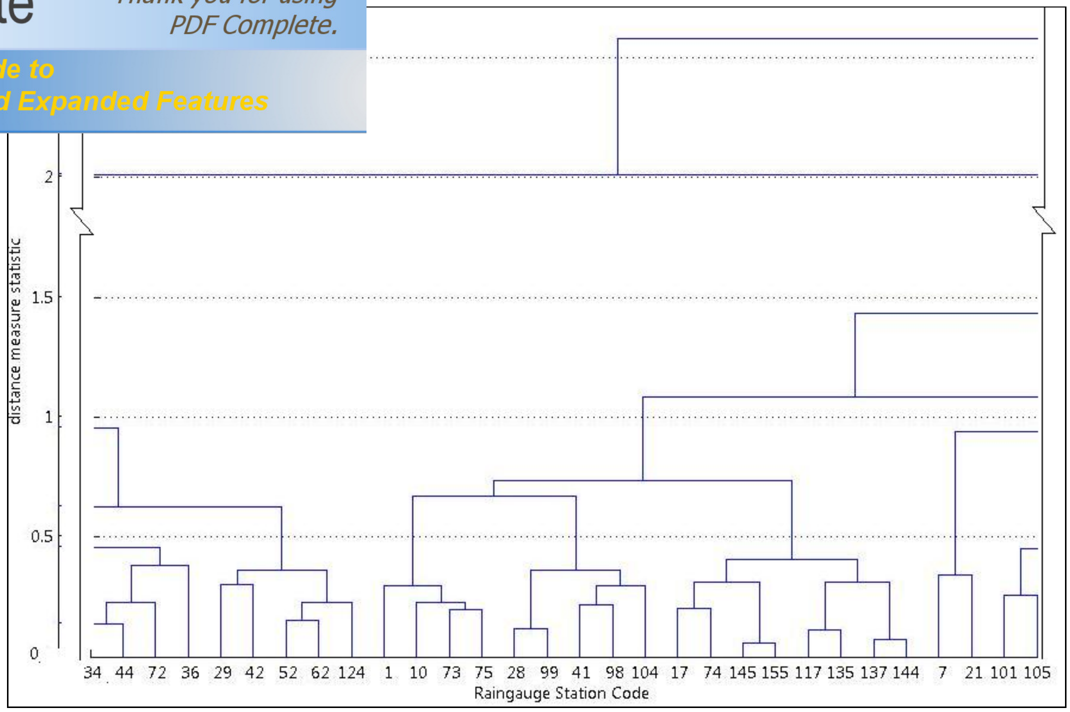


Fig. 6.1 Part of dendrogram of 167 raingauge stations of north Gujarat region

While considering ANN method different neural networks are explored for determining the best network. It is found that for competitive neural network the output for any input data is either one or zero. For cascade back propogation, elman back propogation, feedï forward backpropagation, feedï forward inputï delay backpropagation etc., the network output yields one random constant value for all the inputs. Hopfield recurrent, linear layer, perceptron and probabilistic neural networks are found infeasible to the present input data. Generalized regression neural network (GRNN) and radial basis network yield some realistic results. Amongst the two the radial basis network does not give any value for input of three digits while the generalized regression performs well. Thus generalized regression network is used for ANN models amongst the different types of ANN networks studied. The network architecture of one of the model out of the 68 different GRNNs created is presented in Fig. 6.2. The input varies according to the data availability but is equal to or greater than 3,535 (70% of the total number of sample) number for model preparation.

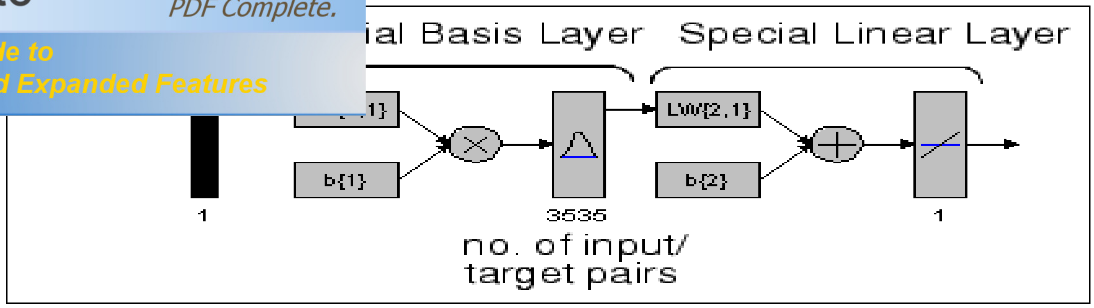


Fig. 6.2 Network architecture of generalized regression neural network for one of the model out of 68

Table 6.2 presents the frequency distribution for Bias score. In case of Bias values for model preparation data, it is observed that out of 68 models prepared by the ANN method, 45 are in the range of 0.81 to 1.19. Out of these 45, 14 are in the range of 0.81 to 0.98 i.e. these are underforecasting, 27 are in the range of 1.02 to 1.19 i.e. these are overforecasting. In the range of 0.99 to 1.01 there are 4 models which are more or less perfect. Similarly, in case of models prepared by the closest station method, 52 are in the range of 0.81 to 1.19. Out of these 52, 23 are underforecasting and 27 are overforecasting. 2 models are more or less perfect i.e between 0.99 to 1.01 range. In case of models prepared by the non linear regression method, 35 are in the range of 0.81 to 1.19. Out of these, 13 are underforecasting and 19 are overforecasting. 3 models are more or less perfect. If one can see the models in the range of 0.96 to 1.04 then there are 6, 5 and 8 models prepared by the ANN, closest station and non linear regression methods respectively.

S and NLR Methods for Model Preparation and

class	Frequency					
	ANN		Closest station (CS)		Non linear regression (NLR)	
	Preparation	Validation	Preparation	Validation	Preparation	Validation
0.01-0.20	0	0	0	0	0	0
0.21-0.40	0	0	0	0	0	0
0.41-0.60	0	1	0	1	0	2
0.61-0.80	0	4	1	5	2	3
0.81-0.98	14	14	23	20	13	13
0.99-1.01	4	7	2	2	3	2
1.02-1.19	27	11	27	19	19	10
1.21-1.40	15	18	8	13	18	17
1.41-1.60	6	9	5	3	5	7
1.61-1.80	1	3	1	4	3	6
1.81-2.00	1	0	0	0	1	2
2.01-2.20	0	0	1	1	2	1
2.21-2.40	0	0	0	0	0	1
2.41-2.60	0	1	0	0	0	0
Total	**68**	**68**	**68**	**68**	**66**	**66**

In case of Bias values for model validation data, it is observed that out of 68 models prepared by the ANN method and tested for Bias, 32 are in the range of 0.81 to 1.19. Out of these 32, 14 are in the range of 0.81 to 0.98 and are underforecasting, 11 are in the range of 1.02 to 1.19 and are overforecasting. In the range of 0.99 to 1.01 there are 7 models which are more or less perfect. Similarly, in case of models prepared by the closest station method and tested for Bias, 41 are in the range of 0.81 to 1.19. Out of these 41, 20 are underforecasting and 19 are overforecasting. 2 models are more or less perfect. In case of models prepared by the non linear regression method and tested for Bias, 25 are in the range of 0.81 to 1.19. Out of these, 13 are underforecasting and 10 are overforecasting. 2 models are more or less perfect. If one can see the models in the range of 0.96 to 1.04 then there are 11, 4 and 6 models prepared by the ANN, closest station and non linear regression methods respectively. Thus looking to the maximum number of models in the range nearer to 1, it can be said that the ANN method is the best method for forecasting and validating the models on the basis of Bias.

Fig. 6.3 shows the box plot for the Bias scores obtained during the model preparation and validation. For all the further boxplot figures ANN, CS and NLR denotes the Artificial Neural Network, the closest station and the non linear regression methods respectively and the alphabets M and V denote model preparation data and validation data respectively. Thus ANN_M presents the plot

...del preparation data and ANN_V presents the plot of ... validation data. The box plot indicates the minimum, the maximum, the 25th, 50th (median) and the 75th percentile data values. The interquartile range is the difference between the 25th and the 75th percentile values. From the Fig. 6.3 it is clear that the range of data points is the largest in case of non linear regression method using model validation data indicating more variation. The range of data points is the smallest in case of closest station method using model preparation data indicating less variation. But there are more outliers (data points having values greater that one third of the interquartile range) in case of the closest station and the non linear regression methods compared to the ANN method for both the model preparation and model validation dataset.

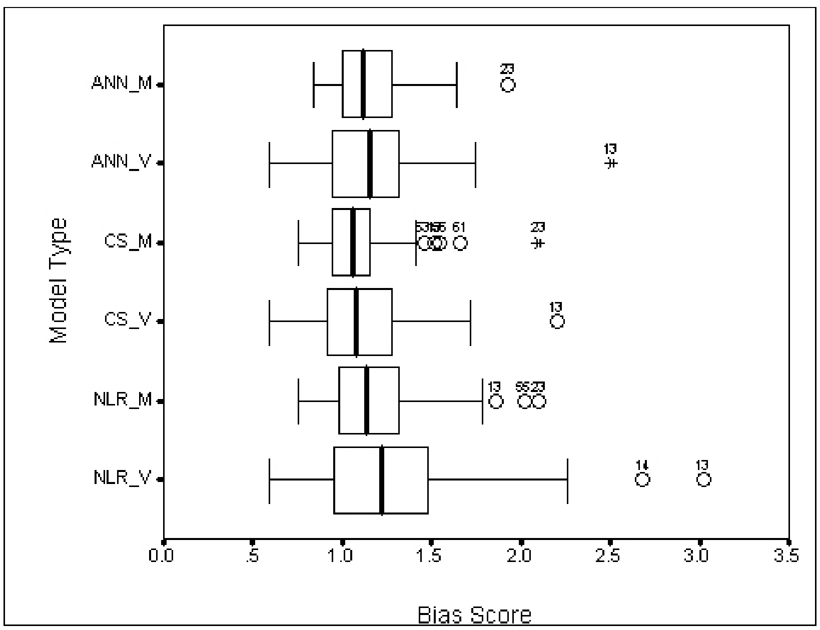


Fig. 6.3 Box plot of the bias score for model preparation and validation

Table 6.3 and Table 6.4 represent the POD, FAR, ETS and HK scores for model preparation and model validation data respectively. For the POD score greater than 0.70 the ANN method has frequency of 31 and 30 for model preparation and model validation data respectively, as compared to the closest station and the non linear regression methods having frequency of 22 and 26 respectively for model preparation data and 16 and 33 for model validation data respectively. The frequency of the ANN method is higher than that of the closest station and the non linear regression methods for preparation of the models and is just less than 3 compared to non linear regression and greater than 4 for closest station for refore it can be said that the ANN method, is the best validation on the basis of POD.

Table 6.3 Frequency Distribution for POD, FAR, ETS and HK Scores for Model Preparation

Frequency classes	Frequency											
	POD			FAR			ETS			HK		
	ANN	CS	NLR	ANN	CS	NLR	ANN	CS	NLR	ANN	CS	NLR
0.01 - 0.05	0	0	0	0	0	0	0	0	0	0	0	0
0.06 - 0.10	0	0	0	1	0	0	0	0	5	0	0	3
0.11 - 0.15	0	0	0	0	0	0	0	0	0	0	0	1
0.16 - 0.20	0	0	0	1	1	0	0	0	1	0	0	1
0.21 - 0.25	0	0	4	1	2	4	3	5	5	0	0	0
0.26 - 0.30	0	0	0	6	6	5	6	4	8	0	0	1
0.31 - 0.35	0	0	1	8	10	1	11	14	20	0	0	0
0.36 - 0.40	0	0	1	11	11	9	29	27	15	1	3	2
0.41 - 0.45	1	1	0	16	15	16	7	8	2	4	4	3
0.46 - 0.50	2	3	2	15	14	6	4	2	3	4	8	7
0.51 - 0.55	1	4	3	6	7	10	2	3	2	17	16	15
0.56 - 0.60	6	13	6	2	1	7	5	5	5	11	15	16
0.61 - 0.65	18	14	10	0	0	2	0	0	0	18	12	8
0.66 - 0.70	9	11	23	1	1	1	0	0	0	7	5	4
0.71 - 0.75	20	12	7	0	0	4	0	0	0	4	4	3
0.76 - 0.80	8	8	4	0	0	1	0	0	0	1	1	2
0.81 - 0.85	2	2	5	0	0	0	0	0	0	0	0	0
0.86 - 0.90	0	0	0	0	0	0	0	0	0	0	0	0
0.91 - 0.95	0	0	0	0	0	0	1	0	0	0	0	0
0.96 – 1.00	1	0	0	0	0	0	0	0	0	1	0	0
Total	**68**	**68**	**66**	**68**	**68**	**66**	**68**	**68**	**66**	**68**	**68**	**66**

For FAR values less than or equal to 0.3 the ANN, closest station and non linear regression methods give the frequency of 9 each for preparing the models and 14, 18 & 12 while validating the models respectively. It is observed that in case of model preparation all the methods have same frequency but in case of validation of models, the closest station method has the highest frequency.

The values of ETS and HK also indicate the effectiveness of the ANN method by having maximum frequency for best values. The ANN, closest station and non linear regression methods have the frequency of 1, 0 and 0 respectively with respect to greater than 0.7 value of ETS while preparing and frequency of 2, 1 and 1 respectively while validating the model. For HK 70% data give 6, 5 and 5 frequency for values greater than 0.7 in case of the ANN, closest station and non linear regression methods respectively. When the results for 30% data are obtained it is observed that the frequency for the same is 8, 8 and 7 for the ANN, closest station and non linear regression methods respectively. Thus it can be the best for model preparation and validation on the

s.

Table 6.4 Frequency Distribution for POD, FAR, ETS and HK Scores for Model Validation

Frequency classes	Frequency											
	POD			FAR			ETS			HK		
	ANN	CS	NLR	ANN	CS	NLR	ANN	CS	NLR	ANN	CS	NLR
0.01 - 0.05	0	0	0	1	0	0	1	0	8	1	0	7
0.06 - 0.10	0	0	3	0	0	0	0	0	0	0	0	1
0.11 - 0.15	0	0	2	0	0	0	0	0	0	0	0	0
0.16 - 0.20	1	0	2	1	2	3	0	1	1	0	0	0
0.21 - 0.25	0	0	1	5	8	4	4	1	1	0	0	0
0.26 - 0.30	0	0	0	7	8	5	13	11	8	0	0	0
0.31 - 0.35	0	0	0	7	6	7	10	15	10	1	1	1
0.36 - 0.40	0	1	0	9	12	8	16	12	14	3	3	3
0.41 - 0.45	2	1	2	8	7	5	7	12	9	6	5	1
0.46 - 0.50	4	5	2	17	12	9	10	8	9	7	9	2
0.51 - 0.55	6	5	1	5	6	11	3	4	3	7	5	7
0.56 - 0.60	6	9	5	5	6	3	1	1	1	10	18	5
0.61 - 0.65	11	7	5	1	0	2	0	1	0	17	14	17
0.66 - 0.70	8	14	10	1	1	0	1	1	1	8	5	15
0.71 - 0.75	16	17	7	0	0	1	1	1	1	3	4	3
0.76 - 0.80	7	4	13	0	0	1	0	0	0	2	1	1
0.81 - 0.85	3	2	9	0	0	3	0	0	0	1	2	2
0.86 - 0.90	2	2	3	1	0	1	0	0	0	1	1	1
0.91 - 0.95	1	1	1	0	0	2	0	0	0	0	0	0
0.96 - 1.00	1	0	0	0	0	1	1	0	0	1	0	0
Total	**68**	**68**	**66**	**68**	**68**	**66**	**68**	**68**	**66**	**68**	**68**	**66**

Fig. 6.4 shows the box plot of the POD, FAR, ETS and HK scores. For all the parameters the non linear regression method has the largest range of data set hence there is more variation in the parameters obtained. Therefore non linear regression is not preferred for filling in missing records due to the greater variability of the forecast verification parameters. From the point of view of the box plot either ANN or closest station is suitable when considering forecast and verification parameters.

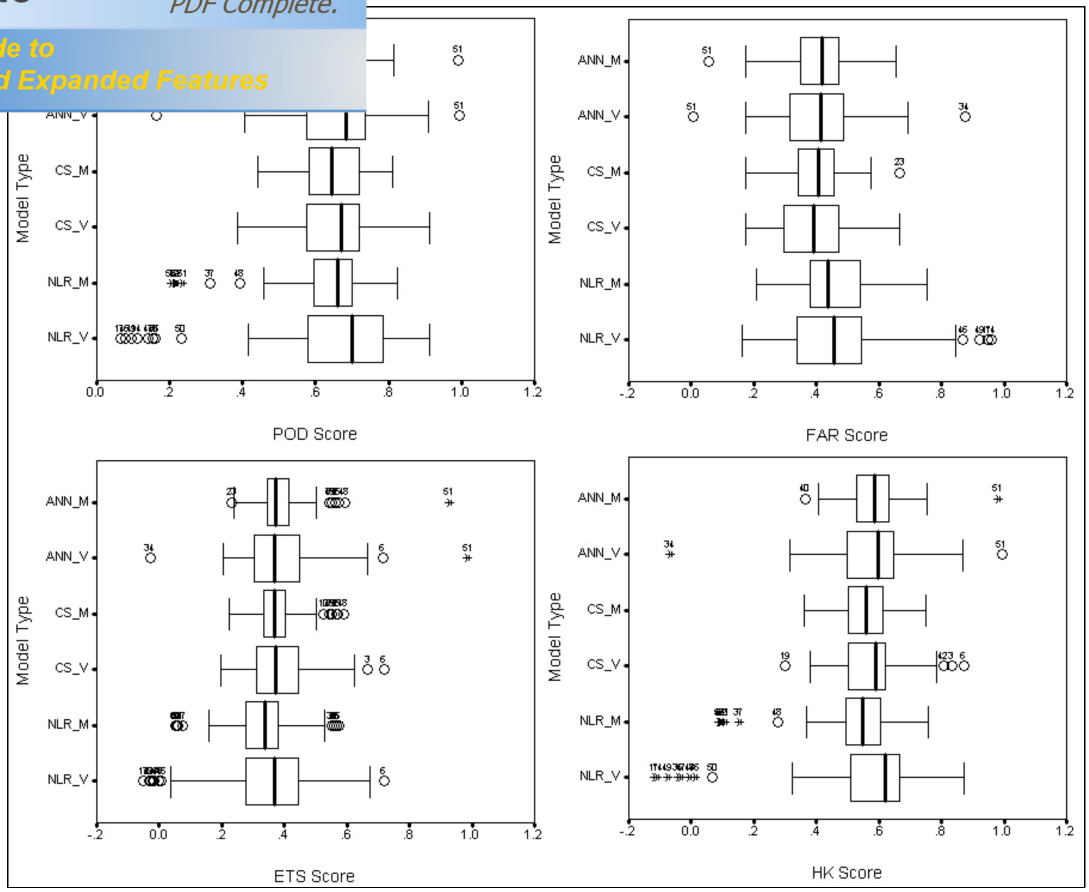


Fig. 6.4 Box plot for POD, FAR, ETS and HK scores for model preparation and validation

Tables 6.5 and 6.6 presents the RMSE and MAE values for model preparation and model validation data. The RMSE value for ANN method obtained is the lowest upto 20 mm, compared to the CS and NLR method. The NLR method gives the highest RMSE value in the range of 81 to 85 mm. The MAE obtained is the least for ANN method. All the models, except one in case for model preparation and ten in case for model validation, are having MAE values less than equal to 5 mm. As the ANN method yields less error for both the RMSE and MAE, it is the best.

for RMSE for Model Preparation and Validation

			Frequency			
			CS		NLR	
		on	Preparation	Validation	Preparation	Validation
01-05	0	0	0	0	0	0
06-10	17	8	4	9	3	4
11-15	47	31	24	22	6	7
16-20	4	25	36	33	8	6
21-25	0	3	4	4	13	5
26-30	0	1	0	0	5	13
31-35	0	0	0	0	8	6
36-40	0	0	0	0	9	3
41-45	0	0	0	0	3	6
46-50	0	0	0	0	1	6
51-55	0	0	0	0	2	3
56-60	0	0	0	0	3	2
61-65	0	0	0	0	1	2
66-70	0	0	0	0	1	1
71-75	0	0	0	0	2	0
76-80	0	0	0	0	0	0
81-85	0	0	0	0	0	1
Total	**68**	**68**	**68**	**68**	**66**	**66**

Table 6.6 Frequency Distribution for MAE for Model Preparation and Validation

Frequency class, mm	**Frequency**					
	ANN		**CS**		**NLR**	
	Preparation	**Validation**	**Preparation**	**Validation**	**Preparation**	**Validation**
01-05	67	58	54	49	14	14
06-10	1	10	14	19	29	29
11-15	0	0	0	0	16	13
16-20	0	0	0	0	6	7
21-25	0	0	0	0	1	2
26-30	0	0	0	0	0	1
Total	**68**	**68**	**68**	**68**	**66**	**66**

From Fig. 6.5 one can observe that the data range and the interquartile range for ANN method is the smallest when preparing model while it is the largest for non linear regression method while validating the model for both the RMSE and MAE scores. Thus it is clear from the box plots that ANN method is best suited for the present dataset.

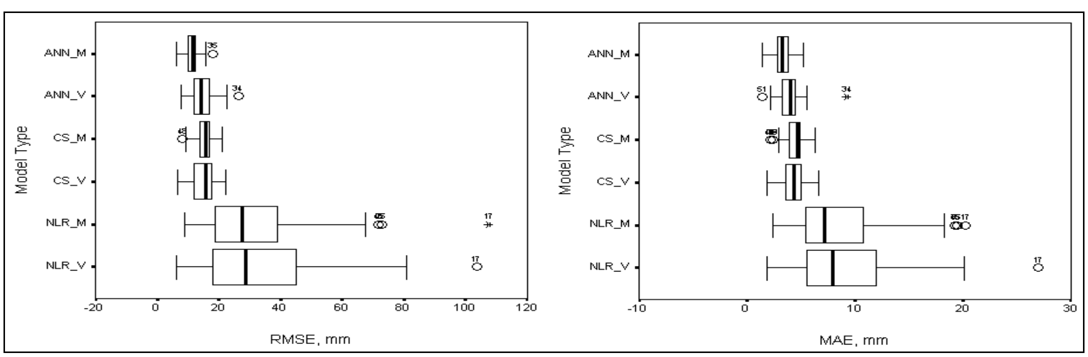


Fig. 6.5 Box plot for RMSE and MAE scores for model preparation and validation data.

mary of 68 best models selected considering the AIC ther conditional / categorical statistics as discussed earlier, for both model preparation and validation. From the Table 6.7 one can say that 66 models out of 68 have ANN method as the best. 2 models out of 68 have closest station method as the best while no model shows non linear regression as the best method for the model preparation. In case for model validation, 39 models show ANN, 26 models show closest station and 3 models show non linear regression method as the best.

Table 6.7 Results for the Models Developed Using the ANN, Closest Station and Non Linear Regression Methods

Model preparation data	**Model validation data**			**Total**
	ANN	**Closest station**	**Non linear regression**	
ANN	39	24	03	**66**
Closest station	00	02	0	**02**
Non linear regression	00	00	0	**0**
Total	**39**	**26**	**03**	**68**

In a nutshell, it can be concluded that the ANN method is the best to fill in the missing daily rainfall data.

6.3 PROBABILITY DISTRIBUTION

The statistical measures of the dataset for one and consecutive 2 to 7 & 10 days maximum rainfall i.e. mean, minimum, maximum, range, etc. are calculated for the 48 years (1961 to 2008) and the results are presented in the Fig.s 6.6 to 6.13.

From the Fig.s 6.6 to 6.13 it is observed that Visnagar raingauge station received the highest maximum, one day to consecutive 2 to 7 & 10 days maximum rainfall (indicated by green line in Figs. 6.6 to 6.13). The maximum value of one day to consecutive 2 to 7 & 10 days rainfall observed are 834 mm (25th June 1997), 1,042 mm, 1,166 mm, 1,180 mm, 1,187 mm, 1,193 mm, 1,193 mm and 1,193 mm respectively. This maximum values observed for 73 raingauge stations are observed for the same 1997 year. But for other raingauge stations the storm years are different. For 73 raingauge stations the maximum value plot shows many fluctuations.

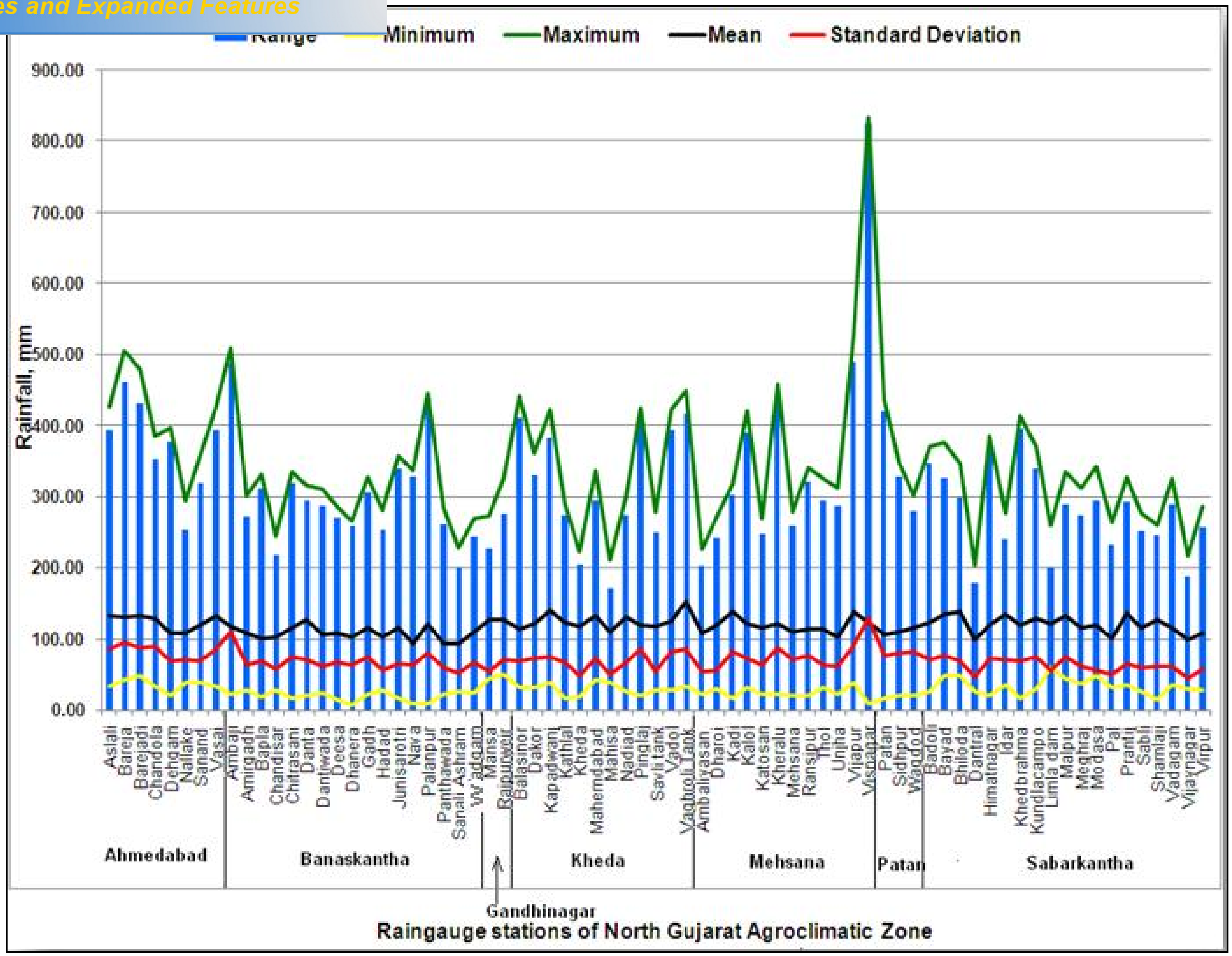


Fig. 6.6 One day maximum rainfall range, minimum, maximum, mean and standard deviation for raingauge stations in north Gujarat agroclimatic zone

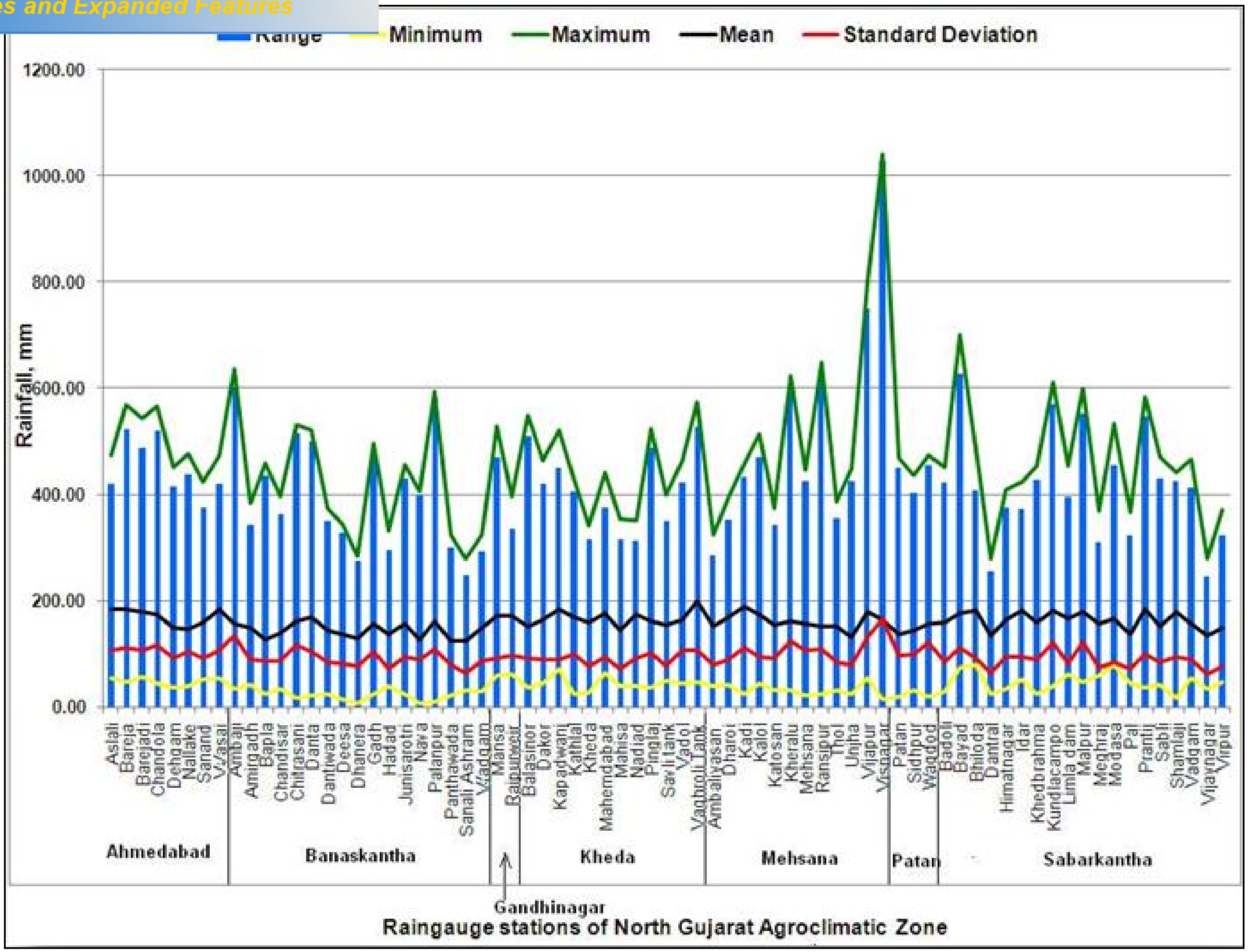


Fig. 6.7 Consecutive 2 days maximum rainfall range, minimum, maximum, mean and standard deviation for raingauge stations in north Gujarat agroclimatic zone

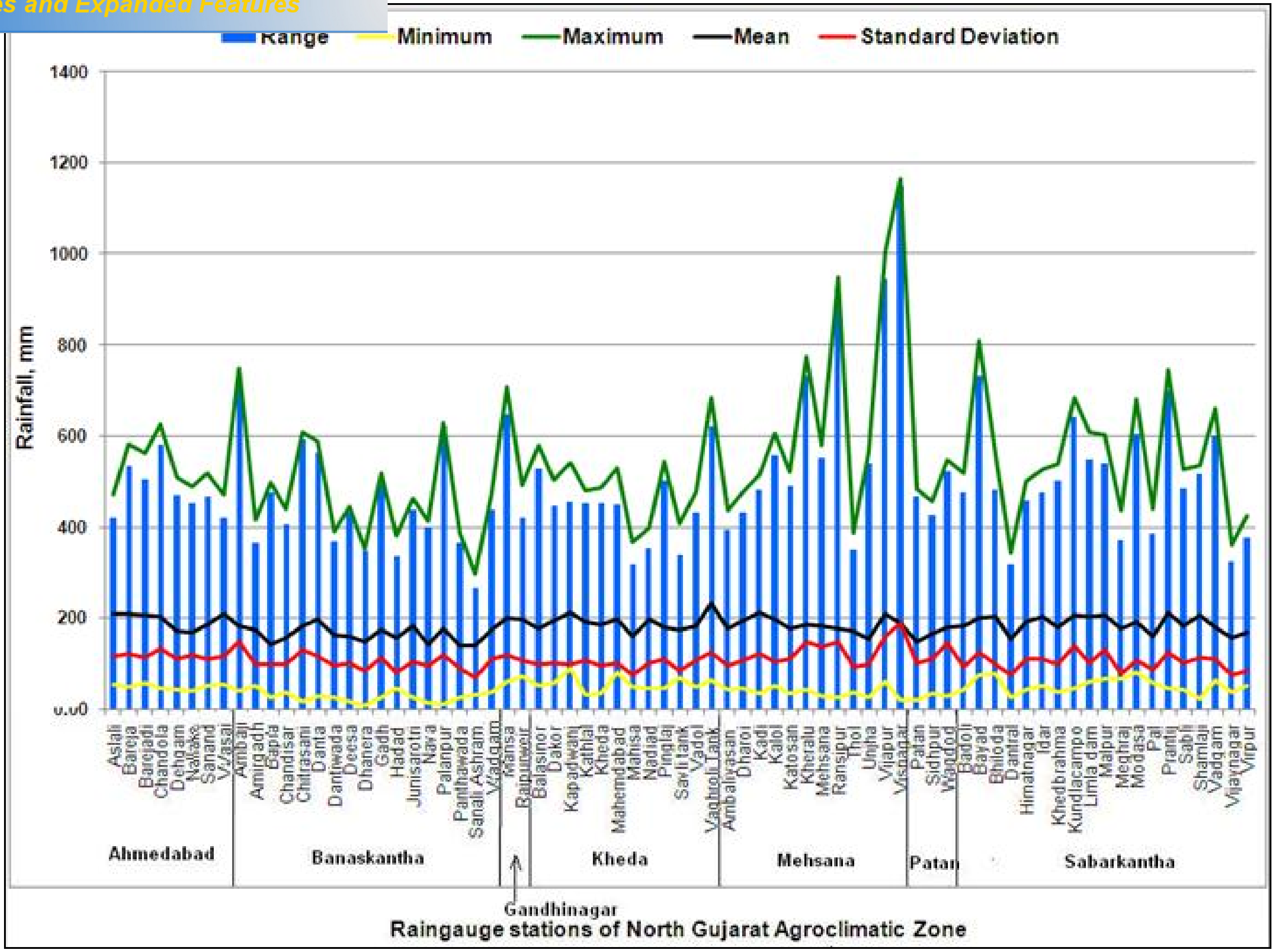


Fig. 6.8 Consecutive 3 days maximum rainfall range, minimum, maximum, mean and standard deviation for raingauge stations in north Gujarat agroclimatic zone

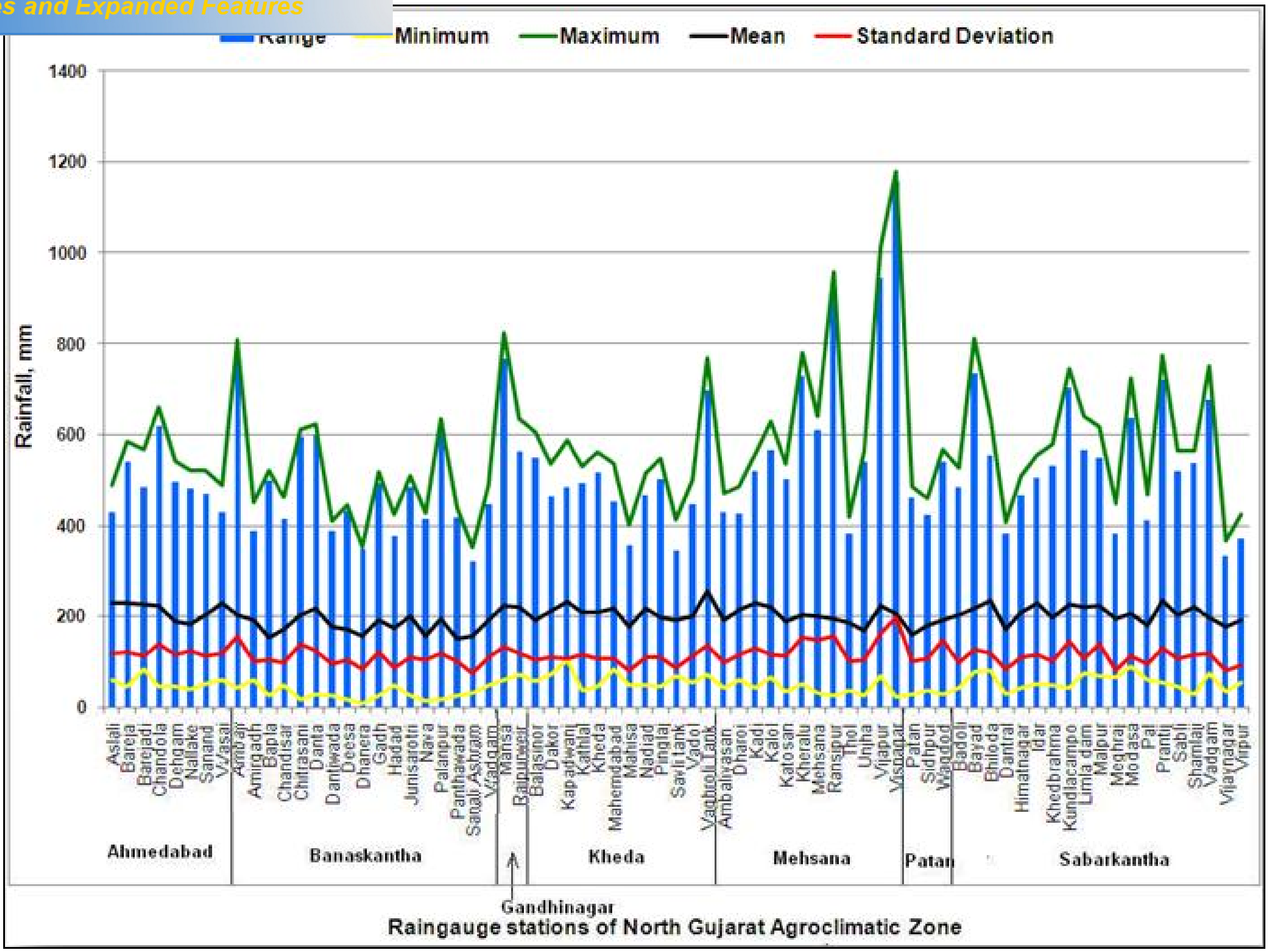


Fig. 6.9 Consecutive 4 days maximum rainfall range, minimum, maximum, mean and standard deviation for raingauge stations in north Gujarat agroclimatic zone

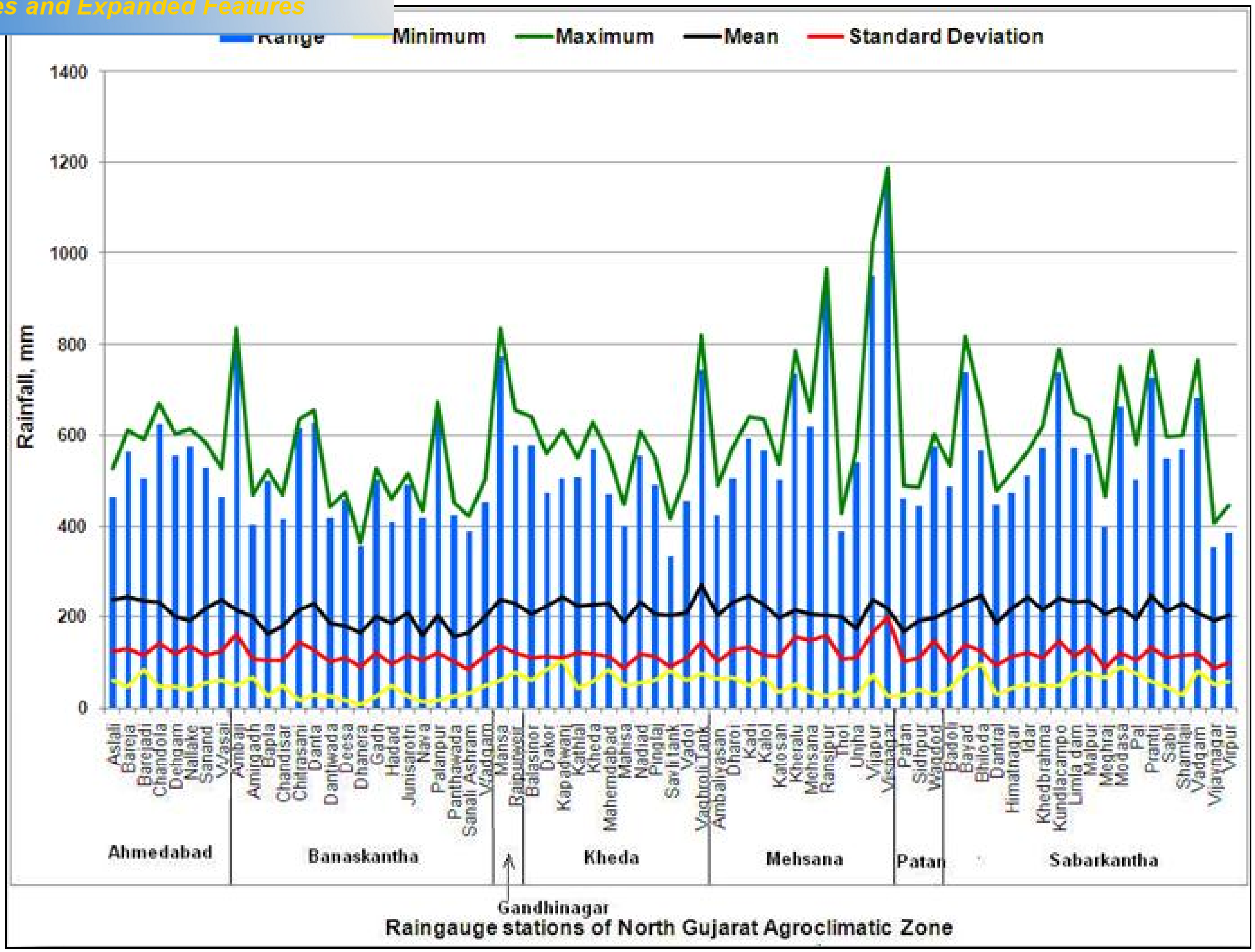


Fig. 6.10 Consecutive 5 days maximum rainfall range, minimum, maximum, mean and standard deviation for raingauge stations in north Gujarat agroclimatic zone

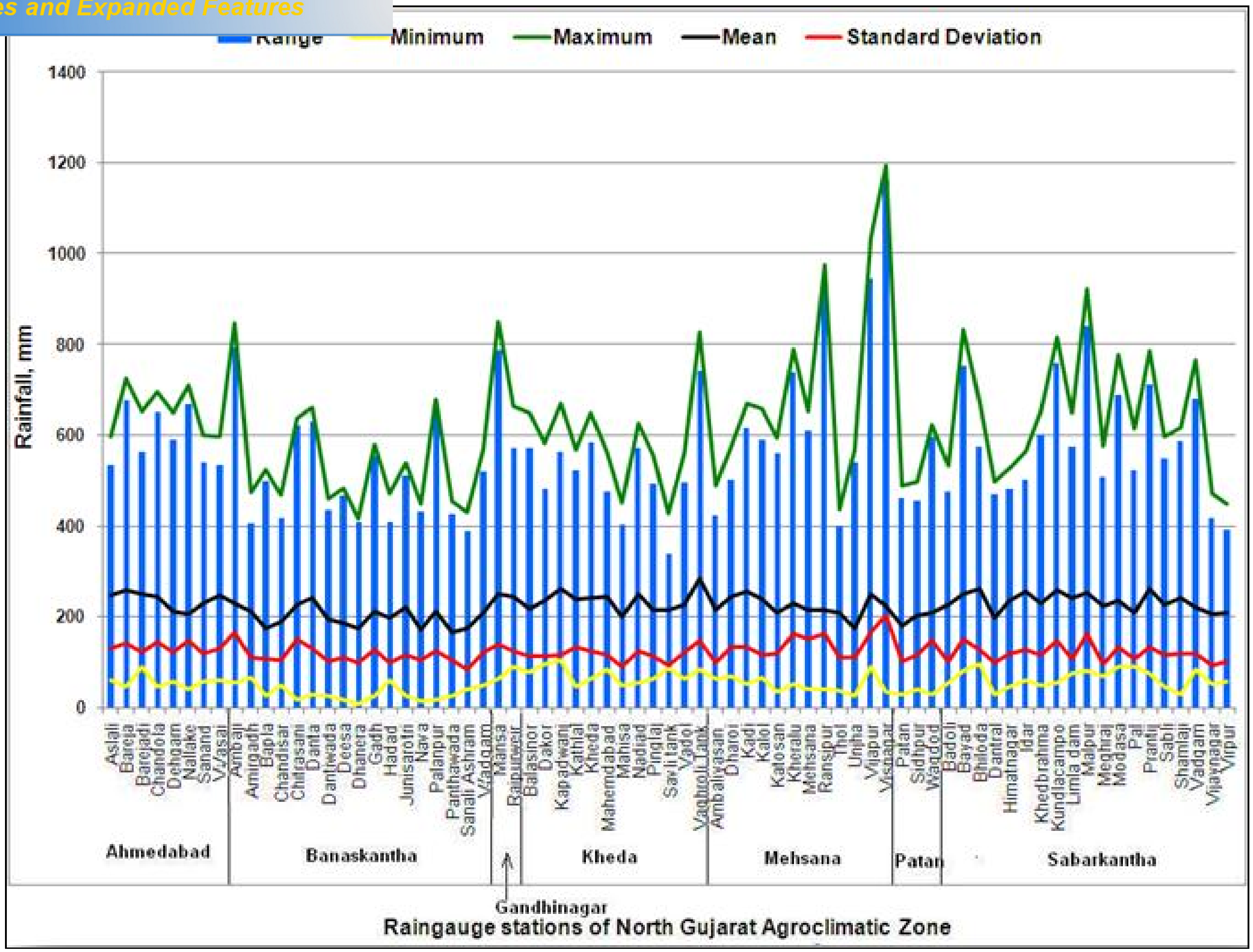


Fig. 6.11 Consecutive 6 days maximum rainfall range, minimum, maximum, mean and standard deviation for raingauge stations in north Gujarat agroclimatic zone

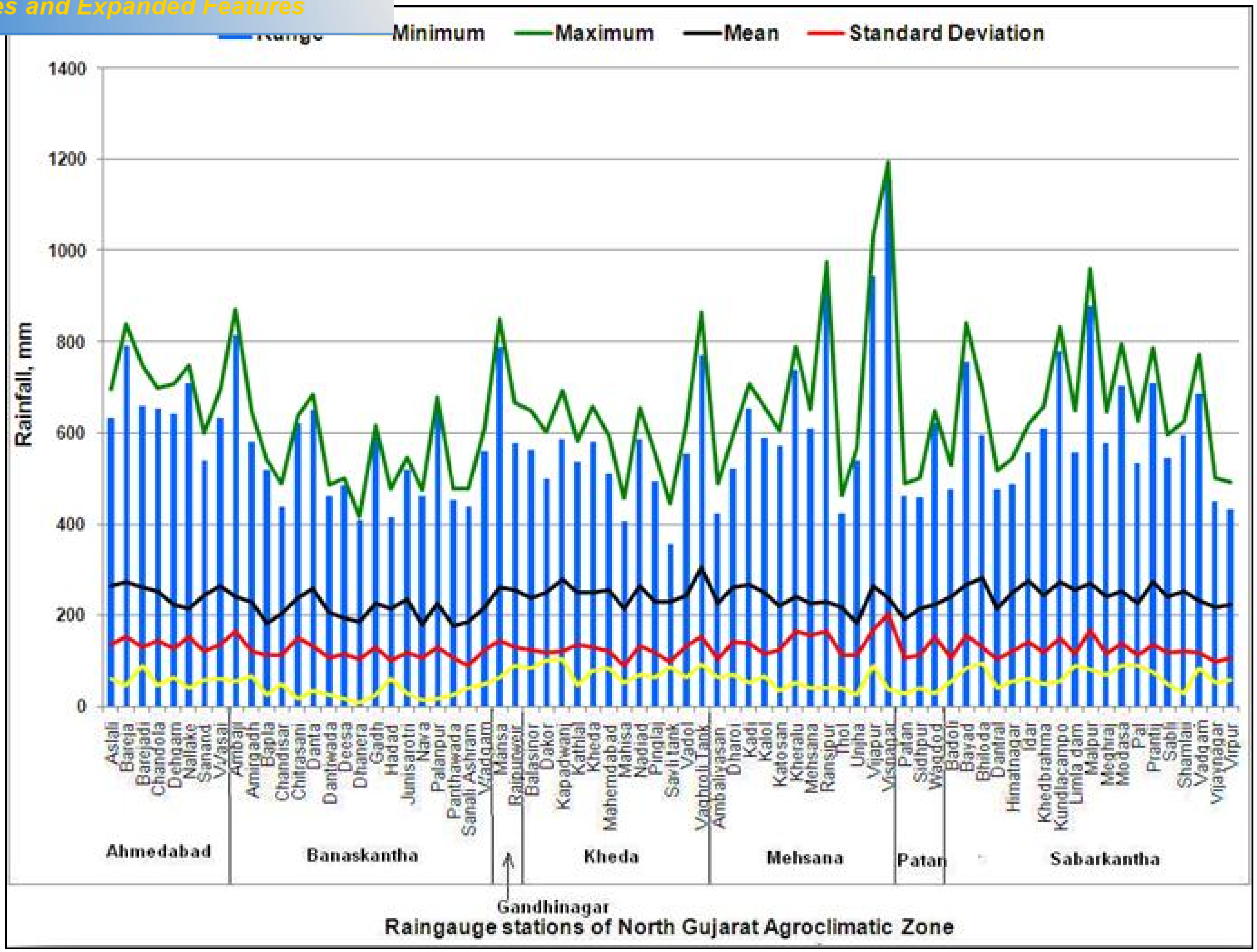


Fig. 6.12 Consecutive 7 days maximum rainfall range, minimum, maximum, mean and standard deviation for raingauge stations in north Gujarat agroclimatic zone

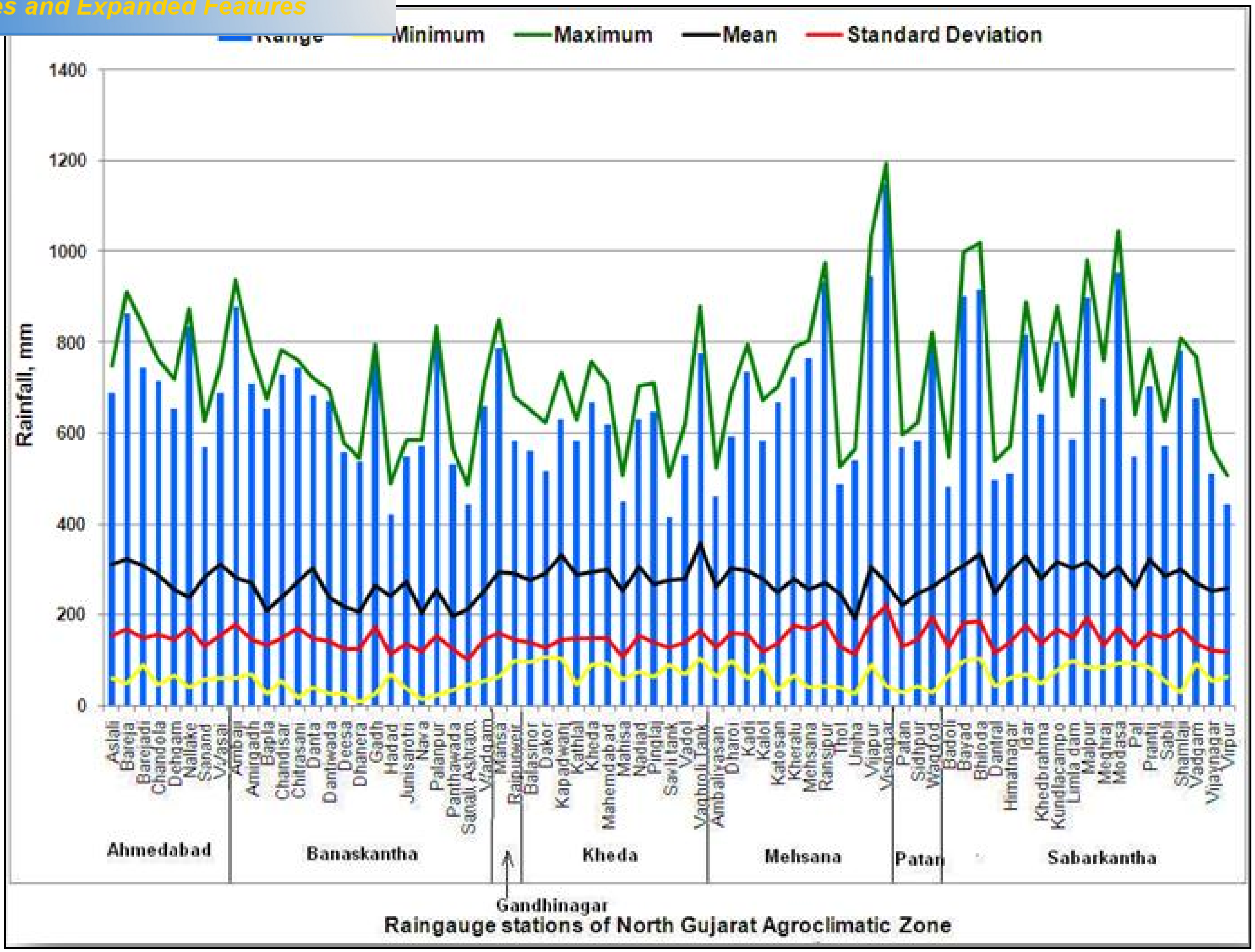


Fig. 6.13 Consecutive 10 days maximum rainfall range, minimum, maximum, mean and standard deviation for raingauge stations in north Gujarat agroclimatic zone

maximum value line (indicated by green colour in tern differs from one to 2 and 2 to 3 but remains almost constant for 3 to 7 days for a given raingauge station. Thus one can say in general that the storms affecting the total rainfall value are observed for one to consecutive 2 and 3 days. For consecutive 4 to 7 days the accumulated rainfall value increases but with less impact on the total amount which does not affect the maximum rainfall pattern line. For consecutive 10 days the accumulated rainfall value shows considerable increase in the total amount of rainfall obtained. Fig. 6.14 shows the plot of one day and consecutive 2 to 7 & 10 days maximum rainfall for Visnagar raingauge station. The linear trend line (indicated by black line in Fig. 6.14) shows increasing trend for one day and consecutive 2 to 7 & 10 days maximum rainfall.

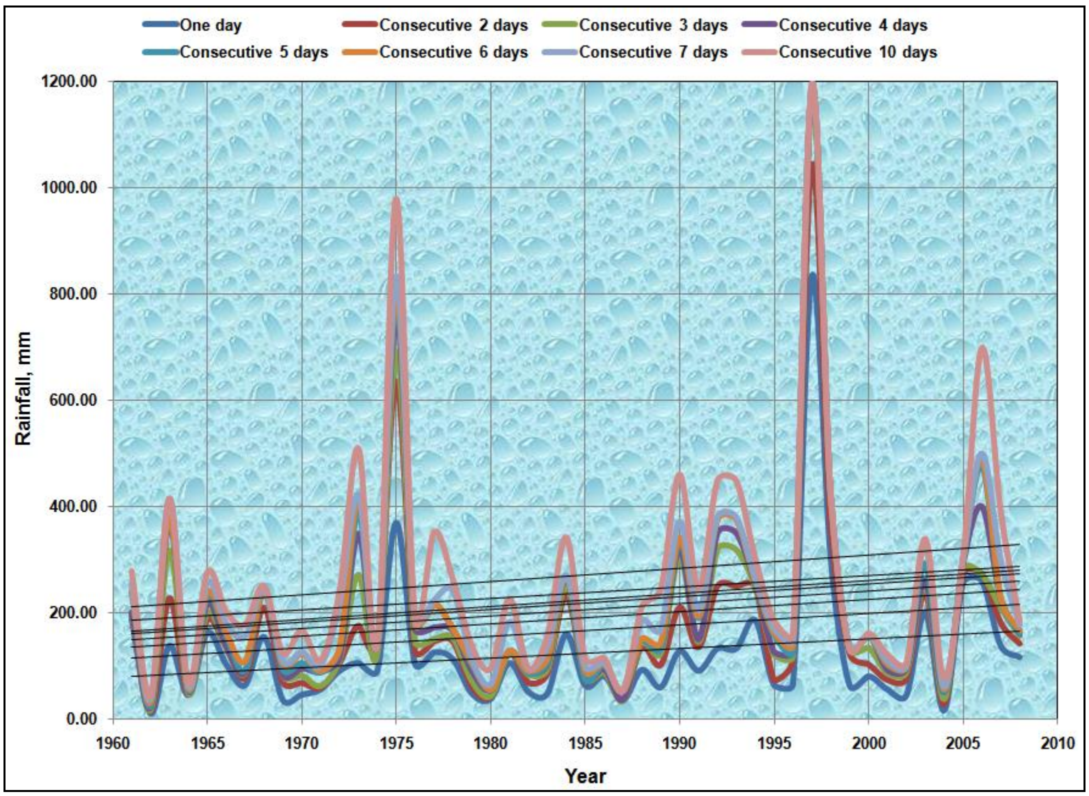


Fig. 6.14 One day to consecutive 2 to 7 & 10 days maximum rainfall for Visnagar raingauge station.

If one observes the minimum values (indicated by yellow line in Figs. 6.6 to 6.13), Dhanera raingauge station show the lowest value of 7 mm (29th June 1987) each for maximum one day to consecutive 2 to 7 & 10 days. The lue is less compared to the maximum value. Fig. e day and consecutive 2 to 7 & 10 days maximum rainfall for Dhanera raingauge station.

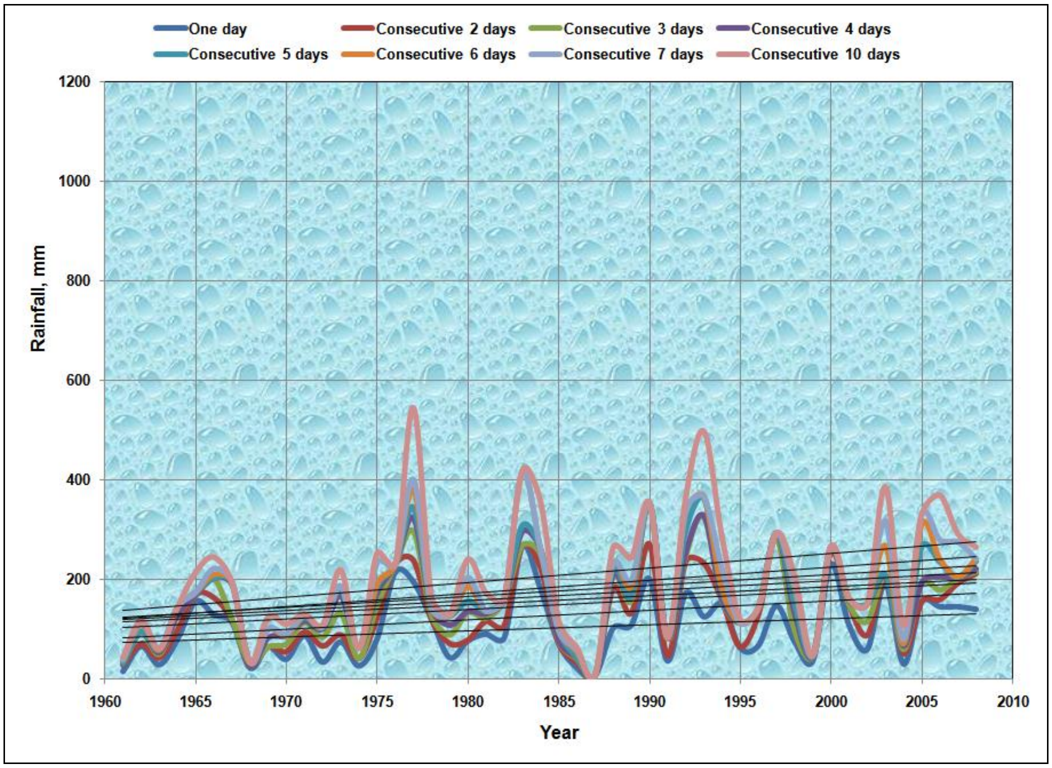


Fig. 6.15 One day to consecutive 2 to 7 & 10 days maximum rainfall for Dhanera raingauge station.

The highest mean value (indicated by black line in Figs. 6.6 to 6.13) of one day and consecutive 2 to 7 & 10 days maximum rainfall is obtained for Vaghroli tank with 153 mm, 200 mm, 233 mm, 255 mm, 270 mm, 285 mm, 304 mm and 359 mm respectively. Lowest mean value of 93 mm and 124 mm for one day and consecutive 2 days rainfall respectively, is observed at Sanali Ashram. At Panthawada the lowest mean value observed for consecutive 3, 4, 5, 6 & 7 days maximum rainfall are 140 mm, 150 mm, 157 mm, 166 mm and 176 mm respectively. At Unjha the same for consecutive 10 days maximum rainfall of 190 mm is observed. The standard deviation varies from 45.07 mm at Vijaynagar raingauge station to 221.02 mm at Visnagar considering all the raingauge stations for all 584 (= 73 x 8) datasets. The mean and standard deviation lines show less fluctuation.

eeds to be studied for proper planning of the water around the region consisting of diverse rainfall pattern. Tables 6.8 and 6.9 present the results obtained by determining best probability function for one of the raingauge station, Aslali situated in Ahmedabad district. Similar results are obtained for other 72 raingauge stations, and presented in Tables 6.10 to 6.153 and are provided in the CD.

Table 6.8 AIC for Aslali Raingauge Station, Ahmedabad District

Name of probability distribution	1D	C2D	C3D	C4D	C5D	C6D	C7D	C10D
Birnbaumï Saunders	525	553	568	576	582	588	594	612
Exponential	554	584	598	607	613	617	622	636
Extreme value	571	594	598	601	605	614	621	633
Gamma	527	555	567	574	580	586	592	609
Generalized extreme value	527	556	570	577	583	589	594	612
Generalized Pareto	549	576	574	578	584	591	598	614
Inverse Gaussian	437	465	480	488	494	500	506	525
Logï Logistic	525	555	569	577	582	588	594	612
Logistic	539	566	576	583	588	595	601	618
Lognormal	525	553	568	576	581	587	593	611
Nakagami	533	559	570	576	582	588	594	609
Normal	545	570	578	583	589	596	602	617
Rayleigh	531	557	568	575	580	586	592	608
Rician	533	559	570	577	582	588	594	610
t locationï scale	536	567	578	585	591	597	603	619
Weibull	532	559	570	576	582	588	594	610

Table 6.9 BIC for Aslali Raingauge Station, Ahmedabad District

Name of probability distribution	1D	C2D	C3D	C4D	C5D	C6D	C7D	C10D
Birnbaumï Saunders	529	557	572	579	585	591	597	616
Exponential	556	586	599	608	615	619	623	638
Extreme value	575	597	601	605	609	617	625	637
Gamma	531	559	571	578	584	590	595	613
Generalized extreme value	533	562	576	583	588	594	600	617
Generalized Pareto	555	582	580	584	590	597	604	620
Inverse Gaussian	441	469	484	491	498	504	510	528
Logï Logistic	529	559	573	580	586	592	597	616
Logistic	543	570	580	587	592	599	604	621
Lognormal	529	557	572	579	585	591	597	615
Nakagami	536	563	573	580	585	592	597	613
Normal	549	574	582	587	592	600	606	620
Rayleigh	533	559	570	576	582	588	594	609
Rician	537	563	574	580	586	592	598	613
t locationï scale	542	572	584	591	596	603	608	624
Weibull	536	563	574	580	586	592	598	613

Note: 1Dï One day; C2Dï Consecutive 2 days; C3Dï Consecutive 3 days; C4Dï Consecutive 4 days; C5Dï Consecutive 5 days; C6Dï Consecutive 6 days; C7Dï Consecutive 7 days; C10Dï Consecutive 10 days lues presented in Table 6.8 to 6.153, one can say ne best fitted distribution for all the stations for one day and consecutive 2 to7 & 10 days maximum rainfall. The probability density function (pdf) for the fitted distribution is

$$y = f(x|\lambda,\mu) = \sqrt{\frac{\lambda}{2\pi x^3}}\ \exp\left\{-\frac{\lambda}{2\mu^2 x}(x-\mu)^2\right\} \tag{6.1}$$

Where

ε (mu) = scale parameter; μ>0 is the mean of the distribution

λ (lambda) = shape parameter

It is observed that the second ranking probability distributions differ when comparing AIC and BIC. According to AIC ranking, Birnbaumï Saunders for 176 (30.1 %) datasets, Rayleigh for 110 (18.8 %) datasets, Log Logistic for 98 (16.8 %) dataset, Lognormal for 54 (9.2 %) dataset, Generalized Extreme for 17 (2.9 %), Generalized Pareto for 32 (9.2 %), Gamma for 88 (15.1 %), Nakagami for 3 (0.5%) and Weibull, Logistic and Exponential for 2 (0.3 %) each, are at second position, out of 584 dataset.

According to BIC ranking, Rayleigh for 206 (35 %) datasets, Birnbaumï Saunders for 168 (29 %) dataset, Log Logistic for 94 (16 %) dataset, Lognormal for 53 (9 %) dataset and Generalized Pareto for 15 (3 %), Gamma for 37 (6 %) dataset, Generalized Extreme for 7 (1 %) dataset, Logistic for 2 (0.3 %) dataset and Weibull and Exponential for 1 (0.2 %) dataset, are at second position out of 584 dataset.

Though these distributions are second ranked the difference between the AIC and BIC values of the best distribution i.e. inverse Gaussian and the second best distribution is very large in the range of 69ï 193 units. While the difference between the second best distribution and distributions ranking third to sixteen are in the range of 1ï 29. Thus the first best distribution is considered for further analysis.

Extreme value and exponential probability distributions are commonly used for hydrological analysis by many practicing researchers and hydrologists. It is alue probability distribution ranked 16th (i.e. last) in 357 (61.1 %) datasets out of 584 datasets and exponential distribution ranked 16th for 223 (38.2 %) cases while for rest 4 (0.7 %) cases Birnbaumï Saunders ranked 16th based on AIC values. Based on BIC values it is observed that extreme value probability distribution ranked 16th (i.e. last) among the 16 distributions in 213 (36.5 %) datasets, exponential distribution ranked 16th for 366 (62.7 %) cases and Birnbaumï Saunders ranked 16th for rest of the 5 (0.9 %) cases out of 584 datasets. Figs. 6.16 and 6.17 represents the first ranked and sixteen ranked probability distribution respectively to the dataset for Aslali raingauge station.

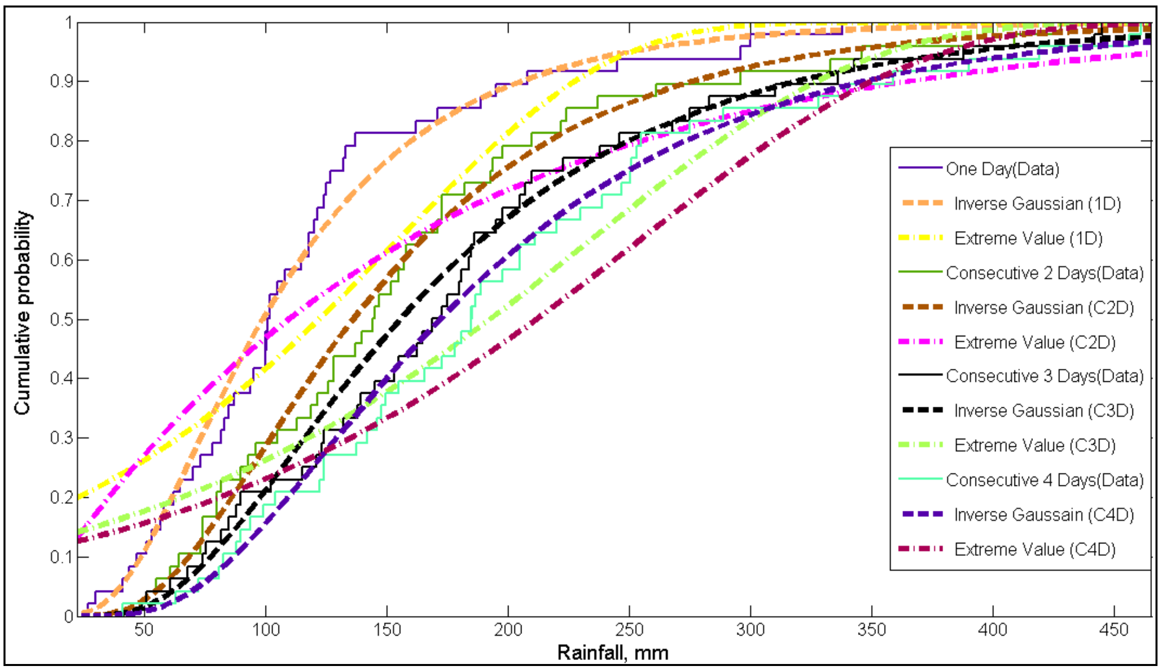


Fig. 6.16 First and sixteenth ranked probability distribution to the one day and consecutive 2 to 4 days maximum rainfall series of Aslali raingauge station

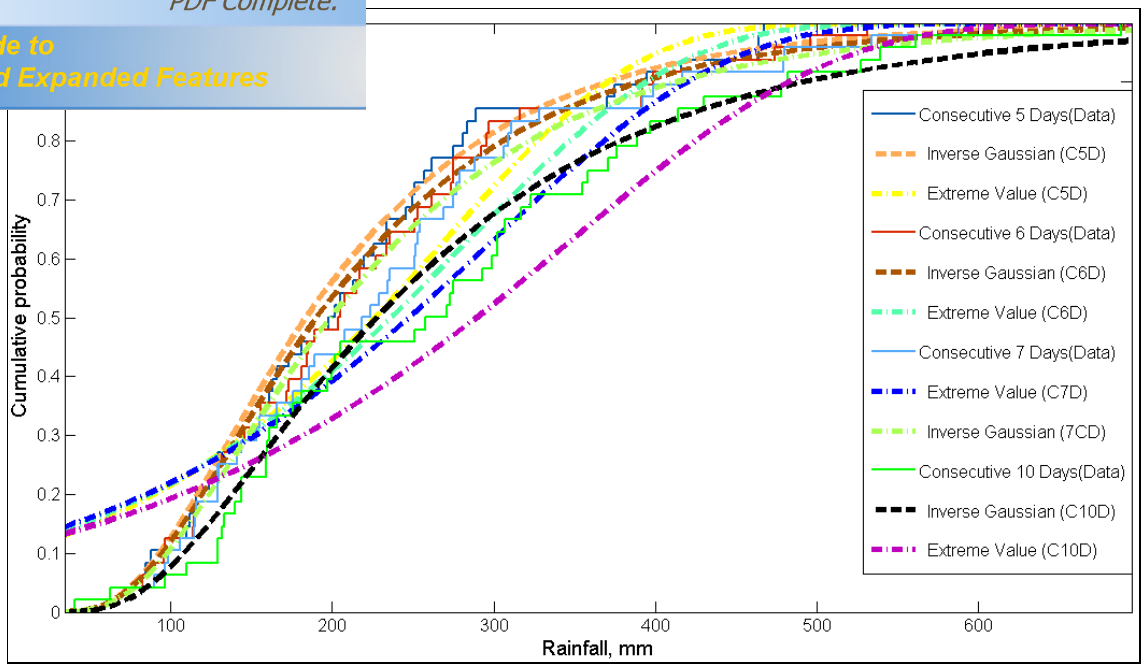
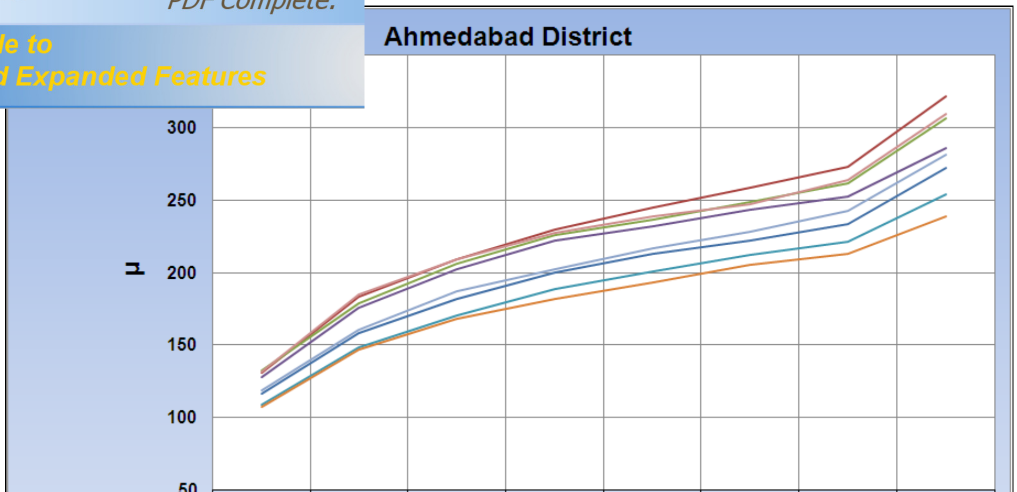


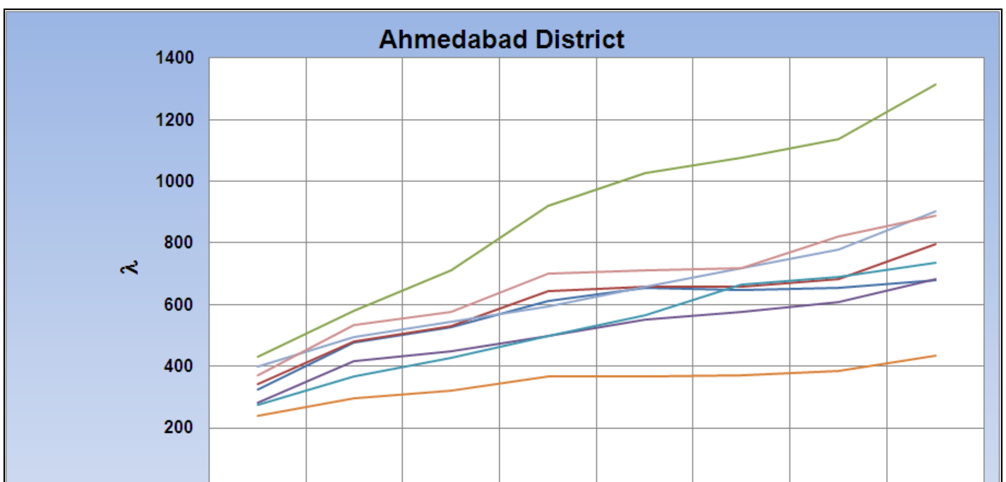
Fig. 6.17 First and sixteenth ranked probability distribution to the consecutive 5 to 7 and 10 days maximum rainfall series of Aslali raingauge station

Each station has eight dataset (one day and consecutive 2 to 7 &10 days maximum rainfall). Thus 584 different datasets have been analyzed for 73 raingauge stations. One can say that though there are different datasets for different raingauge stations the best fitted distribution at the first place is unique (i.e. Inverse Gaussian) according to both AIC and BIC. For the same distribution, there are varying populations described by the 584 different datasets having different values of the distribution parameters, μ and λ presented in Figs 6.18 to 6.31. The value of μ ranges from 92.88 to 358.09 for the raingauge stations in the study area while that for λ ranges from 108.50 to 1647.06. From Figs. 6.18 to 6.31 one can observe that the plots for μ values for the districts are parallel to each other while those for λ are varying and lines are intersecting each other. A shape parameter affects the shape of a distribution rather than simply shifting it (as a location parameter does) or stretching/shrinking it (as a scale parameter does). Therefore the intersecting lines for λ indicate the varying shapes in the population of the rainfall data of the region indicating no uniform pattern.



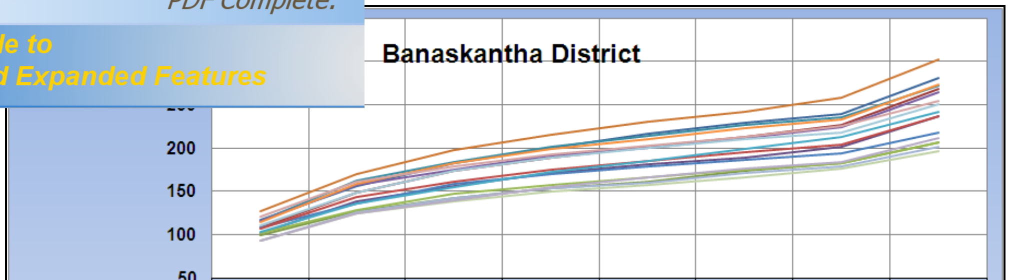
	1 D	C 2 D	C 3 D	C 4 D	C 5 D	C 6 D	C 7 D	C 10 D
Aslali	116.16	158.44	182.00	199.76	212.93	222.49	233.70	272.17
Bareja	131.15	183.52	209.09	229.67	245.02	258.92	273.12	321.91
Barejadi	132.62	179.20	206.44	225.73	236.84	248.86	261.43	306.77
Chandola	127.93	175.68	202.25	221.91	232.04	243.66	252.44	286.01
Dehgam	108.58	148.17	170.58	189.05	200.53	212.39	221.25	253.76
Nallake (Vekariya)	107.30	146.98	168.07	181.64	193.05	205.36	212.90	238.84
Sanand	118.76	160.36	187.44	202.11	216.92	228.59	243.08	281.52
Wasai	131.72	184.87	209.16	227.73	238.68	247.30	264.01	310.00

Fig. 6.18 Mean μ for one day and consecutive 2 to 7 & 10 days for raingauge stations situated in Ahmedabad district



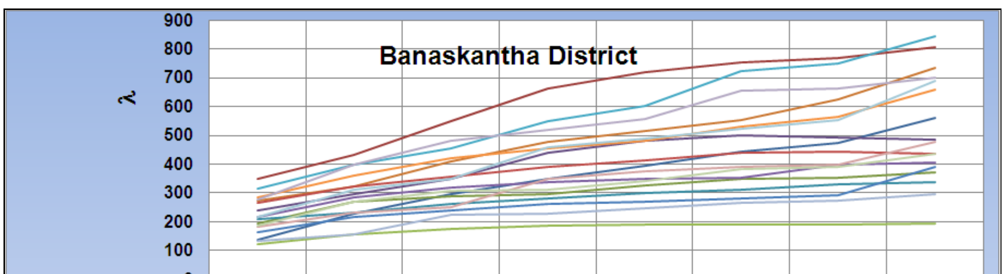
	1 D	C 2 D	C 3 D	C 4 D	C 5 D	C 6 D	C 7 D	C 10 D
Aslali	325.60	476.00	528.11	611.21	654.76	646.79	654.29	678.01
Bareja	343.57	480.42	530.99	643.82	657.35	656.75	683.85	796.98
Barejadi	429.97	579.91	710.26	922.10	1025.55	1077.24	1135.43	1313.96
Chandola	281.69	414.96	448.37	496.61	552.21	577.89	607.83	683.54
Dehgam	274.36	368.65	426.73	497.73	567.39	664.70	689.27	736.38
Nallake (Vekariya)	240.70	295.76	322.55	366.51	368.21	369.45	384.91	434.77
Sanand	399.41	494.56	543.92	594.83	657.84	718.93	778.93	901.88
Wasai	369.32	532.36	574.76	700.55	710.87	718.22	819.65	887.12

Fig. 6.19 Shape parameter, λ for one day and consecutive 2 to 7 & 10 days for raingauge stations situated in Ahmedabad district



	1 D	C 2 D	C 3 D	C 4 D	C 5 D	C 6 D	C 7 D	C 10 D
Ambaji	116.85	156.75	182.98	200.89	216.32	228.98	239.57	280.61
Amirgadh	108.73	148.21	173.94	189.31	201.39	212.76	227.20	268.33
Bapla	99.78	126.96	142.37	153.26	161.76	173.58	183.11	206.83
Chandisar	101.89	139.15	156.84	170.84	181.24	189.44	202.05	236.42
Chitrasani	116.02	162.98	184.50	201.24	214.71	226.44	235.65	272.31
Danta	127.13	170.37	197.38	216.00	230.12	242.00	258.22	302.34
Deesa	108.00	136.29	158.74	170.11	179.03	185.93	194.38	217.80
Dantiwada	106.56	143.70	161.70	174.53	184.87	195.42	204.14	236.65
Dhanera	101.74	128.06	147.61	156.97	165.95	175.65	183.17	206.32
Gadh	115.48	157.02	174.67	191.24	200.26	211.43	224.90	265.10
Hadad	103.06	136.16	155.41	172.07	185.49	198.51	212.91	241.52
Junisarotri	114.67	158.18	182.71	198.75	210.96	222.55	232.79	273.46
Nava	93.81	126.20	142.43	154.26	160.34	170.84	178.84	202.13
Palanpur	121.03	160.91	178.63	192.50	203.45	213.27	225.47	254.73
Panthawada	93.40	125.28	139.02	149.69	157.21	165.89	175.85	196.94
Sanali Ashram	92.88	124.21	139.75	154.43	166.27	175.83	184.31	211.11
Wadgam	110.73	149.12	173.88	189.22	200.44	210.76	217.62	251.04

Fig. 6.20 Mean μ for one day and consecutive 2 to 7 & 10 days for raingauge stations situated in Banaskantha district



	1 D	C 2 D	C 3 D	C 4 D	C 5 D	C 6 D	C 7 D	C 10 D
Ambaji	139.03	229.56	297.11	350.63	394.98	441.97	472.27	558.91
Amirgadh	349.32	430.57	549.12	664.28	720.54	754.89	766.96	804.63
Bapla	193.57	267.87	289.49	294.68	327.12	350.06	350.99	370.13
Chandisar	240.95	297.63	348.30	441.20	481.33	500.12	491.29	485.16
Chitrasani	210.30	233.30	261.46	281.76	298.49	312.70	328.46	338.13
Danta	275.19	321.78	407.65	478.57	516.48	552.84	625.64	734.19
Deesa	164.48	216.31	238.98	263.19	270.48	279.50	290.45	390.51
Dantiwada	265.44	321.96	357.80	389.43	414.50	438.52	443.77	436.25
Dhanera	121.76	158.09	175.75	186.96	188.96	191.61	190.81	193.96
Gadh	215.96	284.18	318.42	337.50	349.41	353.50	397.16	406.43
Hadad	314.94	399.84	455.88	550.34	602.17	723.79	749.70	844.37
Junisarotri	284.48	360.97	419.69	453.94	479.81	528.54	565.71	659.86
Nava	131.72	158.08	224.95	227.22	248.74	267.39	275.27	296.25
Palanpur	182.24	230.46	250.30	348.71	375.65	391.22	399.37	477.57
Panthawada	185.41	268.66	306.77	312.45	340.12	381.83	391.40	435.65
Sanali Ashram	278.66	399.73	480.92	518.38	556.72	654.79	662.82	700.91
Wadgam	216.97	312.91	348.95	457.49	487.90	522.57	553.95	687.31

Fig. 6.21 Shape parameter, λ for one day and consecutive 2 to 7 & 10 days for raingauge stations situated in Banaskantha district

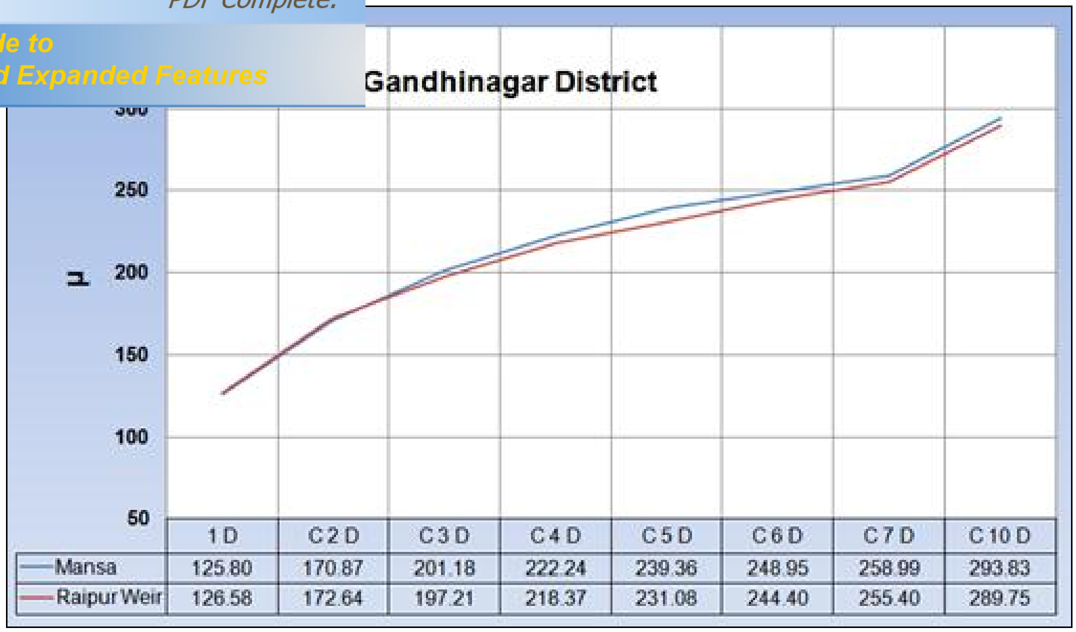


Fig. 6.22 Mean μ for one day and consecutive 2 to 7 & 10 days for raingauge stations situated in Gandhinagar district

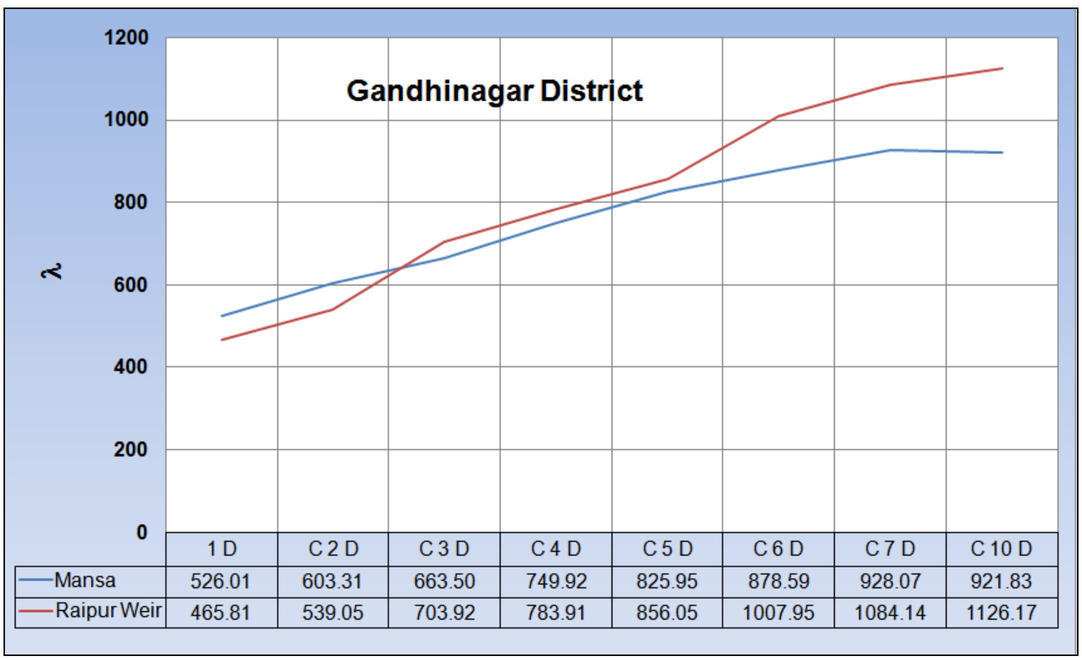
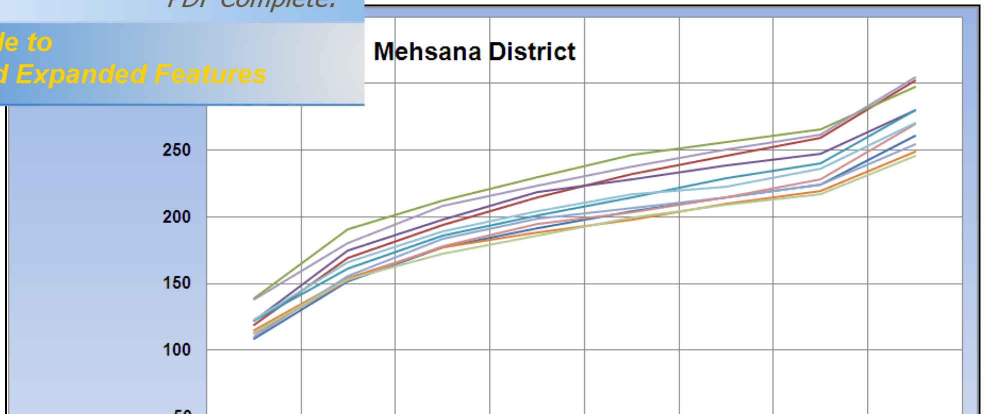
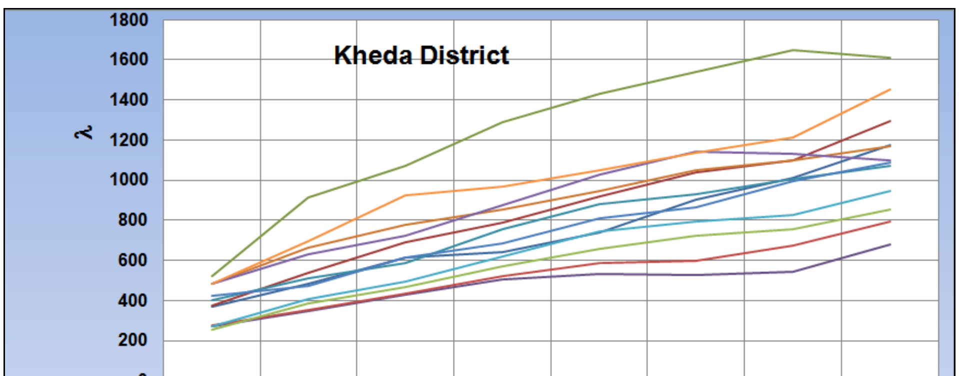


Fig. 6.23 Shape parameter, λ for one day and consecutive 2 to 7 & 10 days for raingauge stations situated in Gandhinagar district



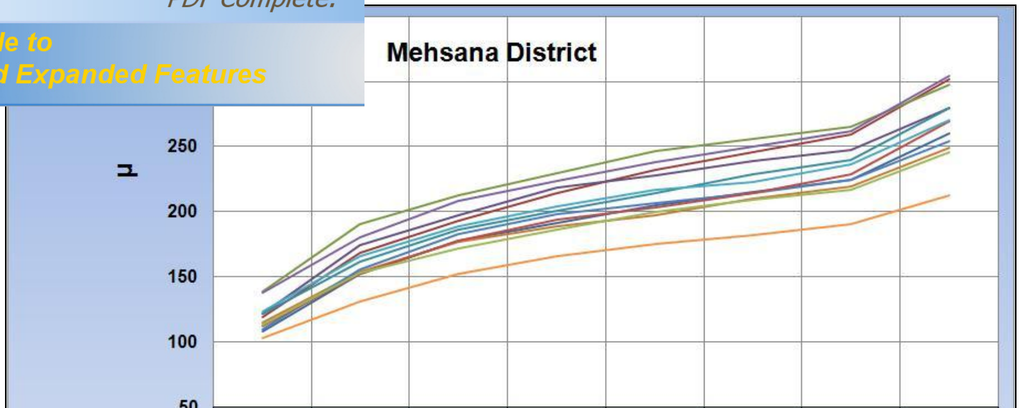
	1 D	C 2 D	C 3 D	C 4 D	C 5 D	C 6 D	C 7 D	C 10 D
Ambaliyasan	108.50	151.95	177.50	191.18	204.63	215.00	224.33	260.54
Dharoi	119.34	168.80	193.51	214.63	232.45	245.34	259.34	302.19
Kadi	138.83	190.40	212.47	229.63	246.28	255.92	265.65	297.30
Kalol	121.75	174.78	197.70	218.38	228.18	238.70	247.25	279.70
Kheralu	121.94	161.40	186.31	201.04	214.26	228.86	239.76	279.82
Katosan	115.16	154.39	177.25	188.50	197.63	209.68	219.03	248.73
Mehsana	109.80	155.75	183.32	198.60	206.75	214.61	224.14	254.11
Ransipur	112.74	152.71	178.16	194.38	203.35	214.49	228.54	269.53
Thol	113.63	152.87	172.19	185.96	199.74	209.06	217.14	245.81
Vijapur	138.00	180.18	208.15	223.63	237.93	250.17	261.73	304.75
Visnagar	123.25	165.62	189.19	204.12	217.11	222.90	236.47	270.07

Fig. 6.24 Mean µ for one day and consecutive 2 to 7 & 10 days for raingauge stations situated in Kheda district



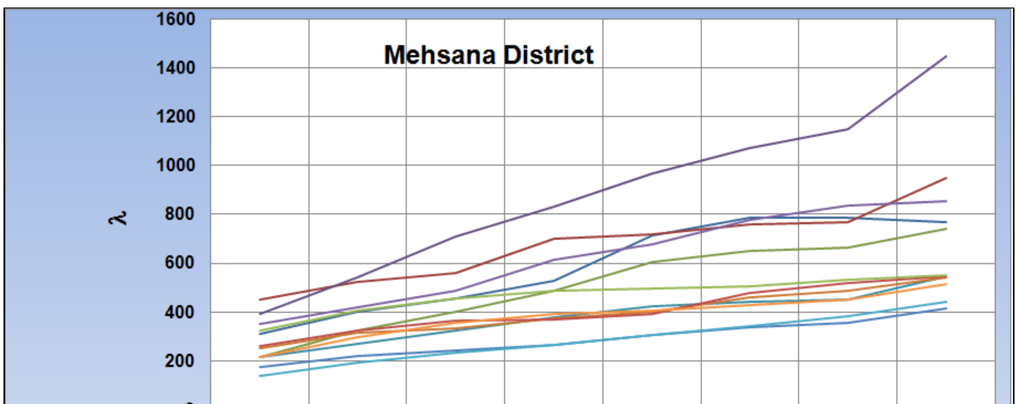
	1 D	C 2 D	C 3 D	C 4 D	C 5 D	C 6 D	C 7 D	C 10 D
Balasinor	371.72	485.91	612.01	638.79	739.09	903.37	1011.77	1173.48
Dakor	374.41	538.67	691.57	789.70	920.32	1037.02	1096.70	1294.19
Kapadwanj	520.35	910.91	1070.14	1290.91	1430.94	1539.88	1647.06	1612.04
Kathlal	272.77	348.16	431.59	502.87	534.55	529.23	541.37	682.04
Kheda	402.76	511.71	587.62	755.81	878.56	929.08	1007.52	1071.79
Mahemdabad	481.27	665.07	776.58	855.33	944.25	1050.22	1100.22	1172.03
Mahisa	426.00	471.34	612.16	686.56	807.40	864.43	996.84	1086.55
Nadiad	277.62	355.29	436.37	519.35	584.36	597.83	674.04	795.70
Pinglaj	254.07	385.95	469.76	570.61	659.60	723.96	753.03	852.04
Savli	481.96	630.81	720.45	876.20	1029.19	1141.67	1133.17	1099.19
Vadol	269.86	405.10	494.62	621.86	745.82	793.75	827.39	948.64
Vaghroli	481.22	693.47	923.07	969.79	1052.08	1134.85	1214.32	1451.95

Fig. 6.25 Shape parameter, λ for one day and consecutive 2 to 7 & 10 days for raingauge stations situated in Kheda district



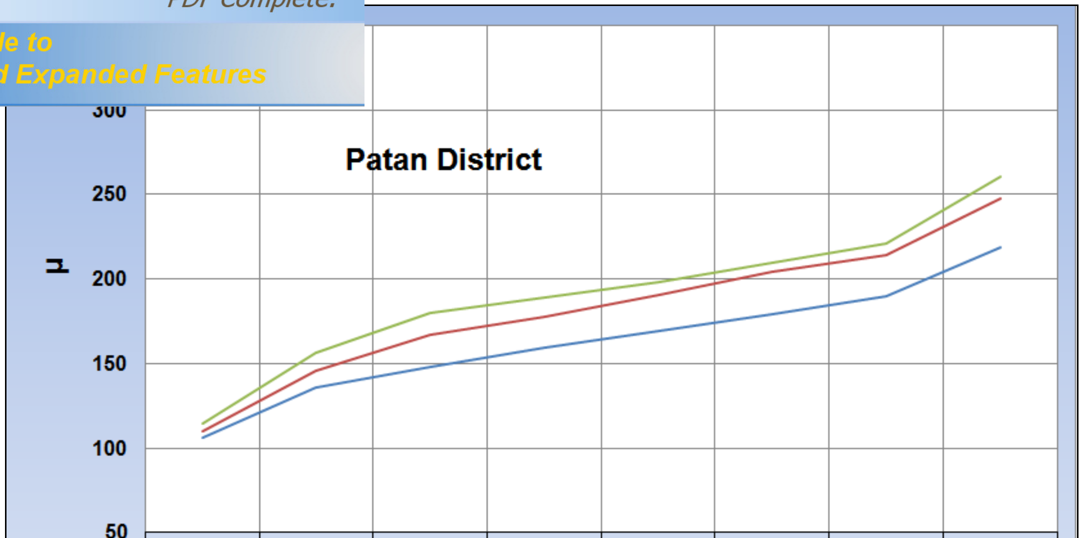
	1 D	C 2 D	C 3 D	C 4 D	C 5 D	C 6 D	C 7 D	C 10 D
Ambaliyasan	108.50	151.95	177.50	191.18	204.63	215.00	224.33	260.54
Dharoi	119.34	168.80	193.51	214.632	232.45	245.34	259.34	302.19
Kadi	138.83	190.40	212.47	229.63	246.28	255.92	265.65	297.30
Kalol	121.75	174.78	197.70	218.38	228.18	238.70	247.25	279.70
Kheralu	121.94	161.40	186.31	201.04	214.26	228.86	239.76	279.82
Katosan	115.16	154.39	177.25	188.50	197.63	209.68	219.03	248.73
Mehsana	109.80	155.75	183.32	198.60	206.75	214.61	224.14	254.11
Ransipur	112.74	152.71	178.16	194.38	203.35	214.49	228.54	269.53
Thol	113.63	152.87	172.19	185.96	199.74	209.06	217.14	245.81
Unjha	103.14	130.82	152.75	166.06	175.22	182.07	190.30	212.69
Vijapur	138.00	180.18	208.15	223.63	237.93	250.17	261.73	304.75
Visnagar	123.25	165.62	189.19	204.12	217.11	222.90	236.47	270.07

Fig. 6.26 Mean, μ for one day and consecutive 2 to 7 & 10 days for raingauge stations situated in Mehsana district



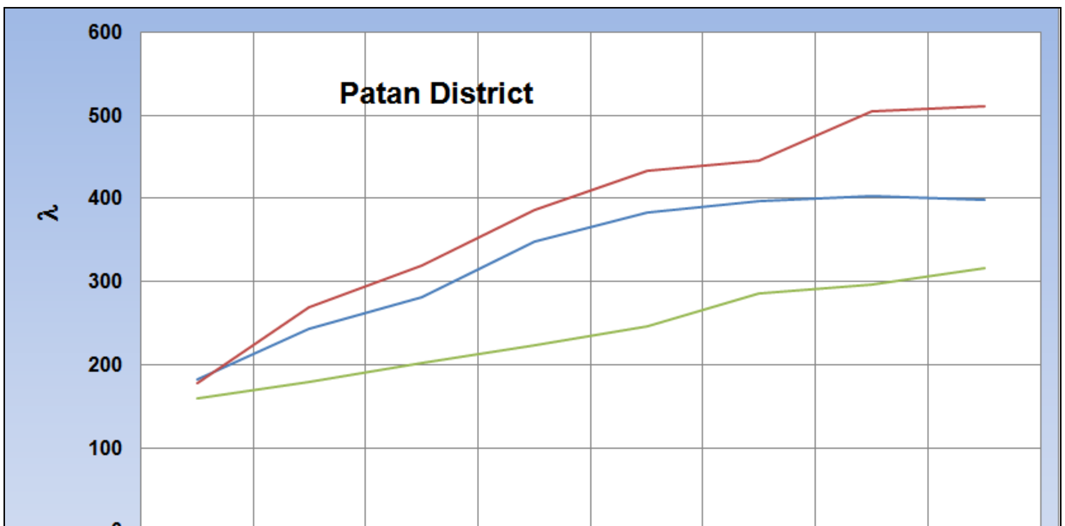
	1 D	C 2 D	C 3 D	C 4 D	C 5 D	C 6 D	C 7 D	C 10 D
Ambaliyasan	308.60	400.54	457.63	527.59	712.27	785.09	787.88	768.39
Dharoi	451.27	523.37	559.92	698.34	719.02	760.00	766.34	947.99
Kadi	213.69	323.02	401.31	485.10	605.31	651.77	665.53	742.25
Kalol	390.43	542.04	708.18	829.52	965.88	1072.96	1147.20	1448.35
Kheralu	214.79	270.28	325.48	377.68	422.89	439.57	451.82	544.75
Katosan	253.74	315.96	331.07	371.88	400.85	461.41	487.99	540.09
Mehsana	174.62	217.89	244.59	265.48	304.86	337.87	356.13	412.75
Ransipur	259.43	325.74	366.01	369.55	391.96	478.06	518.32	545.02
Thol	322.49	406.88	457.53	486.32	495.98	507.36	531.92	548.86
Unjha	216.69	295.46	354.98	389.84	406.83	428.30	450.92	513.57
Vijapur	353.37	418.50	489.01	615.75	675.59	776.93	835.94	853.09
Visnagar	138.27	191.74	233.23	265.52	305.82	341.42	384.47	439.75

Fig. 6.27 Shape parameter, λ for one day and consecutive 2 to 7 & 10 days for raingauge stations situated in Mehsana district



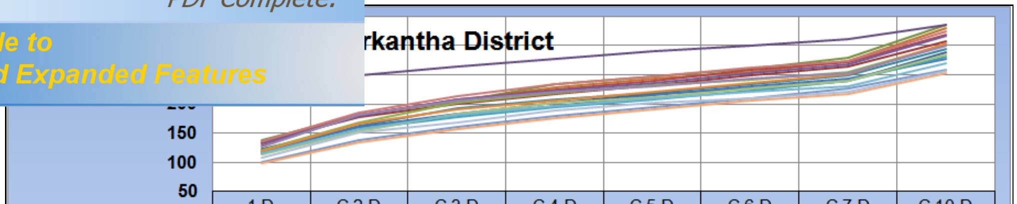
	1 D	C 2 D	C 3 D	C 4 D	C 5 D	C 6 D	C 7 D	C 10 D
Patan	106.034	135.714	148.306	159.845	169.465	179.409	189.535	218.752
Sidhpur	110.402	145.54	166.725	177.903	191.007	204.511	214.261	247.316
Wagdod	114.798	156.244	180.238	189.371	198.098	209.997	220.948	260.3

Fig. 6.28 Mean, μ for one day and consecutive 2 to 7 & 10 days for raingauge stations situated in Patan district



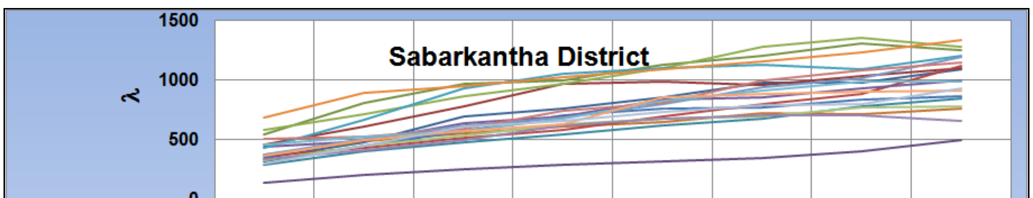
	1 D	C 2 D	C 3 D	C 4 D	C 5 D	C 6 D	C 7 D	C 10 D
Patan	183.183	243.605	281.09	348.914	383.784	396.909	402.46	398.623
Sidhpur	177.895	268.553	318.628	385.486	434.116	444.915	505.607	511.664
Wagdod	159.676	180.055	202.765	224.187	246.843	285.959	296.379	316.414

Fig. 6.29 Shape parameter, λ for one day and consecutive 2 to 7 & 10 days for raingauge stations situated in Patan district



	1 D	C 2 D	C 3 D	C 4 D	C 5 D	C 6 D	C 7 D	C 10 D
Badoli	123.64	160.50	182.82	202.55	216.19	225.87	239.65	287.97
Bayad	133.80	178.27	199.44	216.94	232.76	248.88	264.92	307.27
Bhiloda	138.81	182.13	203.23	233.83	247.24	260.99	279.32	335.06
Dantral	223.29	248.78	264.33	276.50	289.38	299.34	310.16	335.74
Himatnagar	118.39	163.38	193.09	207.82	219.44	234.42	248.33	294.06
Idar	133.63	181.85	205.06	228.85	243.62	254.77	274.03	329.18
Khedbrahma	119.35	159.88	180.66	196.27	215.75	230.56	242.84	277.60
Kundlacampo	128.67	181.64	207.43	225.19	240.26	257.64	272.21	317.81
Limla dam	120.67	168.06	202.83	218.68	231.84	241.10	254.84	301.69
Malpur	131.98	179.92	206.71	222.79	235.70	252.47	267.42	316.06
Meghraj	114.96	156.88	177.56	193.96	207.11	223.47	240.28	280.37
Modasa	119.10	166.77	191.22	205.75	220.39	235.88	251.51	304.33
Pal	100.31	137.44	160.04	179.37	195.29	210.36	225.72	259.17
Prantij	135.66	184.22	213.52	233.72	246.21	262.63	273.13	323.83
Sabli	114.66	152.39	183.92	202.47	212.16	225.61	239.23	284.67
Shamlaji	127.43	180.54	206.41	220.33	230.35	242.39	252.20	299.30
Vadagam	115.29	157.45	181.14	195.86	209.78	220.09	230.28	269.14
Vijaynagar	98.61	134.61	156.67	176.12	191.21	205.35	217.41	252.85
Virpur	107.93	150.51	168.61	189.76	202.74	209.99	221.58	257.09

Fig. 6.30 Mean, µ for one day and consecutive 2 to 7 & 10 days for raingauge stations situated in Sabarkantha district



	1 D	C 2 D	C 3 D	C 4 D	C 5 D	C 6 D	C 7 D	C 10 D
Badoli	342.71	474.52	692.10	760.41	855.25	975.19	977.05	1090.70
Bayad	458.69	610.97	782.92	961.95	982.19	961.26	1036.45	1100.98
Bhiloda	547.34	808.77	962.48	998.49	1123.44	1200.14	1301.81	1247.51
Dantral	144.64	210.25	256.28	289.13	320.85	342.94	400.00	493.61
Himatnagar	294.66	403.71	482.58	548.27	621.91	676.69	780.16	840.24
Idar	379.53	488.89	549.02	612.64	645.18	725.52	711.52	761.45
Khedbrahma	321.88	448.04	574.94	703.13	758.40	767.69	836.70	865.40
Kundlacampo	363.00	432.22	513.89	579.54	698.58	802.19	878.77	1112.43
Limla dam	583.66	717.42	860.14	962.60	1095.14	1271.93	1348.31	1274.40
Malpur	439.72	491.43	637.87	693.98	834.22	858.47	929.11	991.57
Meghraj	427.13	668.27	925.49	1050.90	1102.46	1122.06	1087.61	1198.69
Modasa	682.03	890.48	951.72	1020.05	1092.80	1158.70	1228.93	1334.15
Pal	371.26	510.46	621.70	687.53	797.65	939.32	1009.60	1190.92
Prantij	508.28	522.34	591.08	736.83	807.86	997.50	1080.48	1144.29
Sabli	323.58	454.09	533.49	628.65	674.57	691.71	770.14	780.28
Shamlaji	333.71	412.63	493.99	615.90	672.12	702.37	706.05	658.51
Vadagam	461.68	525.61	573.25	678.17	824.66	909.00	986.43	981.13
Vijaynagar	368.97	500.07	573.56	625.56	856.76	882.35	904.86	914.33
Virpur	300.22	454.13	611.33	661.10	734.39	788.14	795.72	932.76

Fig. 6.31 Shape parameter, λ for one day and consecutive 2 to 7 & 10 days for raingauge stations situated in Sabarkantha district

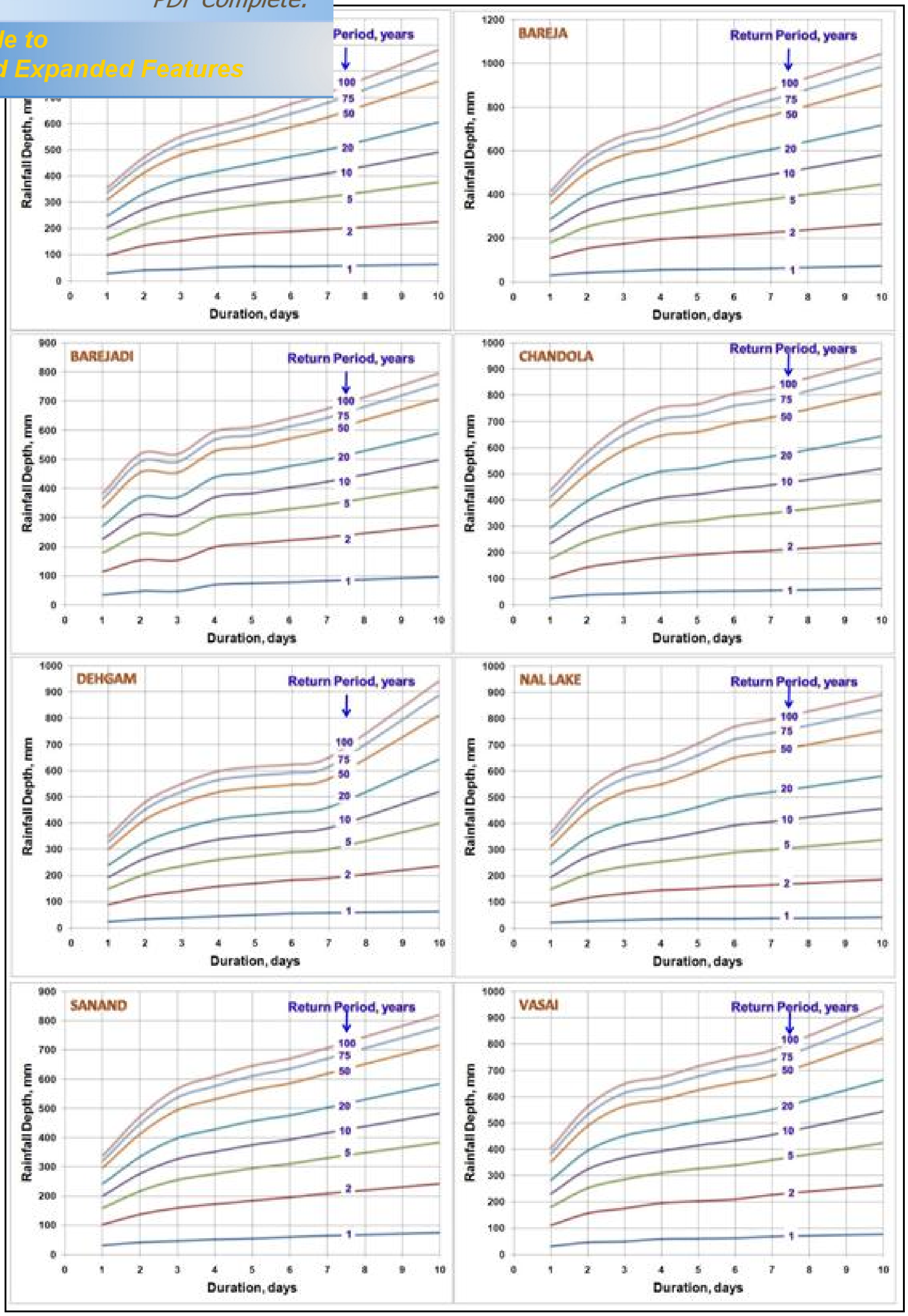


Fig. 6.32 Rainfall depthï durationï return period relations for Aslali, Bareja, Barejadi, Chandola, Dehgam, Nal Lake, Sanand and Wasai raingauge stations in Ahmedabad district

...ommended that 2ï 100 yea is a sufficient return ... r conservation measures, construction of dams, irrigation and drainage works. The rainfall depthï durationï return periods for all the 73 raingaguge stations are presented from Figs. 6.32 to 6.424.

Based on the best fit probability distribution for the raingauge stations situated in Ahmedabad district the maximum rainfall of 88 mm, 118 mm, 134 mm, 146 mm, 153 mm, 161 mm, 167 mm and 188 mm is expected to occur every two years for one day and consecutive 2 to 7 & 10 days respectively at Nal Lake raingauge station. It is observed that this rainfall depth is the lowest amongst the eight raingauge stations in the Ahmedabad district. The highest maximum rainfall of 115 mm, 201 mm, 212 mm, 223 mm, 234 mm and 275 mm is expected to occur every two years for one day & consecutive 4, 5, 6, 7 & 10 days respectively at Barejadi raingauge station. The highest maximum rainfall of 158 mm and 177 mm is expected to occur every two years for consecutive 2 and 3 days respectively at wasai raingauge station.

The maximum rainfall of 339 mm, 474 mm, 520 mm, 594 mm, 612 mm, 625 mm, 653 mm and 797 mm is expected to occur every 100 years for one day and consecutive 2 to 7 & 10 days respectively at Sanand, Aslali, Barejadi, Aslali, Barejadi, Dehgam, Dehgam and Barejadi raingauge stations. It is observed that these rainfall depths are the lowest in the Ahmedabad district. The highest maximum rainfall of 438 mm, 583 mm, 691 mm and 755 mm are expected to occur every 100 years for one day & consecutive 2, 3 & 4 days respectively at Chandola raingauge station. The highest maximum rainfall of 770 mm, 834 mm, 884 mm and 1,048 mm are expected to occur every 100 years for consecutive 5, 6, 7 and 10 days respectively at Bareja raingauge station.

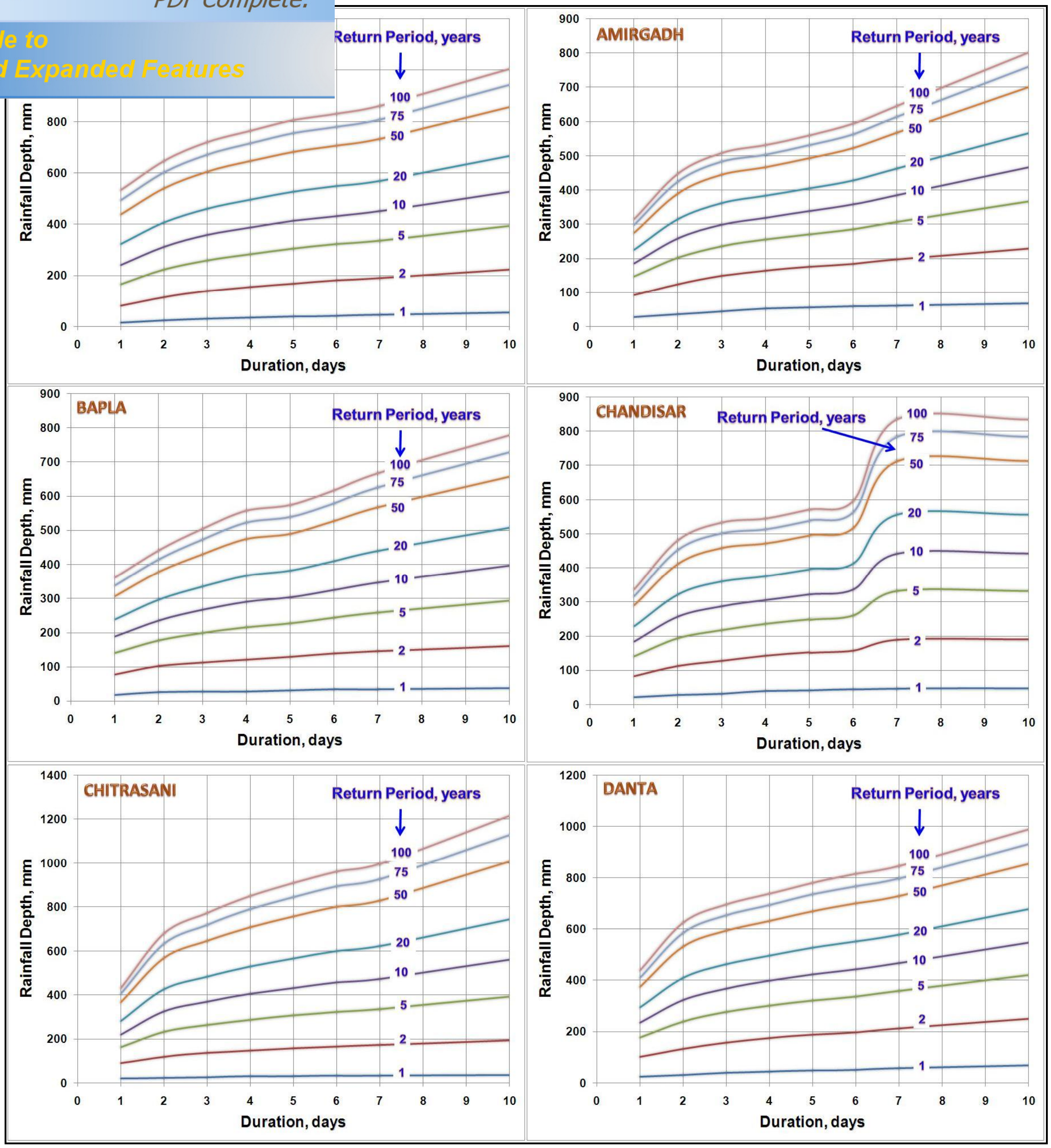


Fig 6.33 Rainfall depthï durationï return period relations for Ambaji, Amirgadh, Bapla, Chandisar, Chitrasani and Danta raingauge stations in Banaskantha district

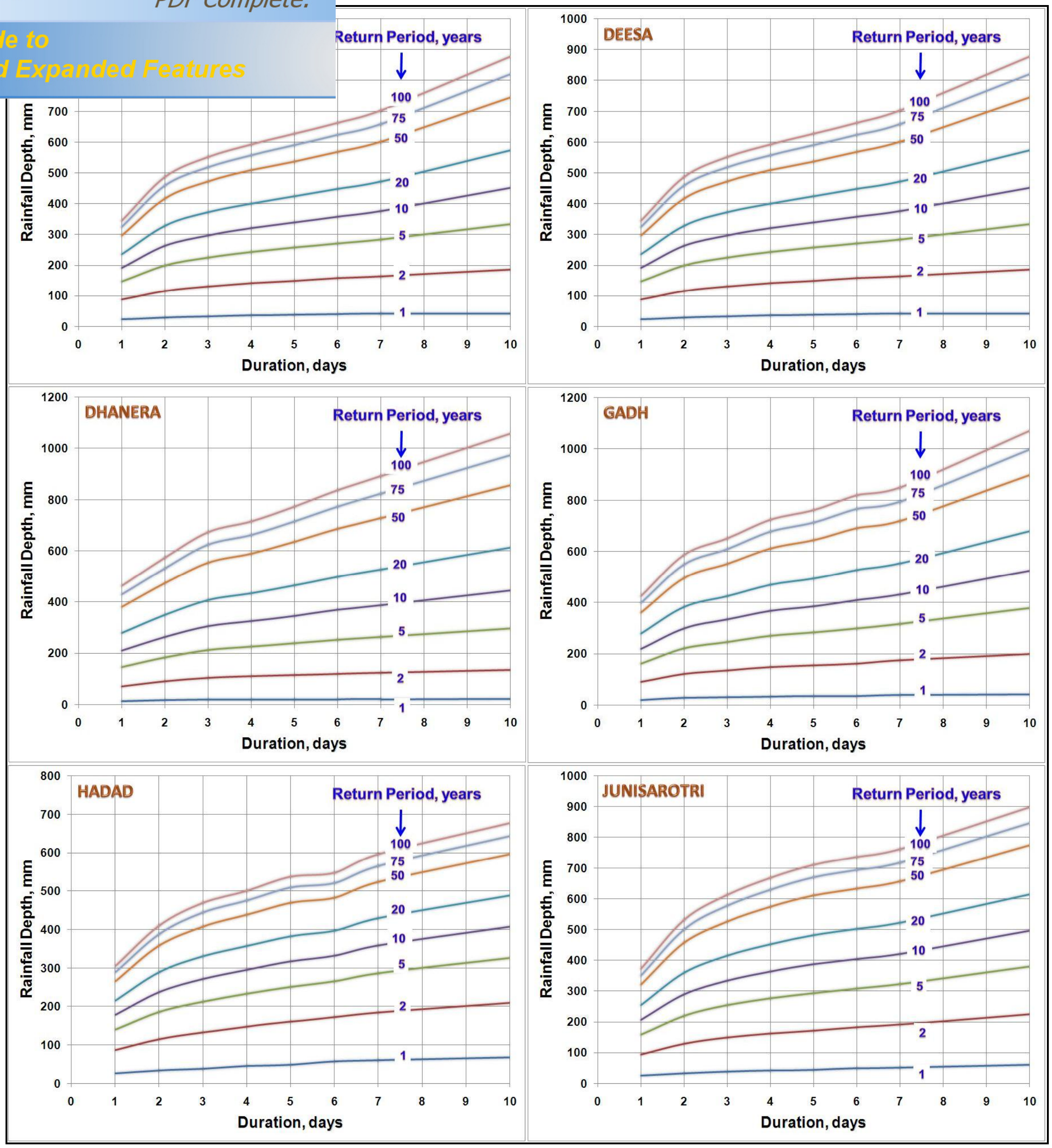


Fig 6.34 Rainfall depthï durationï return period relations for Dantiwada, Deesa, Dhanera, Gadh, Hadad and Junisarotri raingauge stations in Banaskantha district

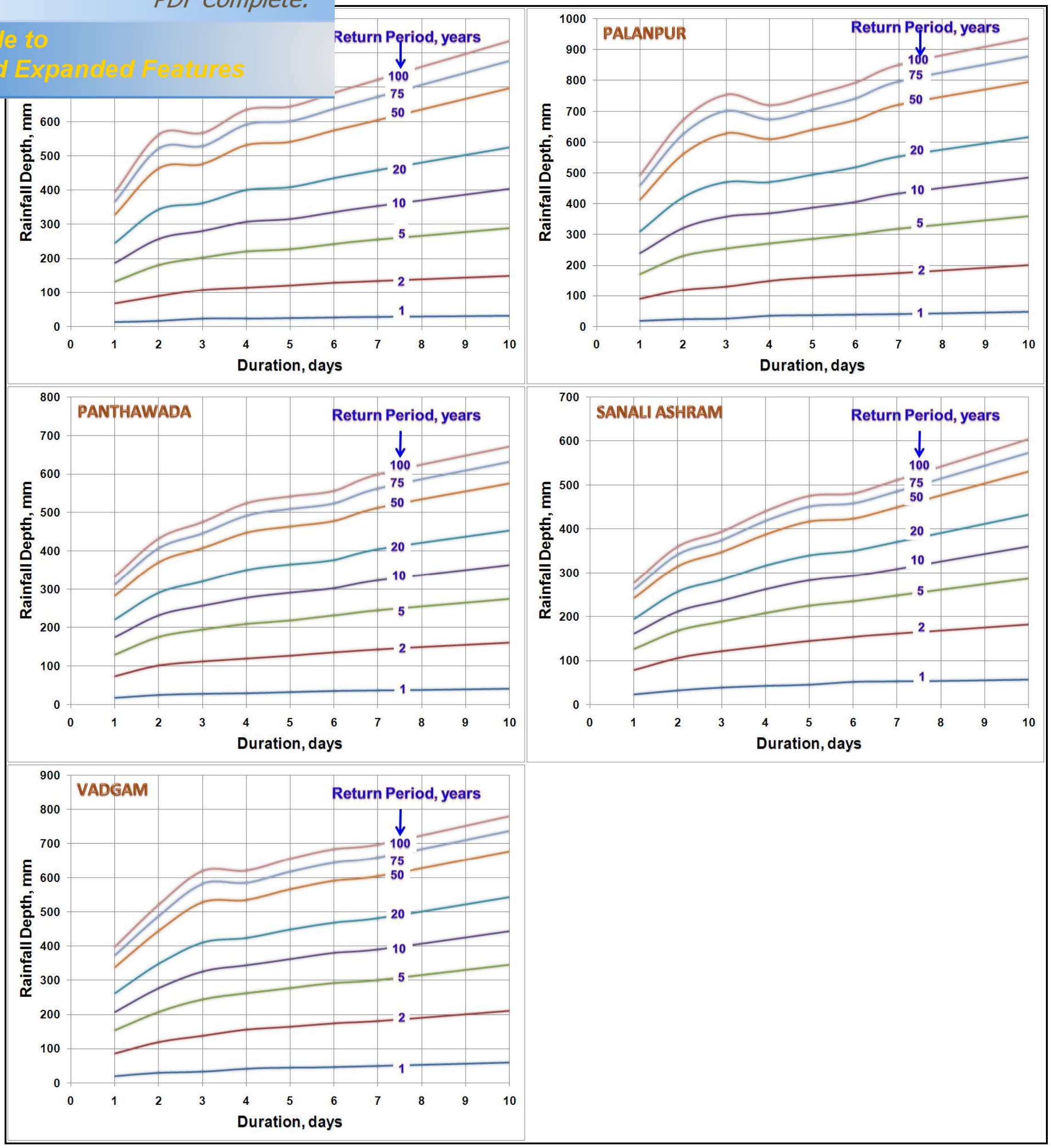


Fig 6.35 Rainfall depthï durationï return period relations for Nava, Palanpur, Panthawada, Sanali Ashram and Wadgam raingauge stations in Banaskantha district

For Banaskantha district the maximum rainfall of 69 mm and 91 mm is expected to occur every two years for one day and consecutive 2 days respectively at Nava raingauge station while 105 mm, 111 mm, 116 mm, 121 mm, 125 mm and 136 mm is expected to occur every two years for one day

0 days respectively at Dhanera raingauge station. It ıfall depth is the lowest amongst the seventeen raingauge stations in the Banaskantha district. The highest maximum rainfall of 103 mm, 135 mm, 159 mm, 177 mm, 189 mm, 199 mm, 214 mm and 251 mm is expected to occur every two years for one day & consecutive 2 to 7 & 10 days respectively at Danta raingauge station.

The maximum rainfall of 278 mm, 361 mm, 395 mm, 441 mm, 476 mm, 482 mm, 512 mm and 606 mm is expected to occur every 100 years for one day and consecutive 2 to 7 & 10 days respectively at Sanali Ashram raingauge station. It is observed that this rainfall depth is the lowest amongst the seventeen raingauge stations in the Banaskantha district. The highest maximum rainfall of 534 mm is expected to occur every 100 years for one day at Ambaji raingauge station. The highest maximum rainfall of 682 mm, 775 mm, 851 mm, 911 mm, 964 mm, 998 mm and 1,220 mm is expected to occur every 100 years for consecutive 2 to 7 & 10 days respectively at Chitrasani raingauge station.

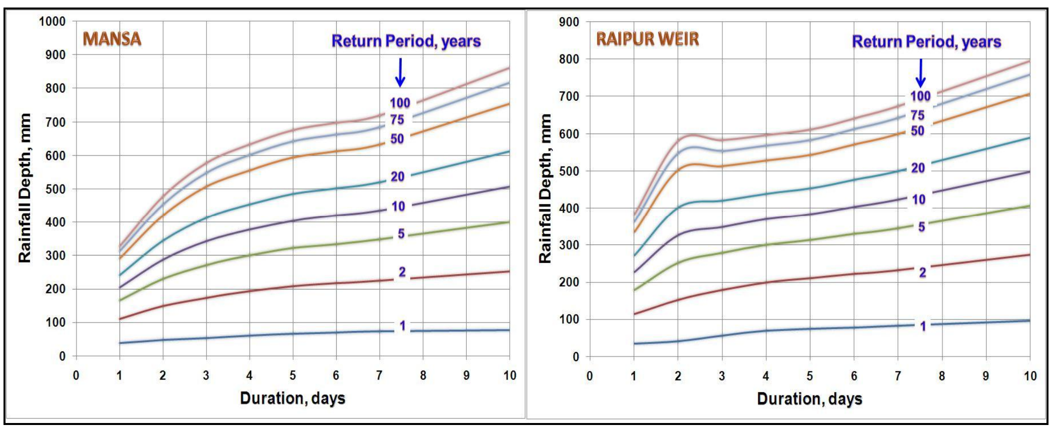


Fig 6.36 Rainfall depthï durationï return period relations for Mansa and Raipur Weir raingauge stations in Gandhinagar district

For Gandhinagar district the maximum rainfall of 112 mm, 150, 175 mm, 194 mm, 209 mm, 218 mm, 227 mm and 254 mm is expected to occur every two years for one day and consecutive 2 to 7 & 10 days respectively at Mansa raingauge station. It is observed that this rainfall depth is the lowest amongst the two raingauge stations in the Gandhinagar district. The highest maximum m, 180 mm, 201 mm, 212 mm, 223 mm, 234 mm o occur every two years for one day & consecutive 2 to 7 & 10 days respectively at Raipur weir raingauge station.

The maximum rainfall of 329 mm, 479 mm and 579 mm is expected to occur every 100 years for one day and consecutive 2 & 3 days respectively at Mansa raingauge station. The maximum rainfall of 597 mm, 612 mm, 643 mm, 675 mm and 797 mm is expected to occur every 100 years for consecutive 4 to 7 & 10 days respectively at Raipur weir raingauge station. These rainfall depths are the lowest amongst the two available raingauge stations in the Gandhinagar district. The highest maximum rainfall of 385 mm, 583 mm and 584 mm is expected to occur every 100 years for one day and consecutive 2 & 3 days respectively at Raipur weir raingauge station. The highest maximum rainfall of 634 mm, 677 mm, 698 mm, 721 mm and 864 mm is expected to occur every 100 years for consecutive 4 to 7 & 10 days respectively at Mansa station.

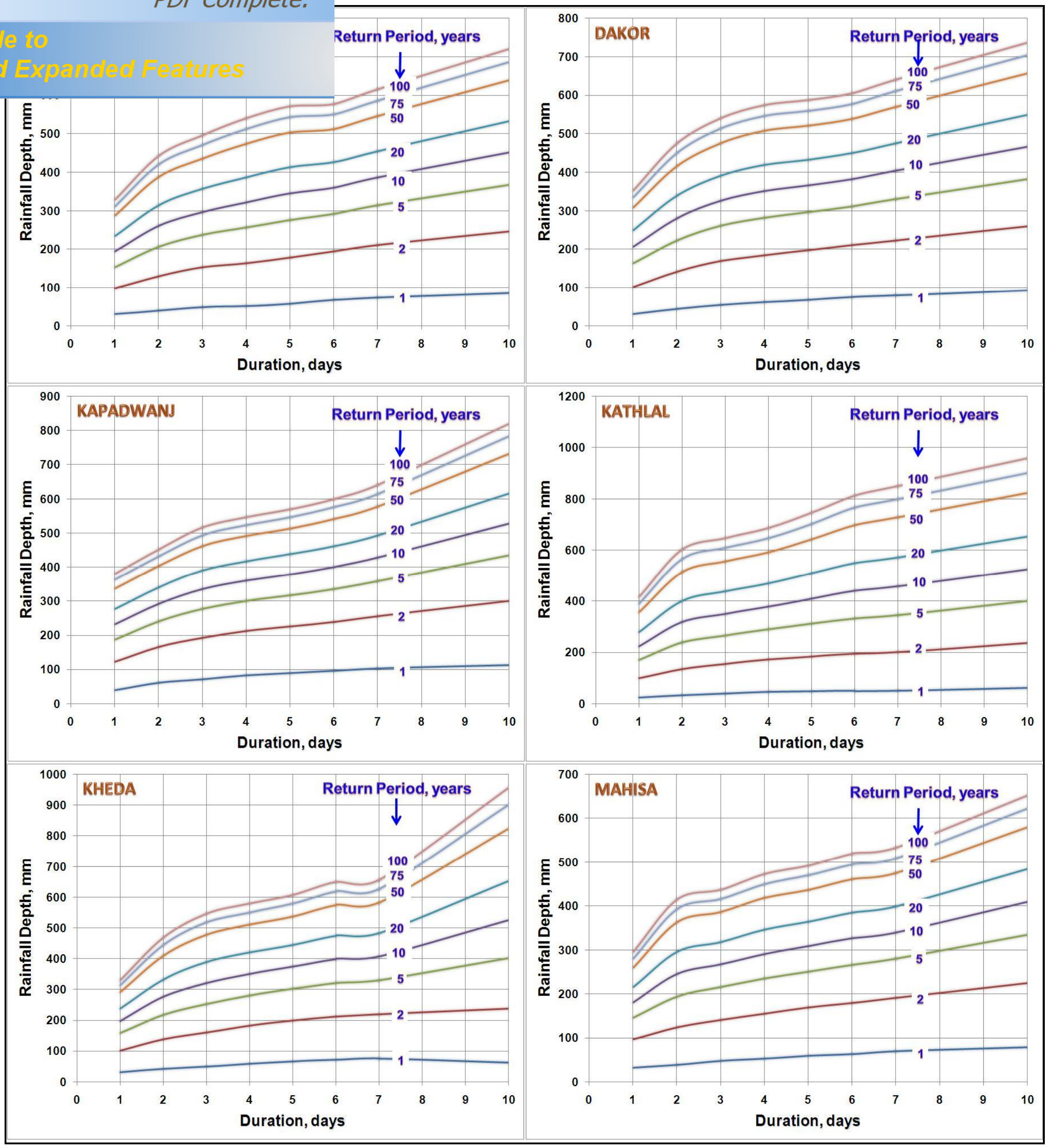


Fig 6.37 Rainfall depthï durationï return period relations for Balasinor, Dakor, Kapadwanj, Kathlal, Kheda and Mahisa raingauge stations in Kheda district.

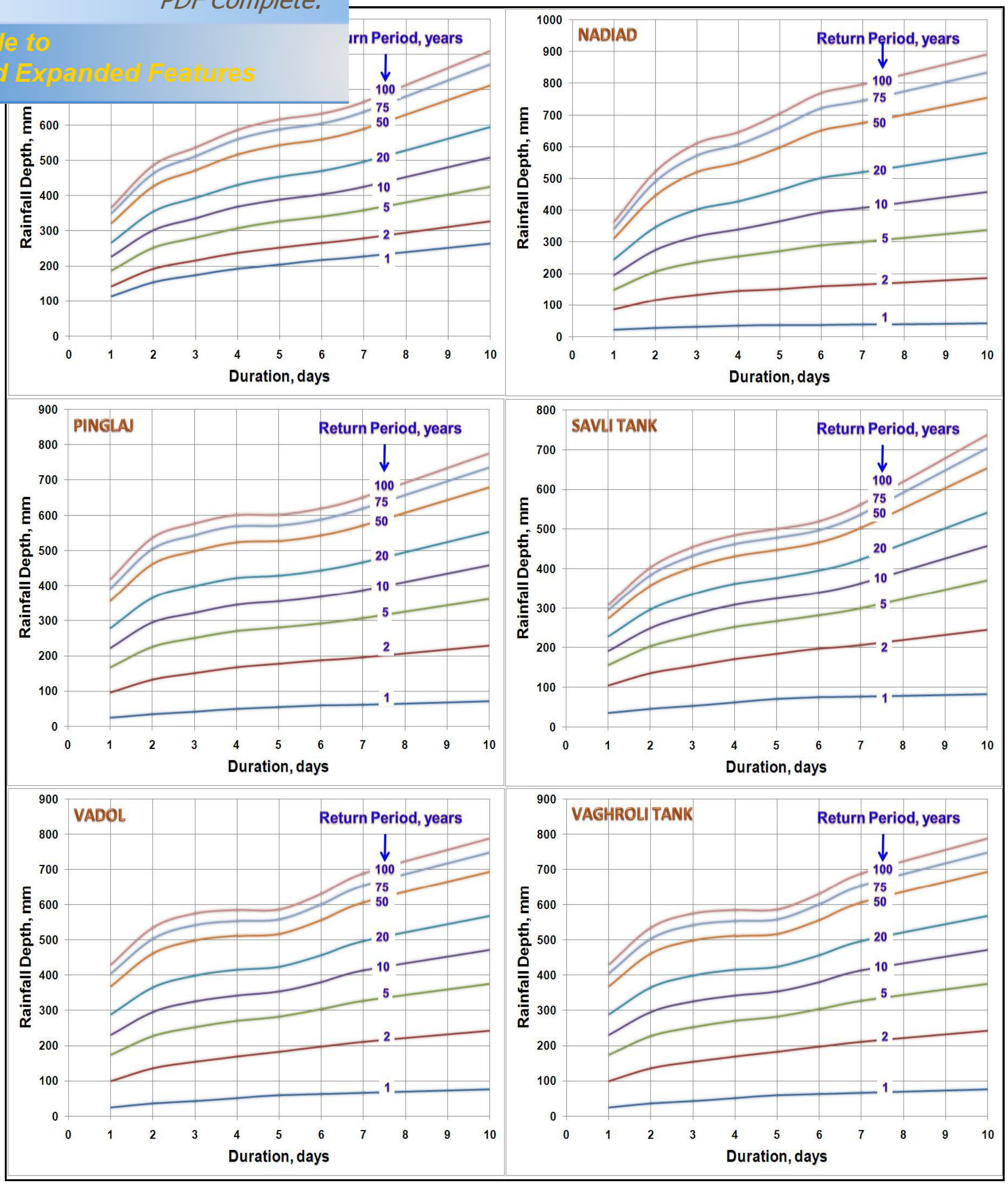


Fig 6.38 Rainfall depthï durationï return period relations for Mahemadabad, Nadiad, Pinglaj, Savli Tank, Vadol and Vaghroli Tank raingauge stations in Kheda district

For the raingauge stations situated in Kheda district the maximum rainfall of 97 mm, 125, 142 mm, 156 mm, 170 mm, 180 mm, 192 mm and 226 mm is expected to occur every two years for one day and consecutive 2 to 7 & 10 days respectively at Mahisa raingauge station. It is observed that this rainfall depth is the lowest amongst the twelve raingauge stations in the Kheda um rainfall of 144 mm, 193 mm, 217 mm, 238 mm, and 328 mm is expected to occur every two years for one day & consecutive 2 to 7 & 10 days respectively at Mahemadabad raingauge station.

The maximum rainfall of 296 mm, 438 mm, 474 mm, 493 mm, 520 mm, 534 mm and 654 mm is expected to occur every 100 years for one day and consecutive 3 to 7 & 10 days respectively at Mahisa raingauge station. The maximum rainfall of 404 mm is expected to occur every 100 years for consecutive 2 days at Savali tank raingauge station. These rainfall depths are the lowest amongst the twelve available raingauge stations in the Kheda district. The highest maximum rainfall of 451 mm, 619 mm, 677 mm, 715 mm, 757 mm, 824 mm, 852 mm and 976 mm is expected to occur every 100 years for one day and consecutive 2 to 7 & 10 days respectively at Nadiad raingauge station.

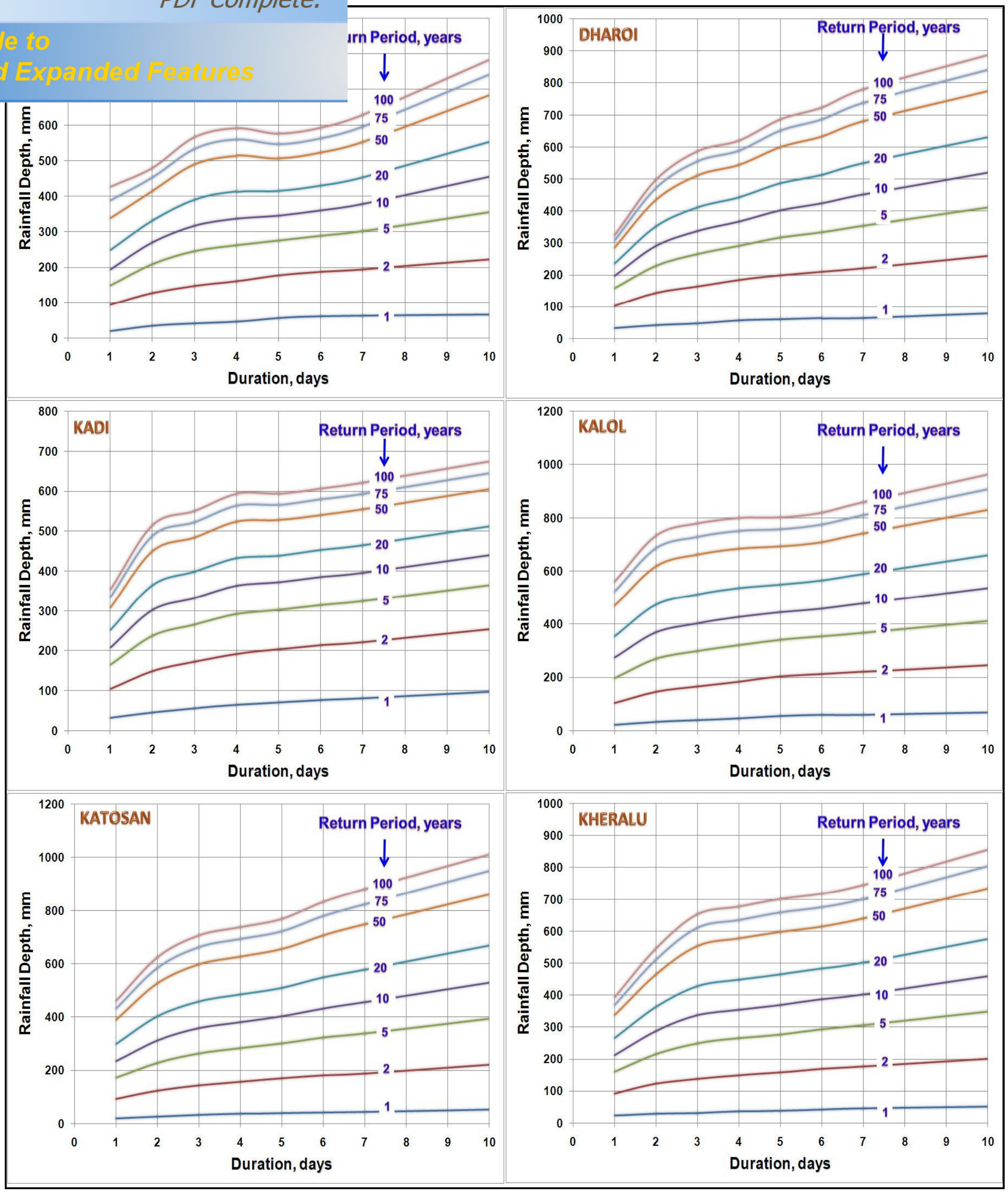


Fig 6.39 Rainfall depthï durationï return period relations for Ambaliyasan, Dharoi, Kadi, Kalol, Katosan and Kheralu raingauge stations in Mehsana district

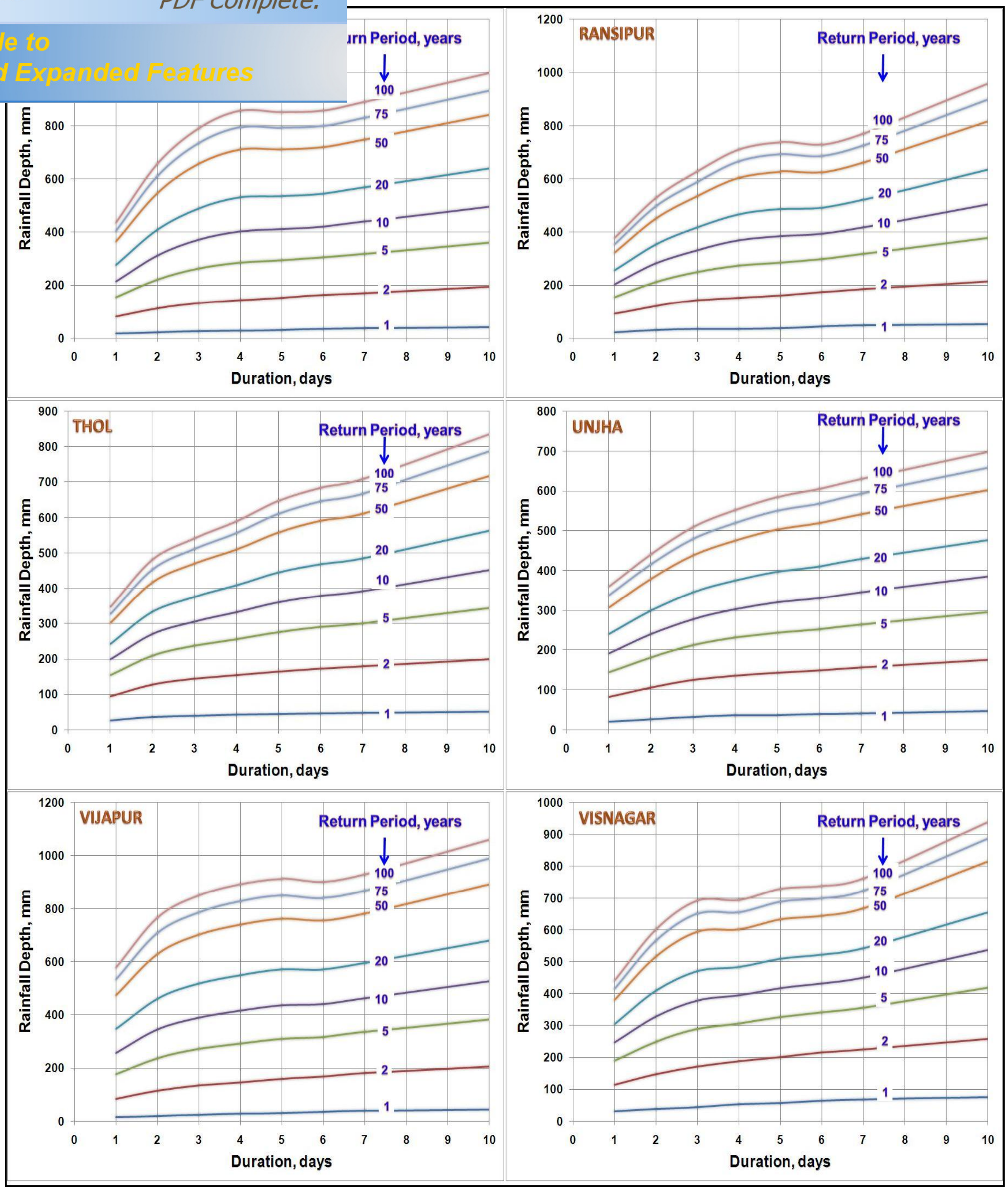


Fig 6.40 Rainfall depthï durationï return period relations for Mehsana, Ransipur, Thol, Unjha, Vijapur and Visnagar raingauge stations in Mehsana district

The maximum rainfall of 84 mm, 115 mm, 134 mm, 145 mm, 155 mm, 164 mm, 171 mm and 195 mm is expected to occur every two years for one day and consecutive 2 to 7 & 10 days respectively at Mehsana raingauge station. It is observed that this rainfall depth is the lowest amongst the eleven raingauge stations in the Mehsana district. The highest maximum rainfall of mm is expected to occur every two years for one 7 days respectively at Visnagar raingauge station. The highest maximum rainfall of 150 mm, 173 mm and 190 mm is expected to occur every two years for consecutive 2, 3 and 4 days respectively at Kadi raingauge station every two year. The highest maximum rainfall of 205 mm is expected to occur consecutive 5 days at Kalol raingauge station and 261 mm is expected to occur every two years for consecutive 10 days at Dharoi raingauge station.

For a recurrence interval of 100 years, the lowest maximum rainfall expected in one day and consecutive 2 to 7 & 10 days are 325 mm, 481 mm, 543 mm, 591 mm, 577 mm, 594 mm, 623 mm and 677 mm respectively at Dharoi, Ambaliyasan, Thol, Thol, Ambaliyasan, Ambaliyasan, Kadi and Kadi raingauge stations respectively. It is observed that this rainfall depth is the lowest amongst the eleven raingauge stations. The highest maximum rainfall of 580 mm, 768 mm, 851 mm, 894 mm, 951 mm, 903 mm, 931 mm and 1,063 mm is expected to occur at interval of 100 years for one day and consecutive 2 to 7 & 10 days respectively at Vijapur raingauge station.

For the raingauge stations situated in Patan district the maximum rainfall of 82 mm, 106, 118 mm, 130 mm, 139 mm, 147 mm, 154 mm and 172 mm is expected to occur every two years for one day and consecutive 2 to 7 & 10 days respectively at Patan raingauge station. It is observed that this rainfall depth is the lowest amongst the three raingauge stations in the Patan district. The highest maximum rainfall of 85 mm, 115 mm, 132 mm, 145 mm, 157 mm, 167 mm, 177 mm and 200 mm is expected to occur every two years for one day & consecutive 2 to 7 & 10 days respectively at Sidhpur raingauge station.

The maximum rainfall of 406 mm, 510 mm, 544 mm, 550 mm, 573 mm, 613 mm, 660 mm and 817 mm is expected to occur every 100 years for one day and consecutive 2 to 7 & 10 days respectively at Patan raingauge station. These rainfall depths are the lowest amongst the three available raingauge stations in the Patan district. The highest maximum rainfall of 487 mm, 726 mm, 847 mm, 868 mm, 886 mm, 900 mm, 954 mm and 1178 mm is expected for one day and consecutive 2 to 7 & 10 days ngauge station.

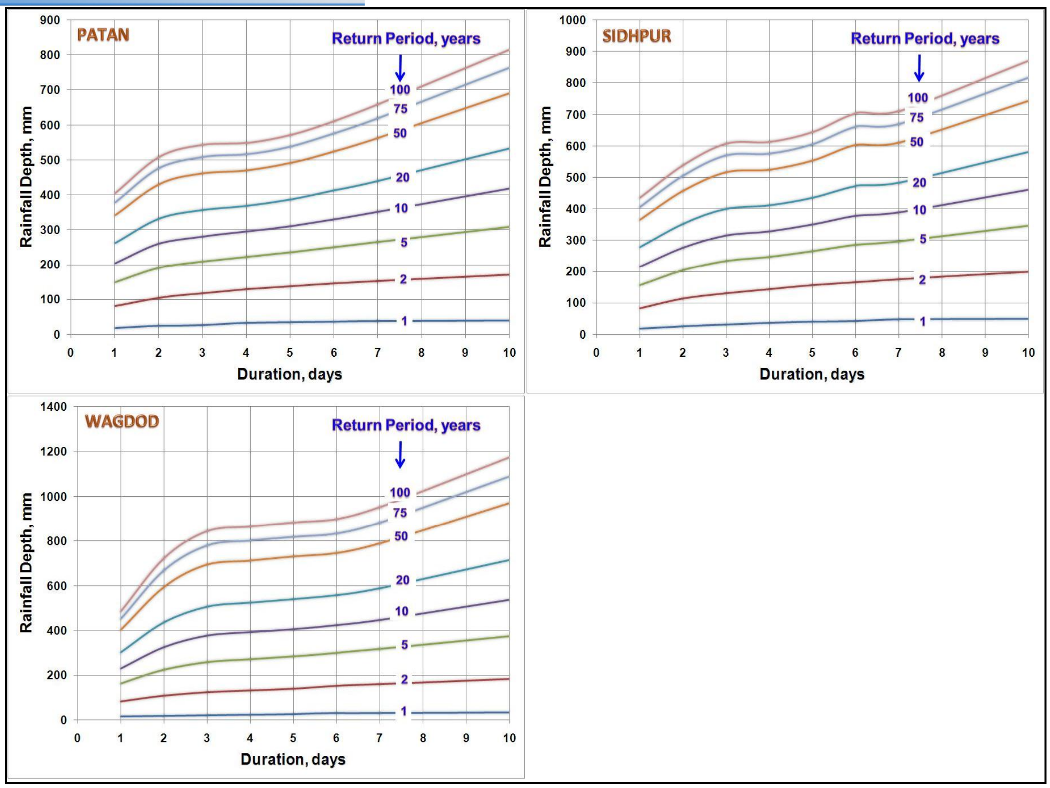


Fig 6.41 Rainfall depthï durationï return period relations for Patan, Sidhpur and Wagdod raingauge stations in Patan district

For the raingauge stations situated in Sabarkantha district the maximum rainfall of 87 mm, 118 mm, 138 mm, 154 mm, 172 mm, 184 mm, 194 mm and 222 mm is expected to occur every two years for one day and consecutive 2 to 7 & 10 days respectively at Vijaynagar raingauge station. It is observed that this rainfall depth is the lowest amongst the nineteen raingauge stations in the Sabarkantha district. The highest maximum rainfall of 128 mm at Dantral, 163 mm, 184 mm, 209 mm, 223 mm, 235 mm, 252 mm and 295 mm is expected to occur every two years for one day & consecutive 2 to 7 & 10 days respectively at Bhiloda raingauge station.

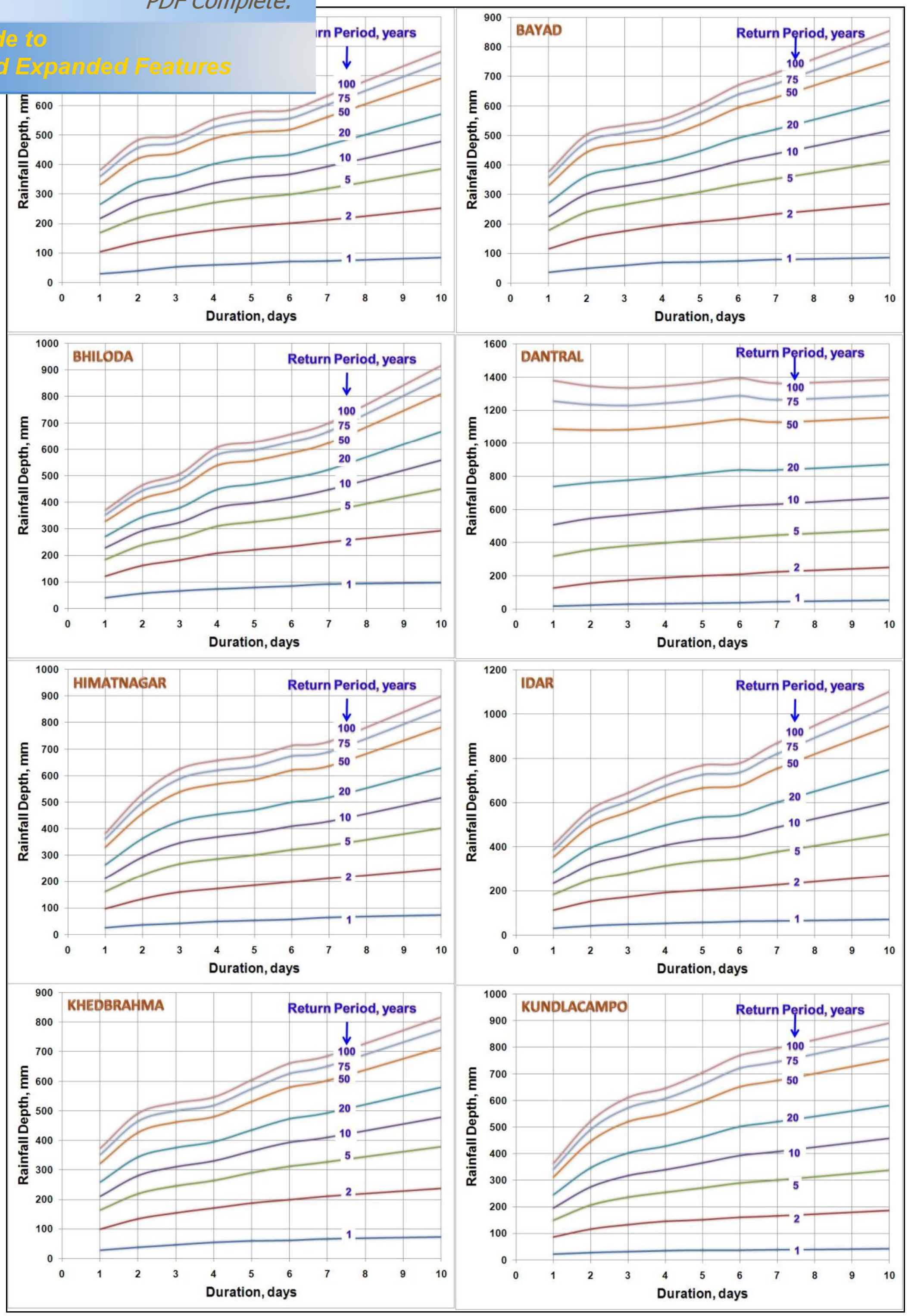


Fig 6.42 Rainfall depthï durationï return period relations for Badoli, Bayad, Bhiloda, Dantral, Himmatnagar, Idar, Khedbrahma and Kundlacampo raingauge stations in Sabarkantha district

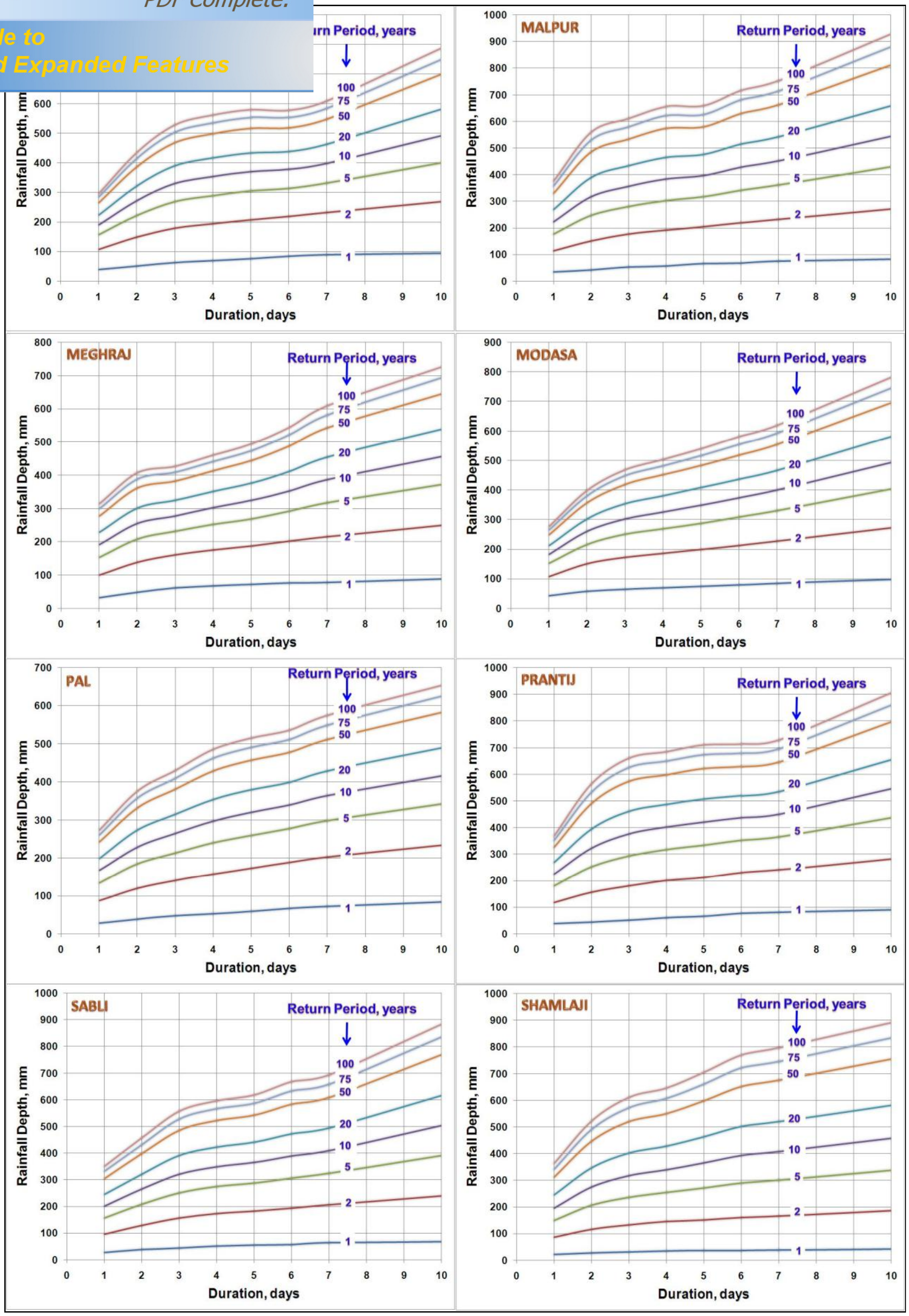


Fig. 6.43 Rainfall depthï durationï return period relations for Limla Dam, Malpur, Meghraj, Modasa, Pal, Prantij, Sabli and Shamlaji raingauge stations in Sabarkantha district

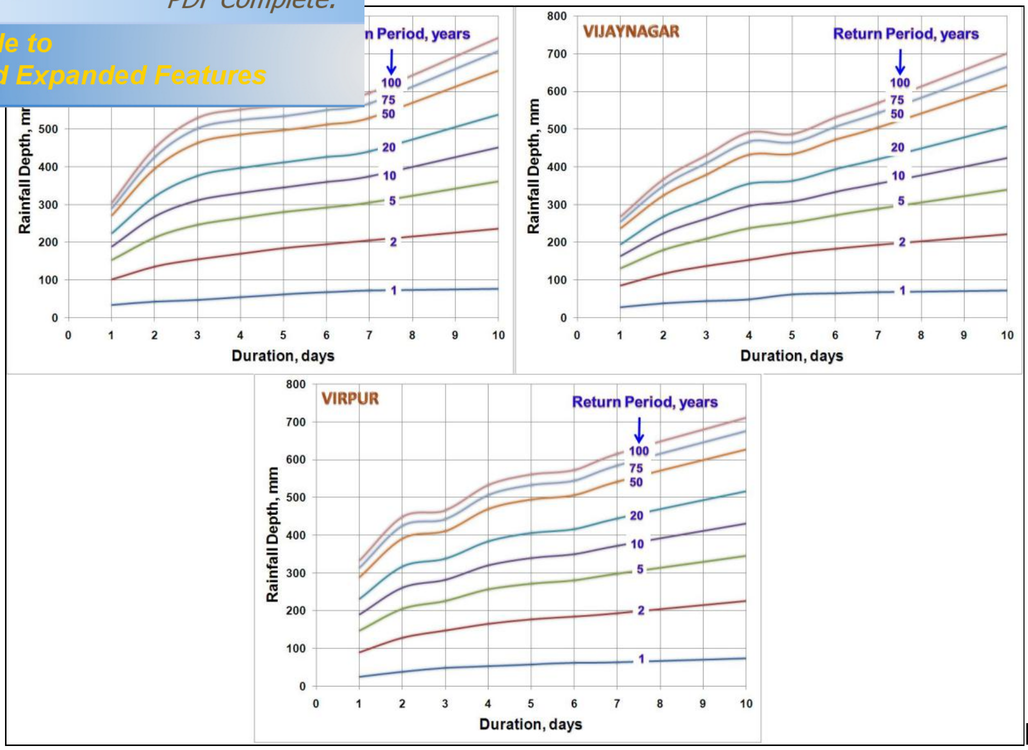


Fig 6.44 Rainfall depthï durationï return period relations for Vadgam, Vijaynagar and Virpur raingauge stations in Sabarkantha district.

The maximum rainfall of 270 mm, 369 mm, 488 mm, 532 mm and 571 mm is expected to occur every 100 years for one day and consecutive 2, 5, 6 & 7 days respectively at Vijaynagar raingauge station. The maximum rainfall of 428 mm and 461 mm is expected to occur every 100 years for consecutive 3 & 4 days respectively at Meghraj raingauge station. The maximum rainfall of 655 mm is expected to occur every 100 years for consecutive 10 days at Pal raingauge station. These rainfall depths are the lowest amongst the nineteen available raingauge stations in the Sabarkantha district. The highest maximum rainfall of 410 mm, 770 mm, 780 mm, 873 mm and 1104 mm is expected to occur every 100 years for one day and consecutive 5 to 7 & 10 days respectively at Idar raingauge station. The highest maximum rainfall of 608 mm and 682 mm is expected to occur every 100 years for consecutive 2 & 3 days respectively at Shamlaji raingauge station. The highest maximum rainfall of 720 mm is expected to occur every 100 years for consecutive 4 days at Kundlacampo raingauge station.

groclimatic zone, for a recurrence interval of 2 years 9 mm and 91 mm is expected to occur every two years for one day and consecutive 2 days respectively at Nava raingauge station while 105 mm, 111 mm, 116 mm, 121 mm, 125 mm and 136 mm is expected to occur every two years for one day and consecutive 3 to 7 & 10 days respectively at Dhanera raingauge station of Banaskantha district. It is observed that this rainfall depth is the lowest amongst the 73 raingauge stations in the north Gujarat agroclimatic zone. The highest maximum rainfall of 144 mm, 193 mm, 217 mm, 238 mm, 253 mm, 266 mm, 280 mm and 328 mm is expected to occur every two years for one day & consecutive 2 to 7 & 10 days respectively at Mahemadabad raingauge station of Kheda district.

For a recurrence interval of 100 years, the lowest maximum rainfall of 270 mm is expected to occur every 100 years for one day at Vijaynagar raingauge station of Sabarkantha district. The lowest maximum rainfall of 361 mm, 395 mm, 441 mm, 476 mm, 482 mm, 512 mm and 606 mm and consecutive 2 to 7 & 10 days respectively at Sanali Ashram raingauge station. It is observed that this rainfall depth is the lowest amongst the 73 raingauge stations in the north Gujarat agroclimatic zone. The highest maximum rainfall of 580 mm, 768 mm, 851 mm, 894 mm and 951 mm is expected to occur at interval of 100 years for one day and consecutive 2 to 5 days respectively at Vijapur raingauge station of Mehsana district. The highest maximum rainfall of 964 mm, 998 mm and 1,220 mm is expected to occur every 100 years for consecutive 6, 7 & 10 days respectively at Chitrasani raingauge station.

As mentioned earlier it is assumed that 15 % of the rainfall infiltrates into the soil and the remaining 85 % constitutes the runoff (Source: Technical Advisory Report 2009, Sardar Krushinagar Dantiwada Agriculture University). Thus the drainage coefficient for north Gujarat agroclimatic zone of 58.65 mm/day (=65x0.85), 38.68 mm/day (=91x0.85/2), 29.75 mm/day (=105x0.85/3), 23.60 mm/day (=111x0.85/4), 19.72 mm/day (=116x0.85/5), 17.14 mm/day (=121x0.85/6), 15.17 mm/day (=125x0.85/7) and 11.56 mm/day (=136x0.85/10) is expected to occur every two years for the crop grown and having tolerance of one day and consecutive 2 to 7 & 10 days ed that the drainage coefficients are the lowest e stations in the north Gujarat agroclimatic zone. Similarly the highest drainage coefficient obtained for the region are of 122.40 mm/day, 82.02 mm/day, 61.48 mm/day, 50.57 mm/day, 43.01 mm/day, 37.68 mm/day, 34.00 mm/day and 27.88 mm/day is expected to occur every two years for one day & consecutive 2 to 7 & 10 days respectively at Mahemadabad raingauge station of Kheda district.

For a recurrence interval of 100 years, the lowest drainage coefficient of 229.50 mm/day, 153.43 mm/day, 111.92 mm/day, 93.71 mm/day, 80.92 mm/day, 68.28 mm/day, 62.17 mm/day and 51.51 mm/day for the crop grown and having tolerance of one day and consecutive 2 to 7 & 10 days respectively is determined. The highest drainage coefficient of 493 mm/day, 326.40 mm/day, 241.12 mm/day, 189.98 mm/day, 161.67 mm/day, 136.57 mm/day, 121.19 mm/day and 103.70 mm/day is expected to occur at interval of 100 years for the crop grown and having tolerance of one day and consecutive 2 to 7 and 10 days respectively for north Gujarat agroclimatic zone.

Hence based on the sample data of 73 raingauge stations, the 16 different distribution functions describing the population were determined. Thus it can be concluded that all the 16 distributions fitted the dataset of 73 raingauge stations and a unique distribution was identified at the first place as the best fit according to AIC and BIC. Birnbaumï Saunders, Rayleigh, Log Logistic, Lognormal, Generalized Pareto & Gamma distributions were the second best distributions among the dataset analyzed. The commonly used extreme value and exponential distributions were the least ranked amongst the 16 distributions. For the design of the hydraulic and water conservation structures the required amount of rainfall depth (design rainfall) for the intended design return period can be obtained by considering 15 % runoff for economical considerations. Hence the rainfall depthï durationï return periods for all the 73 raingauge stations developed can be used as a guideline for planning the water resources in the area. In particular, these values could be very beneficial during the construction of drainage systems in the area as identified as one of the major factors causing

6.4 REGRESSION RELATIONSHIPS

Curve expert 1.4 software was used to develop relationship between return period and one day & consecutive 2 to 7 & 10 days maximum rainfall. Amongst the different relationships obtained based on the maximum correlation value of more than 0.98, it is evident that the logarithmic relationship exists between the return period and one day and consecutive 2 to 7 & 10 days maximum rainfall. The regression equation is of the type

$$R_x = C_1 + C_2 \ln(T) \quad (6.2)$$

where

R_x = one day maximum rainfall; consecutive 2 to 7 & 10 days maximum rainfall; mm

x = 1 to 7 & 10

T = return period, years

C_1, C_2 = constants

Fig. 6.45 depicts the relationships developed for Aslali raingaguge stations. Similar relationships are obtained for other raingauge stations in the study area. Table 6.154 presents the equation to determine the constants C_1 and C_2. This equation is valid for predicting one day and consecutive 2 to 7 & 10 day over the recurrence interval of 2 to 1000 years for the data used.

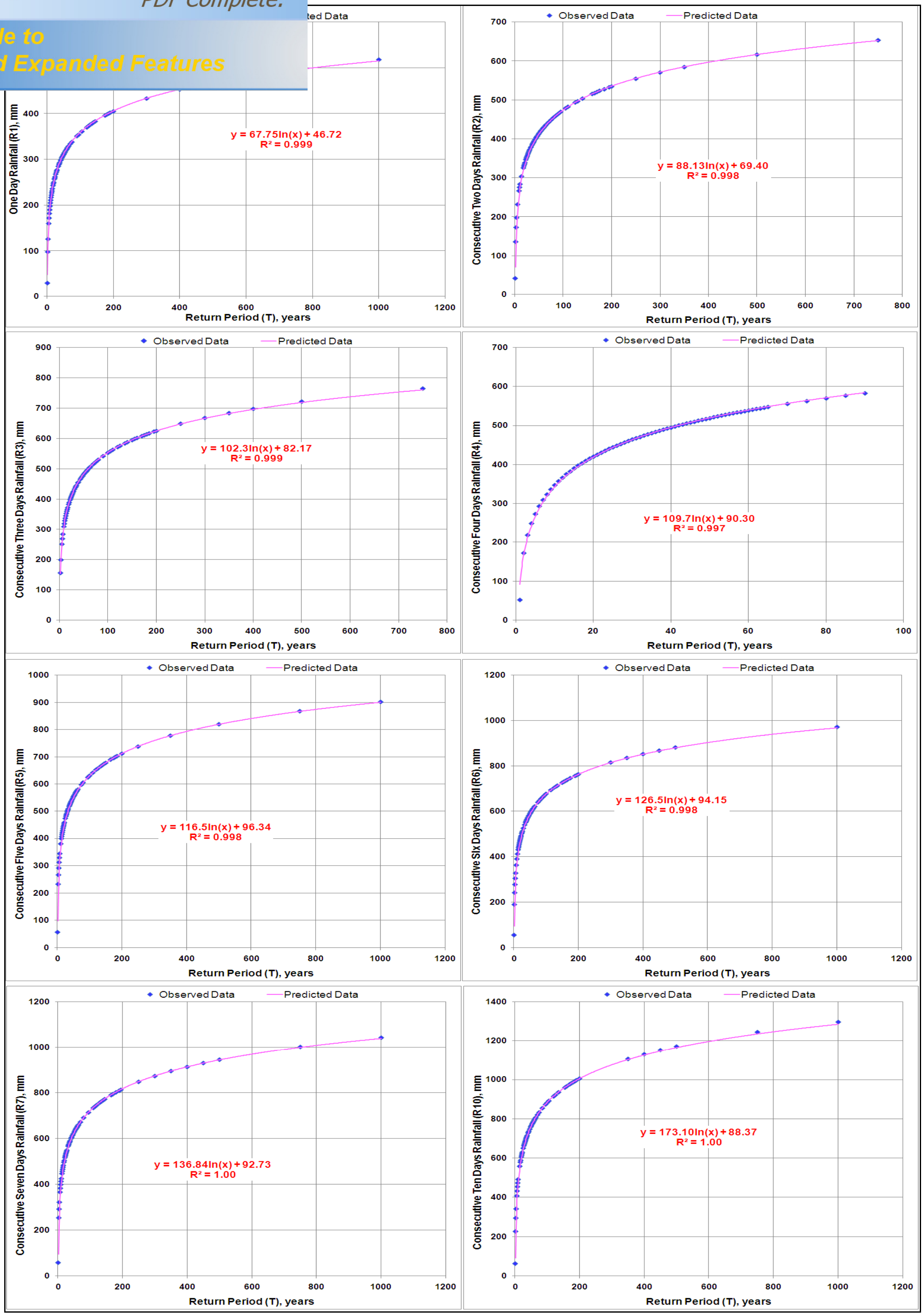


Fig. 6.45 Logarithmic relationship between return period and one day and consecutive 2 to 7 & 10 days rainfall for Aslali raingauge station in Ahmedabad district

tionship between one day maximum rainfall and) days maximum rainfall. Fig. 6.46 depicts the relationships developed for Aslali raingaguge stations. The model developed is of the type

$$R_x = C_3 + C_4 (R_1) \quad (6.3)$$

where,

R_x	=	consecutive 2 to 7 &10 days maximum rainfall, mm;
X	=	2 to 7 & 10
R_1	=	one day maximum rainfall in mm;
C_3, C_4	=	constants

Table 6.154 presents the equation to determine the constants C_3 and C_4. This equation is valid for predicting consecutive day rainfall for 2 to 7 & 10 day over the recurrence interval of 2 to 1000 years for the data used.

For obtaining both the equations 6.1 and 6.2 the respective dataset of 73 raingauge station are randomized and analyzed 35 times to obtain the best results.

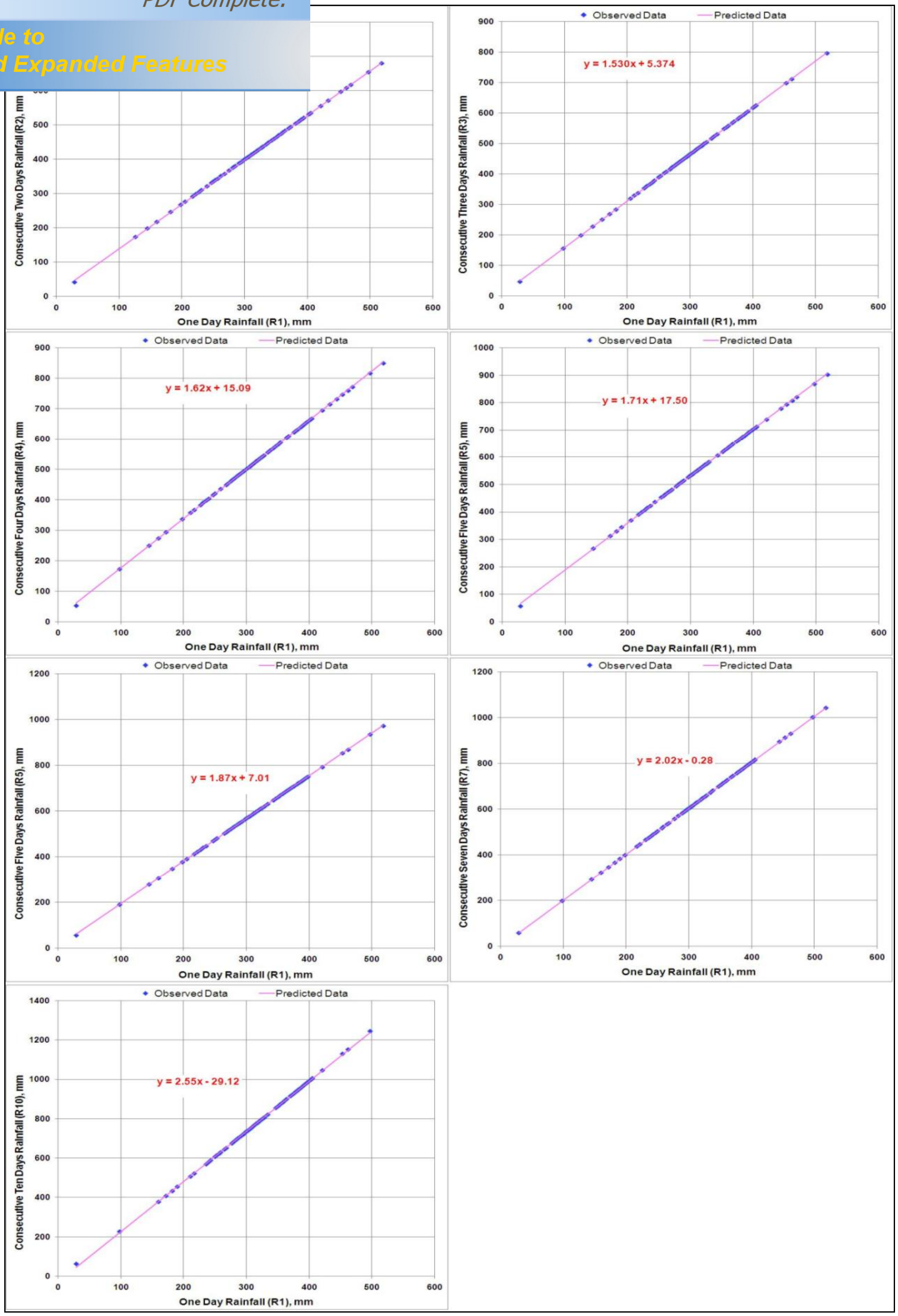


Fig. 6.46 Linear relationship between one day and consecutive 2 to 7 & 10 days rainfall for Aslali raingauge station in Ahmedabad district

nd Linear Relationship for 73 Raingauge Stations of Zone

Name of raingauge station	$R_x = C_1+C_2 \ln(T)$		$R_x = C_3+C_4(R_1)$	
	C_1	C_2	C_3	C_4
Aslali	$(-0.01x^6 + 0.32x^5 - 3.75x^4 + 21.72x^3 - 67.68x^2 + 120.80x - 24.71)$	$(0.01x^6 - 0.28x^5 + 3.21x^4 - 17.19x^3 + 42.33x^2 - 26.31x + 65.98)$	$-0.03x^6 + 0.91x^5 - 9.7557x^4 + 48.258x^3 - 107.17x^2 + 78.075x + 25.018$	$0.0006x^5 - 0.02x^4 + 0.21x^3 - 1.13x^2 + 2.95x - 1.49$
Bareja	$-0.03x^6 + 1.10x^5 - 12.57x^4 + 69.73x^3 - 197.53x^2 + 279.08x - 92.05$	$0.05x^6 - 1.52x^5 + 15.57x^4 - 73.20x^3 + 157.12x^2 - 113.51x + 95.23$	$0.09x^6 - 3.22x^5 + 45.07x^4 - 321.02x^3 + 1{,}216.45x^2 - 2{,}299.66x + 1{,}677.72$	$-0.0005x^6 + 0.01x^5 - 0.24x^4 + 1.75x^3 - 6.73x^2 + 13.08x - 8.50$
Barejadi	$-0.07x^6 + 2.32x^5 - 26.52x^4 + 146.59x^3 - 407.91x^2 + 549.88x - 200.98$	$-0.02x^6 + 0.76x^5 - 9.29x^4 + 56.26x^3 - 178.57x^2 + 282.91x - 81.99$	$0.06x^6 - 2.37x^5 + 33.10x^4 - 235.58x^3 + 894.13x^2 - 1{,}680.09x + 1{,}210.09$	$-0.0002x^6 + 0.0062x^5 - 0.09x^4 + 0.74x^3 - 3.13x^2 + 6.59x - 3.94$
Chandola	$-0.16x^6 + 4.60x^5 - 49.21x^4 + 252.21x^3 - 645.76x^2 + 792.01x - 323.18$	$0.09x^6 - 2.67x^5 + 28.18x^4 - 140.31x^3 + 338.19x^2 - 346.60x + 211.53$	$-0.39x^6 + 12.13x^5 - 146.22x^4 + 892.22x^3 - 2{,}902.46x^2 + 4{,}759.78x - 3{,}059.73$	$0.003x^6 - 0.08x^5 + 0.99x^4 - 6.11x^3 + 20.04x^2 - 32.83x + 22.28$
Dehgam	$0.012x^6 - 0.33x^5 + 3.25x^4 - 14.52x^3 + 30.54x^2 - 16.93x + 34.23$	$-0.01x^6 + 0.31x^5 - 3.40x^4 + 18.55x^3 - 57.01x^2 + 109.05x + 0.78$	$0.05x^6 - 1.69x^5 + 20.45x^4 - 125.42x^3 + 415.92x^2 - 704.59x + 470.54$	$-0.0001x^6 + 0.0035x^5 - 0.03x^4 + 0.17x^3 - 0.50x^2 + 1.03x + 0.38$
Nal Lake	$-0.06x^6 + 1.96x^5 - 22.07x^4 + 119.75x^3 - 325.10x^2 + 407.70x - 155.27$	$0.03x^6 - 1.06x^5 + 11.47x^4 - 58.11x^3 + 138.90x^2 - 115.32x + 97.53$	$0.06x^6 - 2.23x^5 + 32.47x^4 - 238.88x^3 + 930.22x^2 - 1{,}805.46x + 1{,}332.77$	$-0.0002x^6 + 0.01x^5 - 0.14x^4 + 1.15x^3 - 4.82x^2 + 10.12x - 6.64$
Sanand	$-0.0075x^6 + 0.24x^5 - 3.16x^4 + 20.44x^3 - 68.21x^2 + 116.14x - 6.58$	$0.006x^6 - 0.20x^5 + 2.46x^4 - 14.11x^3 + 35.46x^2 - 11.99x + 49.32$	$0.03x^6 - 1.15x^5 + 15.11x^4 - 102.14x^3 + 376.97x^2 - 721.24x + 532.69$	$-0.0005x^6 + 0.01x^5 - 0.21x^4 + 1.43x^3 - 5.25x^2 + 10.08x - 6.28$
Wasai	$-0.05x^6 + 1.58x^5 - 17.62x^4 + 96.02x^3 - 268.99x^2 + 376.43x - 134.16$	$0.02x^6 - 0.68x^5 + 7.40x^4 - 37.46x^3 + 87.57x^2 - 62.11x + 82.01$	$0.09x^6 - 3.39x^5 + 48.23x^4 - 347.10x^3 + 1{,}325.09x^2 - 2{,}521.07x + 1{,}854.03$	$-0.0006x^6 + 0.02x^5 - 0.29x^4 + 2.09x^3 - 7.90x^2 + 15.18x - 9.99$
Ambaji	$-0.007x^6 + 0.24x^5 - 2.95x^4 + 18.24x^3 - 60.85x^2 + 118.20x - 118.82$	$0.01x^6 - 0.39x^5 + 3.91x^4 - 17.66x^3 + 33.57x^2 - 4.55x + 111.33$	$0.06x^6 - 2.00x^5 + 24.31x^4 - 148.03x^3 + 474.34x^2 - 735.94x + 462.79$	$-0.0001x^5 + 0.0030x^4 - 0.02x^3 + 0.11x^2 - 0.09x + 1.08$
Amirgadh	$0.02x^6 - 0.70x^5 + 8.75x^4 - 53.69x^3 + 167.18x^2 - 225.13x + 154.61$	$-0.004x^6 + 0.14x^5 - 2.003x^4 + 14.67x^3 - 59.65x^2 + 128.84x - 24.25$	$0.06x^6 - 1.97x^5 + 26.06x^4 - 175.67x^3 + 633.01x^2 - 1{,}133.87x + 770.64$	$-0.0005x^6 + 0.01x^5 - 0.21x^4 + 1.48x^3 - 5.44x^2 + 10.21x - 6.07$
Bapla	$-0.001x^6 + 0.11x^5 - 2.47x^4 + 21.52x^3 - 86.41x^2 + 155.61x - 74.52$	$0.002x^6 - 0.10x^5 + 1.713x^4 - 12.48x^3 + 41.59x^2 - 45.56x + 90.72$	$-0.07x^6 + 2.57x^5 - 34.78x^4 + 237.43x^3 - 858.24x^2 + 1{,}544.84x - 1{,}067.20$	$0.0009x^6 - 0.02x^5 + 0.37x^4 - 2.50x^3 + 8.78x^2 - 15.21x + 11.34$

Chandisar	[illegible] $108.54x^3 - 338.43x^2 + 498.50x - 223.02$	$.06x^6 + 1.89x^5 -$ $.68x^4 + 113.69x^3 - 333.59x^2 + 499.00x - 193.11$	$0.20x^6 - 6.58x^5 + 83.09x^4 - 536.67x^3 + 1{,}866.41x^2 - 3{,}282.98x + 2{,}248.57$	$-0.002x^6 + 0.08x^5 - 0.98x^4 + 6.18x^3 - 20.84x^2 + 35.86x - 22.93$
Chitrasani	$0.02x^6 - 0.60x^5 + 8.10x^4 - 55.40x^3 + 198.65x^2 - 353.70x + 210.64$	$-0.01x^6 + 0.48x^5 - 6.58x^4 + 45.66x^3 - 169.32x^2 + 336.09x - 113.46$	$= -0.01x^6 + 0.40x^5 - 4.33x^4 + 21.66x^3 - 46.85x^2 + 13.47x + 2.88$	$0.0001x^6 - 0.004x^5 + 0.05x^4 - 0.28x^3 + 0.85x^2 - 0.95x + 1.80$
Danta	$-0.01x^6 + 0.37x^5 - 3.10x^4 + 8.46x^3 + 10.90x^2 - 67.04x + 78.75$	$-0.001x^6 + 0.09x^5 - 1.95x^4 + 17.97x^3 - 82.96x^2 + 192.86x - 36.68$	$0.03x^6 - 1.24x^5 + 17.54x^4 - 124.62x^3 + 463.83x^2 - 839.15x + 552.33$	$-0.0003x^6 + 0.009x^5 - 0.12x^4 + 0.84x^3 - 3.1072x^2 + 5.87x - 2.88$
Dantiwada	$-0.006x^6 + 0.21x^5 - 2.88x^4 + 18.15x^3 - 55.32x^2 + 77.07x - 1.87$	$-0.001x^6 + 0.06x^5 - 0.87x^4 + 7.02x^3 - 33.63x^2 + 93.83x + 1.11$	$0.04x^6 - 1.38x^5 + 17.73x^4 - 116.20x^3 + 411.77x^2 - 746.71x + 520.17$	$-0.0001x^6 + 0.004x^5 - 0.05x^4 + 0.34x^3 - 1.32x^2 + 2.79x - 0.91$
Deesa	$-0.006x^6 + 0.18x^5 - 2.21x^4 + 12.91x^3 - 36.45x^2 + 47.30x + 14.52$	$-0.002x^6 + 0.06x^5 - 0.94x^4 + 7.84x^3 - 37.01x^2 + 99.54x - 2.20$	$0.01x^6 - 0.26x^5 + 3.27x^4 - 21.49x^3 + 78.78x^2 - 153.40x + 105.47$	$0.0035x^3 - 0.05x^2 + 0.38x + 0.88$
Dhanera	$-0.04x^6 + 1.06x^5 - 12.61x^4 + 72.96x^3 - 212.14x^2 + 277.13x - 166.16$	$0.03x^6 - 0.91x^5 + 10.57x^4 - 58.90x^3 + 161.81x^2 - 179.28x + 176.36$	$0.04x^6 - 1.34x^5 + 18.03x^4 - 123.14x^3 + 448.48x^2 - 822.80x + 593.50$	$-0.0003x^6 + 0.009x^5 - 0.12x^4 + 0.90x^3 - 3.50x^2 + 7.01x - 4.27$
Gadh	$-0.03x^6 + 0.82x^5 - 8.80x^4 + 46.18x^3 - 123.70x^2 + 157.11x - 59.83$	$0.003x^6 - 0.03x^5 - 0.27x^4 + 6.17x^3 - 37.14x^2 + 107.68x + 13.81$	$-0.10x^6 + 3.3762x^5 - 41.80x^4 + 263.13x^3 - 888.53x^2 + 1{,}520.05x - 1{,}028.35$	$0.001x^6 - 0.03x^5 + 0.41x^4 - 2.65x^3 + 9.13x^2 - 15.67x + 11.82$
Hadad	$0.003x^6 - 0.06x^5 + 0.31x^4 + 0.49x^3 - 7.77x^2 + 28.94x + 23.88$	$-0.01x^6 + 0.37x^5 - 4.12x^4 + 22.79x^3 - 68.88x^2 + 118.76x - 12.28$	$0.19x^6 - 6.31x^5 + 79.99x^4 - 514.05x^3 + 1{,}767.35x^2 - 3{,}068.45x + 2{,}085.02$	$-0.001x^6 + 0.04x^5 - 0.60x^4 + 3.88x^3 - 13.32x^2 + 23.30x - 14.76$
Junisarotri	$0.01x^6 - 0.41x^5 + 4.89x^4 - 28.35x^3 + 83.18x^2 - 108.80x + 86.66$	$-0.01x^6 + 0.32x^5 - 3.98x^4 + 24.82x^3 - 84.52x^2 + 164.41x - 28.04$	$0.06x^6 - 2.08x^5 + 26.07x^4 - 164.80x^3 + 553.97x^2 - 939.34x + 613.39$	$-0.0004x^6 + 0.01x^5 - 0.14x^4 + 0.90x^3 - 3.11x^2 + 5.67x - 2.73$
Nava	$0.06x^6 - 2.09x^5 + 25.10x^4 - 149.11x^3 + 456.42x^2 - 662.05x + 312.77$	$-0.05x^6 + 1.52x^5 - 18.28x^4 + 109.18x^3 - 340.26x^2 + 526.36x - 187.95$	$-0.11x^6 + 3.96x^5 - 54.32x^4 + 380.58x^3 - 1{,}432.10x^2 + 2{,}734.83x - 2{,}051.96$	$0.001x^6 - 0.04x^5 + 0.63x^4 - 4.30x^3 + 15.60x^2 - 28.48x + 21.72$
Palanpur	$-0.10x^6 + 3.05x^5 - 34.90x^4 + 191.35x^3 - 514.26x^2 + 623.69x - 281.86$	$0.05x^6 - 1.47x^5 + 16.46x^4 - 86.01x^3 + 209.02x^2 - 186.37x + 158.75$	$0.23x^6 - 7.95x^5 + 107.10x^4 - 737.13x^3 + 2{,}719.09x^2 - 5{,}037.19x + 3{,}612.58$	$-0.001x^6 + 0.04x^5 - 0.59x^4 + 4.12x^3 - 15.22x^2 + 28.40x - 19.27$
Panthawada	$0.02x^6 - 0.67x^5 + 7.16x^4 - 36.28x^3 + 88.82x^2 - 89.34x + 45.65$	$-0.02x^6 + 0.75x^5 - 8.33x^4 + 45.58x^3 - 130.05x^2 + 193.41x - 31.74$	$-0.02x^6 + 1.10x^5 - 16.90x^4 + 129.02x^3 - 515.31x^2 + 1{,}015.09x - 754.68$	$0.0002x^6 - 0.008x^5 + 0.13x^4 - 1.00x^3 + 3.97x^2 - 7.60x + 6.75$
Sanali Ashram	$0.02x^6 - 0.65x^5 + 7.23x^4 - 38.09x^3 + 97.74x^2 - 98.47x + 72.86$	$-0.02x^6 + 0.85x^5 - 9.71x^4 + 54.37x^3 - 156.21x^2 + 223.53x - 61.15$	$0.10x^6 - 3.30x^5 + 39.95x^4 - 242.51x^3 + 776.48x^2 - 1{,}238.35x + 777.89$	$-0.001x^6 + 0.03x^5 - 0.34x^4 + 2.08x^3 - 6.59x^2 + 10.54x - 5.43$

Wadgam	[illegible] $132.83x^3 - 371.81x^2 + 496.25x - 218.62$	[illegible]$05x^6 - 1.46x^5 +$ [illegible]$.52x^4 - 90.20x^3 + 242.27x^2 - 276.67x + 192.77$	$0.16x^6 - 5.40x^5 + 72.10x^4 - 504.46x^3 + 1,865.43x^2 - 3,461.63x + 2,501.76$	$-0.001x^6 + 0.03x^5 - 0.45x^4 + 3.18x^3 - 11.95x^2 + 22.78x - 15.64$
Mansa	$-0.02x^6 + 0.57x^5 - 6.40x^4 + 34.97x^3 - 96.96x^2 + 141.68x + 0.74$	$0.005x^6 - 0.15x^5 + 1.65x^4 - 8.44x^3 + 15.73x^2 + 20.42x + 26.17$	$0.08x^6 - 2.96x^5 + 41.83x^4 - 300.35x^3 + 1,146.32x^2 - 2,180.34x + 1,598.70$	$0.001x^5 - 0.04x^4 + 0.44x^3 - 2.20x^2 + 5.20x - 3.13$
Raipur Weir	$0.006x^6 - 0.26x^5 + 4.50x^4 - 36.55x^3 + 144.50x^2 - 232.43x + 183.61$	$-0.02x^6 + 0.69x^5 - 9.36x^4 + 63.92x^3 - 230.04x^2 + 404.55x - 159.82$	$-0.01x^6 + 0.25x^5 - 2.50x^4 + 12.17x^3 - 40.73x^2 + 134.95x - 208.67$	$0.0002x^6 - 0.007x^5 + 0.09x^4 - 0.58x^3 + 2.02x^2 - 3.69x + 4.34$
Balasinor	$0.04x^6 - 1.20x^5 + 13.62x^4 - 74.37x^3 + 202.58x^2 - 239.68x + 153.34$	$-0.02x^6 + 0.82x^5 - 9.34x^4 + 52.48x^3 - 153.71x^2 + 231.48x - 61.70$	$0.02x^6 - 0.46x^5 + 2.74x^4 + 6.38x^3 - 112.01x^2 + 357.74x - 351.45$	$-0.001x^5 + 0.03x^4 - 0.38x^3 + 1.82x^2 - 3.81x + 4.22$
Dakor	$0.04x^6 - 1.34x^5 + 15.42x^4 - 86.16x^3 + 240.26x^2 - 284.68x + 170.96$	$-0.01x^6 + 0.34x^5 - 3.89x^4 + 22.09x^3 - 69.10x^2 + 121.85x - 6.02$	$-0.02x^6 + 0.86x^5 - 13.11x^4 + 99.16x^3 - 391.91x^2 + 777.48x - 590.23$	$0.0002x^6 - 0.006x^5 + 0.08x^4 - 0.60x^3 + 2.19x^2 - 3.73x + 3.66$
Kapadwanj	$0.03x^6 - 0.90x^5 + 10.30x^4 - 56.12x^3 + 144.81x^2 - 126.19x + 104.44$	$0.002x^6 - 0.07x^5 + 0.95x^4 - 6.22x^3 + 19.66x^2 - 21.72x + 74.02$	$-0.01x^6 + 0.37x^5 - 4.63x^4 + 28.70x^3 - 95.90x^2 + 177.74x - 100.89$	$-0.001x^4 + 0.02x^3 - 0.17x^2 + 0.66x + 0.30$
Kathlal	$-0.02x^6 + 0.63x^5 - 5.73x^4 + 21.64x^3 - 27.08x^2 - 0.51x + 39.95$	$0.004x^6 - 0.04x^5 - 0.92x^4 + 15.96x^3 - 87.37x^2 + 205.50x - 48.67$	$-0.02x^6 + 0.50x^5 - 4.62x^4 + 17.10x^3 - 19.41x^2 - 4.60x - 5.14$	$0.0001x^6 - 0.003x^5 + 0.02x^4 - 0.05x^3 - 0.14x^2 + 0.78x + 0.61$
Kheda	$-0.04x^6 + 1.19x^5 - 13.44x^4 + 73.61x^3 - 202.42x^2 + 275.26x - 75.36$	$0.03x^6 - 0.83x^5 + 8.99x^4 - 46.39x^3 + 113.44x^2 - 100.22x + 84.46$	$-0.03x^6 + 0.94x^5 - 8.54x^4 + 29.52x^3 - 1.09x^2 - 176.81x + 220.36$	$0.0005x^6 - 0.01x^5 + 0.17x4 - 0.92x^3 + 2.41x^2 - 2.57x + 2.03$
Mahemadabad	$0.004x^6 - 0.09x^5 + 0.68x^4 - 0.76x^3 - 11.41x^2 + 59.67x + 22.20$	$-0.02x^6 + 0.57x^5 - 6.55x^4 + 37.10x^3 - 110.50x^2 + 173.09x - 29.55$	$0.01x^6 - 0.20x^5 + 0.83x^4 + 7.35x^3 - 71.78x^2 + 210.07x - 194.60$	$-0.0001x^6 + 0.002x^5 - 0.01x^4 - 0.0003x^3 + 0.31x^2 - 0.92x + 2.06$
Mahisa	$0.01x^6 - 0.54x^5 + 6.53x^4 - 39.16x^3 + 120.28x^2 - 161.12x + 135.85$	$-0.01x^6 + 0.50x^5 - 6.30x^4 + 39.96x^3 - 133.61x^2 + 225.06x - 74.72$	$-0.13x^6 + 4.47x^5 - 57.42x^4 + 375.12x^3 - 1,313.55x^2 + 2,340.31x - 1,664.57$	$0.001x^6 - 0.03x^5 + 0.40x^4 - 2.67x^3 + 9.39x^2 - 16.61x + 12.95$
Nadiad	$-0.03x^6 + 0.83x^5 - 8.42x^4 + 39.08x^3 - 83.23x^2 + 81.33x - 1.23$	$0.02x^6 - 0.51x^5 + 4.72x^4 - 17.77x^3 + 15.89x^2 + 56.24x + 33.47$	$-0.12x^6 + 3.75x^5 - 45.09x^4 + 272.52x^3 - 875.06x^2 + 1,432.97x - 944.22$	$0.0008x^6 - 0.02x^5 + 0.28x^4 - 1.69x^3 + 5.40x^2 - 8.54x + 6.64$
Pinglaj	$-0.01x^6 + 0.34x^5 - 4.13x^4 + 24.47x^3 - 74.18x^2 + 126.40x - 48.02$	$-0.004x^6 + 0.12x^5 - 1.49x^4 + 9.65x^3 - 38.16x^2 + 86.13x + 29.57$	$-0.08x^6 + 2.62x^5 - 33.75x^4 + 219.52x^3 - 760.90x^2 + 1,346.01x - 926.09$	$0.0005x^6 - 0.01x^5 + 0.22x^4 - 1.46x^3 + 5.08x^2 - 8.74x + 7.07$
Savli tank	$-0.01x^6 + 0.36x^5 - 4.49x^4 + 27.45x^3 - 85.64x^2 + 142.67x - 11.01$	$-0.002x^6 + 0.05x^5 - 0.42x^4 + 1.87x^3 - 8.34x^2 + 32.52x + 26.74$	$0.02x^6 - 0.68x5 + 8.60x^4 - 57.19x^3 + 213.09x^2 - 406.82x + 302.18$	$-0.0001x^6 + 0.002x^5 - 0.02x^4 + 0.13x^3 - 0.50x^2 + 1.24x + 0.07$

[illegible]	[illegible] $105.09x^2$ + 162.31x - 61.18	[illegible] $01x^6 - 0.37x^5$ + [illegible] $26x^4 - 22.06x^3 + 49.82x^2 - 30.97x + 87.39$	$-0.07x^6 + 2.43x^5 - 31.05x^4 + 199.45x^3 - 679.57x^2$ + 1,182.98x - 800.03	$0.0006x^6 - 0.01x^5 + 0.23x^4 - 1.49x^3 + 4.94x^2 - 8.13x + 6.39$
Vaghroli	$0.07x^6 - 2.28x^5 + 26.54x^4 - 150.02x^3 + 421.78x^2 - 514.56x + 289.99$	$-0.03x^6 + 1.05x^5 - 12.15x^4 + 68.45x^3 - 197.35x^2 + 282.08x - 59.77$	$-0.05x^6 + 1.84x^5 - 26.10x^4 + 189.41x^3 - 738.65x^2$ + 1,462.81x - 1,108.45	$0.0003x^6 - 0.01x^5 + 0.13x^4 - 0.98x^3 + 3.80x^2 - 7.20x + 6.41$
Ambaliyasan	$-0.11x^6 + 3.70x^5 - 45.93x^4 + 285.27x^3 - 929.97x^2 + 1515.60x - 913.75$	$0.03x^6 - 1.16x^5 + 15.28x^4 - 98.75x^3 + 325.30x^2 - 502.44x + 376.87$	$-0.04x^6 + 1.61x^5 - 21.77x^4 + 149.47x^3 - 551.98x^2$ + 1,057.15x - 652.69	$-0.0002x^5 + 0.003x^4 - 0.01x^3 - 0.08x^2 + 0.60x - 0.08$
Dharoi	$-0.01x^5 + 0.43x^4 - 4.62x^3 + 20.81x^2 - 27.16x + 76.56$	$-0.001x^6 + 0.04x^5 - 0.96x^4 + 9.48x^3 - 47.84x^2 + 126.60x - 31.07$	$0.30x^6 - 10.15x^5 + 134.35x^4 - 906.62x^3$ + $3,277.64x^2$ - 5,981.80x + 4,230.79	$-0.002x^6 + 0.07x^5 - 0.92x^4 + 6.15x^3 - 22.03x^2 + 40.07x - 26.98$
Kadi	$-0.004x^6 + 0.14x^5 - 1.81x^4 + 9.31x^3 - 15.72x^2 + 13.78x - 16.40$	$-0.01x^6 + 0.27x^5 - 3.45x^4 + 23.31x^3 - 90.96x^2 + 189.60x + 5.56$	$-0.12x^6 + 4.00x^5 - 50.97x^4 + 326.69x^3$ - $1,108.86x^2$ + 1,911.20x - 1,286.77	$0.0004x^6 - 0.01x^5 + 0.15x^4 - 1.01x^3 + 3.42x^2 - 5.71x + 4.97$
Kalol	$0.005x^6 - 0.14x^5 + 1.72x^4$ - 10.26x3 + $30.36x^2 - 18.16x + 53.60$	$-0.02x^6 + 0.61x^5 - 7.42x^4 + 45.26x^3 - 148.14x^2 + 250.96x - 76.46$	$-0.09x^6 + 3.09x^5 - 41.36x^4 + 280.72x^3$ - $1,019.19x^2$ + 1,884.03x - 1,373.77	$0.0009x^6 - 0.03x^5 + 0.40x^4 - 2.73x^3 + 9.78x^2 - 17.49x + 13.63$
Katosan	$-0.03x^6 + 0.91x^5 - 11.52x^4 + 71.25x^3 - 218.97x^2 + 304.32x - 117.34$	$0.02x^6 - 0.66x^5 + 8.00x^4 - 46.05x^3 + 125.70x^2 - 122.07x + 114.63$	$0.13x^6 - 4.29x^5 + 55.33x^4 - 363.98x^3$ + $1,290.45x^2$ - 2,334.23x + 1,650.57	$-0.0007x^6 + 0.02x^5 - 0.31x^4 + 2.14x^3 - 7.87x^2 + 14.96x - 9.82$
Kheralu	$-0.06x^6 + 1.80x^5 - 19.87x^4 + 104.50x^3 - 267.45x^2 + 306.99x - 118.25$	$0.03x^6 - 0.91x^5 + 9.99x^4 - 50.67x^3 + 117.24x^2 - 82.32x + 105.67$	$-0.04x^6 + 1.27x^5 - 15.08x^4 + 87.59x^3 - 262.00x^2 + 391.65x - 240.84$	$0.0004x^6 - 0.01x^5 + 0.14x^4 - 0.81x^3 + 2.37x^2 - 3.14x + 2.79$
Mehsana	$-0.02x^6 + 0.96x^5 - 13.07x^4 + 84.81x^3 - 263.59x^2 + 340.13x - 159.16$	$0.004x^6 - 0.19x^5 + 3.22x^4 - 22.50x^3 + 62.69x^2 - 19.51x + 73.81$	$-0.04x^6 + 1.58x^5 - 20.99x^4 + 137.89x^3 - 462.34x^2 + 733.97x - 454.46$	$0.0005x^6 - 0.01x^5 + 0.23x^4 - 1.55x^3 + 5.28x^2 - 8.45x + 6.51$
Ransipur	$0.06x^6 - 1.73x^5 + 18.60x^4 - 95.08x^3 + 241.00x^2 - 285.39x + 152.77$	$-0.04x^6 + 1.22x^5 - 13.23x^4 + 69.11x^3 - 186.44x^2 + 271.60x - 66.37$	$0.11x^6 - 3.28x^5 + 37.21x^4 - 206.96x^3 + 595.02x^2 - 852.89x + 473.05$	$-0.0006x^6 + 0.01x^5 - 0.20x^4 + 1.11x^3 - 3.12x^2 + 4.66x - 1.55$
Thol	$-0.0015x^6 + 0.03x^5 - 0.29x^4 + 1.38x^3 - 5.86x^2 + 21.81x + 28.77$	$-0.004x^6 + 0.15x^5 - 2.33x^4 + 17.05x^3 - 64.48x^2 + 131.40x - 15.97$	$0.01x^6 - 0.59x^5 + 8.52x^4 - 60.08x^3 + 218.88x^2 - 393.14x + 264.53$	$-0.0004x^6 + 0.013x^5 - 0.18x^4 + 1.24x^3 - 4.42x^2 + 8.07x - 4.43$
Unjha	$0.001x^6 - 0.03x^5 + 0.41x^4 - 2.07x^3 + 2.59x^2 + 13.73x + 6.76$	$-0.0006x^6 + 0.01x^5 - 0.004x^4 - 0.56x^3 + 1.45x^2 + 14.76x + 58.22$	$0.02x^6 - 0.85x^5 + 11.04x^4 - 71.42x^3 + 243.34x^2 - 408.39x + 272.62$	$-0.0003x^6 + 0.01x^5 - 0.12x^4 + 0.77x^3 - 2.71x^2 + 4.98x - 2.49$

[illegible]	[illegible] 43.05	[illegible]$.015x^6 - 0.44x^5 + 4.77x^4 - 23.14x^3 + 44.48x^2 + 4.99x + 55.37$	$0.22x^6 - 7.48x^5 + 98.14x^4 - 655.34x^3 + 2,344.29x^2 - 4,222.97x + 2,949.64$	$-0.001x^6 + 0.04x^5 - 0.60x^4 + 4.02x^3 - 14.50x^2 + 26.53x - 17.62$
Visnagar	$-0.09x^6 + 3.01x^5 - 35.36x^4 + 202.04x^3 - 572.53x^2 + 731.02x - 386.35$	$0.003x^6 - 0.11x^5 + 1.53x^4 - 8.67x^3 + 12.24x^2 + 48.42x + 85.70$	$-0.01x^6 + 0.50x^5 - 7.48x^4 + 55.58x^3 - 216.53x^2 + 429.55x - 327.38$	$-0.0004x^6 + 0.01x^5 - 0.13x^4 + 0.79x^3 - 2.61x^2 + 4.54x - 1.88$
Patan	$-0.03x^6 + 1.08x^5 - 12.29x^4 + 66.76x^3 - 179.31x^2 + 229.36x - 103.78$	$0.01x^6 - 0.38x^5 + 3.98x^4 - 18.40x^3 + 33.08x^2 + 2.27x + 67.42$	$0.02x^6 - 0.97x^5 + 14.41x^4 - 108.49x^3 + 432.39x^2 - 841.41x + 624.95$	$-0.0002x^6 + 0.006x^5 - 0.08x^4 + 0.63x^3 - 2.57x^2 + 5.19x - 2.77$
Sidhpur	$-0.07x^6 + 2.07x^5 - 23.09x^4 + 125.05x^3 - 343.30x^2 + 459.25x - 226.54$	$0.05x^6 - 1.58x^5 + 17.41^4 - 91.97x^3 + 239.71x^2 - 271.96x + 204.93$	$-0.05x^6 + 1.51x^5 - 17.30x^4 + 97.69x^3 - 286.19x^2 + 424.79x - 234.86$	$0.0004x^6 - 0.01x^5 + 0.10x^4 - 0.44x^3 + 0.77x^2 + 0.04x + 0.22$
Wagdod	$0.01x^6 - 0.03x^5 - 0.43x^4 + 3.70x^3 + 7.65x^2 - 96.88x + 58.41$	$0.007x^6 - 0.22x^5 + 2.74x^4 - 13.45x^3 + 13.13x^2 + 84.81x + 25.12$	$0.17x^6 - 5.54x^5 + 71.14x^4 - 466.80x^3 + 1,652.79x^2 - 2,981.32x + 2,078.63$	$-0.0008x^6 + 0.02x^5 - 0.32x^4 + 2.17x^3 - 7.89x^2 + 14.85x - 9.49$
Badoli	$0.05x^6 - 1.57x^5 + 18.06x^4 - 102.31x^3 + 292.97x^2 - 368.60x + 210.43$	$-0.05x^6 + 1.59x^5 - 18.23x^4 + 103.10x^3 - 299.88x^2 + 422.89x - 136.76$	$0.02x^6 - 0.39x^5 + 0.83x^4 + 26.31x^3 - 219.13x^2 + 650.07x - 627.32$	$-0.002x^5 + 0.05x^4 - 0.60x^3 + 2.98x^2 - 6.78x + 6.85$
Bayad	$0.02x^6 - 0.77x^5 + 9.88x^4 - 61.81x^3 + 191.16x^2 - 243.85x + 172.94$	$0.07x^5 - 1.94x^4 + 19.05x^3 - 84.12x^2 + 168.42x - 33.67$	$0.04x^6 - 1.58x^5 + 22.77x^4 - 164.68x^3 + 620.21x^2 - 1,126.06x + 772.38$	$-0.0001x^6 + 0.005x^5 - 0.08x^4 + 0.69x^3 - 2.84x^2 + 5.61x - 2.86$
Bhiloda	$0.02x^5 - 0.54x^4 + 6.25x^3 - 34.29x^2 + 100.96x + 6.36$	$-0.03x^6 + 0.98x^5 - 10.98x^4 + 59.46x^3 - 162.79x^2 + 220.86x - 43.58$	$-0.17x^6 + 5.94x^5 - 78.98x^4 + 534.91x^3 - 1,938.25x^2 + 3,541.01x - 2,506.58$	$0.001x^6 - 0.05x^5 + 0.70x^4 - 4.80x^3 + 17.43x^2 - 31.69x + 23.53$
Dantral	$-0.02x^6 + 0.47x^5 - 4.72x^4 + 22.70x^3 - 56.10x^2 + 76.58x + 4.25$	$0.05x^5 - 1.29x^4 + 12.10x^3 - 52.07x^2 + 114.01x - 18.22$	$-0.10x^6 + 3.17x^5 - 38.97x^4 + 243.01x^3 - 814.71x^2 + 1,388.42x - 944.35$	$0.0005x^6 - 0.01x^5 + 0.18x^4 - 1.11x^3 + 3.63x^2 - 5.86x + 5.06$
Himmatnagar	$-0.02x^6 + 0.65x^5 - 7.20x^4 + 38.85x^3 - 106.40x^2 + 149.19x - 36.95$	$0.03x^6 - 0.82x^5 + 9.17x^4 - 49.01x^3 + 124.95x^2 - 116.38x + 107.40$	$0.15x^6 - 4.45x^5 + 50.31x^4 - 289.15x^3 + 898.76x^2 - 1,432.32x + 909.42$	$-0.001x^6 + 0.04x^5 - 0.46x^4 + 2.75x^3 - 8.94x^2 + 15.20x - 9.06$
Idar	$0.03x^6 - 0.79x^5 + 8.51x^4 - 44.18x^3 + 114.37x^2 - 126.27x + 102.81$	$-0.05x^6 + 1.46x^5 - 16.24x^4 + 89.05x^3 - 254.06x^2 + 372.92x - 115.78$	$0.22x^6 - 6.98x^5 + 86.26x^4 - 539.05x^3 + 1,798.93x^2 - 3,037.55x + 2,011.35$	$-0.001x^6 + 0.04x^5 - 0.49x^4 + 3.00x^3 - 9.73x^2 + 16.17x - 9.32$
Khebhrama	$-0.02x^6 + 0.59x^5 - 5.98x^4 + 28.33x^3 - 66.19x^2 + 92.27x - 3.98$	$0.01x^6 - 0.32x^5 + 2.54x^4 - 6.29x^3 - 10.95x^2 + 69.72x + 16.83$	$0.002x^6 - 0.21x^5 + 4.87x^4 - 44.73x^3 + 191.66x^2 - 358.09x + 241.33$	$-0.0003x^6 + 0.01x^5 - 0.16x^4 + 1.18x^3 - 4.54x^2 + 8.58x - 4.93$

	[illegible] $+ 104.17$	$-0.01x^6 + 0.26x^5 - 3.30x^4 + 22.05x^3 - 85.74x^2 + 188.69x - 46.88$	$-0.10x^6 + 3.31x^5 - 43.34x^4 + 285.74x^3 - 993.72x^2 + 1,726.22x - 1,198.62$	$0.0008x^6 - 0.02x^5 + 0.34x^4 - 2.25x^3 + 7.74x^2 - 13.04x + 10.04$
Limladam	$0.05x^6 - 1.62x^5 + 18.46x^4 - 102.21x^3 + 282.81x^2 - 339.09x + 219.88$	$-0.01x^6 + 0.41x^5 - 4.40x^4 + 23.52x^3 - 69.45x^2 + 122.96x - 25.06$	$0.08x^6 - 2.47x^5 + 30.58x^4 - 192.33x^3 + 654.54x^2 - 1,143.11x + 773.62$	$-0.0009x^6 + 0.02x^5 - 0.34x^4 + 2.22x^3 - 7.76x^2 + 14.18x - 8.86$
Malpur	$0.02x^6 - 0.58x^5 + 7.18x^4 - 43.99x^3 + 138.99x^2 - 193.63x + 156.40$	$0.03x^5 - 1.00x^4 + 11.33x^3 - 60.17x^2 + 152.80x - 34.54$	$-0.30x^6 + 9.89x^5 - 126.89x^4 + 825.68x^3 - 2,866.48x^2 + 5,028.82x - 3,496.51$	$0.002x^6 - 0.06x^5 + 0.87x^4 - 5.67x^3 + 19.49x^2 - 33.58x + 24.15$
Meghraj	$0.06x^6 - 1.75x^5 + 20.29x^4 - 114.12x^3 + 318.11x^2 - 375.81x + 214.49$	$-0.02x^6 + 0.73x^5 - 8.67x^4 + 51.55x^3 - 158.41x^2 + 236.03x - 65.88$	$-0.03x^6 + 1.14x^5 - 15.38x^4 + 105.62x^3 - 394.19x^2 + 771.80x - 583.57$	$0.0003x^6 - 0.01x^5 + 0.12x^4 - 0.86x^3 + 3.13x^2 - 5.80x + 5.42$
Modasa	$0.04x^6 - 1.23x^5 + 14.02x^4 - 76.79x^3 + 204.91x^2 - 221.99x + 164.20$	$0.01x^5 - 0.31x^4 + 3.36x^3 - 18.17x^2 + 54.91x + 2.53$	$-0.008x^6 + 0.21x^5 - 2.05x^4 + 7.25x^3 + 2.05x^2 - 67.52x + 86.72$	$0.0006x^5 - 0.01x^4 + 0.19x^3 - 1.03x^2 + 2.81x - 1.30$
Pal	$0.02x^6 - 0.64x^5 + 6.88x^4 - 35.32x^3 + 88.87x^2 - 84.57x + 79.59$	$-0.02x^6 + 0.59x^5 - 6.62x^4 + 36.28x^3 - 103.94x^2 + 157.74x - 36.01$	$-0.006x^6 + 0.34x^5 - 6.54x^4 + 57.39x^3 - 250.50x^2 + 524.89x - 412.60$	$-0.001x^5 + 0.04x^4 - 0.38x^3 + 1.76x^2 - 3.55x + 3.92$
Prantij	$0.02x^6 - 0.59x^5 + 6.74x^4 - 38.44x^3 + 117.02x^2 - 166.79x + 155.41$	$0.01x^5 - 0.37x^4 + 5.10x^3 - 35.24x^2 + 117.96x - 22.72$	$0.36x^6 - 11.70x^5 + 152.13x^4 - 1,008.64x^3 + 3,588.77x^2 - 6,462.60x + 4,508.81$	$-0.001x^6 + 0.05x^5 - 0.66x^4 + 4.43x^3 - 15.89x^2 + 29.14x - 19.37$
Sabli	$-0.03x^6 + 0.94x^5 - 10.41x^4 + 56.17x^3 - 155.65x^2 + 222.79x - 68.78$	$0.04x^6 - 1.07x^5 + 12.33x^4 - 68.78x^3 + 190.92x^2 - 226.66x + 160.13$	$-0.05x^6 + 1.37x^5 - 14.77x^4 + 75.86x^3 - 187.99x^2 + 199.13x - 50.37$	$0.0007x^6 - 0.02x^5 + 0.25x^4 - 1.47x^3 + 4.40x^2 - 6.09x + 4.23$
Shamlaji	$0.02x^6 - 0.40x^5 + 3.68x^4 - 16.12x^3 + 38.00x^2 - 41.84x + 61.42$	$0.01x^6 - 0.34x^5 + 3.50x^4 - 14.74x^3 + 12.87x^2 + 65.65x + 11.33$	$-0.34x^6 + 11.31x^5 - 146.85x^4 + 964.33x^3 - 3,362.46x^2 + 5,884.77x - 4,047.87$	$0.0008x^6 - 0.02x^5 + 0.30x^4 - 1.90x^3 + 6.17x^2 - 9.72x + 7.41$
Wadgam	$-0.02x^6 + 0.57x^5 - 6.74x^4 + 38.27x^3 - 106.35x^2 + 140.55x + 6.86$	$0.02x^6 - 0.65x^5 + 7.71x^4 - 44.48x^3 + 125.75x^2 - 146.21x + 122.66$	$-0.0607x^6 + 1.89x^5 - 22.99x^4 + 137.33x^3 - 415.45x^2 + 590.03x - 330.14$	$0.0003x^6 - 0.008x^5 + 0.08x^4 - 0.46x^3 + 1.06x^2 - 0.43x + 0.71$
Vijaynagar	$-0.01x^6 + 0.46x^5 - 6.21x^4 + 40.63x^3 - 132.88x^2 + 214.55x - 62.60$	$0.01x^6 - 0.22x^5 + 3.01x^4 - 19.25x^3 + 57.43x^2 - 59.77x + 65.86$	$-0.35x^6 + 11.5x^5 - 148.68x^4 + 970.14x^3 - 3,360.69x^2 + 5,837.36x - 3,961.33$	$0.003x^6 - 0.10x^5 + 1.35x^4 - 8.82x^3 + 30.55x^2 - 52.81x + 36.88$
Virpur	$0.02x^6 - 0.64x^5 + 7.32x^4 - 40.76x^3 + 111.48x^2 - 115.65x + 80.25$	$-0.05x^6 + 1.40x^5 - 16.22x^4 + 92.28x^3 - 270.04x^2 + 386.47x - 130.32$	$-0.04x^6 + 1.58x^5 - 23.64x^4 + 179.01x^3 - 721.23x^2 + 1,464.78x - 1,135.75$	$0.0002x^6 - 0.01x^5 + 0.16x^4 - 1.31x^3 + 5.49x^2 - 11.24x + 10.00$

nd C_4 are predicted using the respective equation corresponding to one day and consecutive 2 to 7 & 10 days maximum rainfall for each of the chosen return period. These values are compared with the observed values to evaluate the performance of the equations determined. The absolute difference between the observed and predicted values for constants is not more than 5 % in any case. Moreover the prediction in case for C_3 and C_4 are 98 % accurate because the absolute differences between predicted and observed values are well below 2 %. Thus the relationships developed are almost exact for predicting the constants C_1, C_2, C_3 and C_4.

The constants obtained and the equations developed are validated using different goodness of fit parameters. Tables 6.155 and 6.156 present the summary of average values for the parameters obtained for the relationships developed.

Table 6.155 Summary of Average Value of Parameters for Logarithmic Relationship between Return Period and One Day, Consecutive 2 to 7 & 10 Days Maximum Rainfall in North Gujarat Agroclimatic Zone

Day maximum rainfall	Constants		Data type	r	R2	E1	d1	U	RMSE	MAE
	C_1	C_2							mm	mm
One	35.39	75.66	M	0.9983	0.9983	0.9638	0.9819	0.0000	4.8202	2.8944
			V	0.9991	0.9995	0.9672	0.9835	0.0000	3.0734	2.3839
Two	43.55	106.94	M	0.9988	0.9988	0.9659	0.9830	0.0000	6.4640	3.8623
			V	0.9994	0.9996	0.9701	0.9850	0.0000	4.4059	3.3588
Three	57.63	115.26	M	0.9976	0.9985	0.9584	0.9795	0.0000	6.6108	3.5422
			V	0.9982	0.9999	0.9545	0.9769	0.0000	4.1341	2.7025
Four	71.35	119.79	M	0.9984	0.9987	0.9634	0.9817	0.0000	7.5217	4.3606
			V	0.9991	0.9997	0.9668	0.9834	0.0000	4.6649	3.6575
Five	80.47	124.98	M	0.9986	0.9986	0.9657	0.9829	0.0000	7.5115	4.1057
			V	0.9994	0.9998	0.9697	0.9849	0.0000	4.3891	3.3770
Six	87.62	130.18	M	0.9985	0.9985	0.9642	0.9822	0.0000	7.9077	4.3555
			V	0.9994	0.9998	0.9686	0.9843	0.0000	4.6992	3.6323
Seven	92.47	137.58	M	0.9985	0.9985	0.9643	0.9822	0.0000	8.3775	4.5896
			V	0.9994	0.9997	0.9689	0.9845	0.0000	4.9243	3.8387
Ten	96.50	167.14	M	0.9987	0.9987	0.9655	0.9828	0.0000	9.8171	5.5631
			V	0.9994	0.9997	0.9699	0.9850	0.0000	6.1080	4.6819

of Average Value of Parameters for Linear Day and Consecutive 2 to 7 & 10 Days Maximum Rainfall in North Gujarat Agroclimatic Zone

Day maximum rainfall	Constants		Data type	r	R^2	E1	d1	U	RMSE mm	MAE mm
	C_3	C_4								
Two	-2.28	1.37	M	0.9993	0.9993	0.9870	0.9936	0.0000	2.0131	1.2760
			V	0.9996	0.9996	0.9883	0.9944	0.0000	1.4098	1.1206
Three	2.80	1.54	M	0.9989	0.9998	0.9816	0.9907	0.0000	2.4869	1.4285
			V	0.9979	0.9999	0.9755	0.9884	0.0000	1.7676	1.2729
Four	12.12	1.62	M	0.9993	0.9993	0.9836	0.9920	0.0000	2.9715	1.8538
			V	0.9995	0.9997	0.9840	0.9920	0.0000	1.9547	1.5626
Five	19.50	1.67	M	0.9992	0.9992	0.9810	0.9908	0.0000	3.4220	2.1177
			V	0.9996	0.9997	0.9824	0.9915	0.0000	2.1550	1.7467
Six	23.83	1.75	M	0.9991	0.9991	0.9802	0.9903	0.0000	3.6302	2.2313
			V	0.9996	0.9997	0.9822	0.9911	0.0000	2.3774	1.8553
Seven	24.76	1.85	M	0.9992	0.9992	0.9794	0.9900	0.0000	4.1206	2.5356
			V	0.9992	0.9997	0.9786	0.9896	0.0000	2.5619	2.1392
Ten	13.00	2.25	M	0.9992	0.9992	0.9801	0.9900	0.0000	5.0300	3.0726
			V	0.9995	0.9996	0.9814	0.9906	0.0000	3.2491	2.6047

For all the goodness parameters obtained it is observed that the lowest value of coefficient of efficiency (E1) corresponds to the model having lowest correlation coefficient (r) value. The highest RMSE and MAE values correspond to the lowest correlation coefficient value. Physically coefficient of Efficiency is the ratio of the MAE to the variance in the observed data, subtracted from unity. Thus as the correlation coefficient improves the efficiency is increased and error is minimized. Thus based on the above goodness of fit parameters the relationship obtained for each of the 73 raingauge stations is the best.

Therefore it can be concluded that the relationship between the return period and one day maximum rainfall, consecutive two, three, four, five, six, seven and ten days maximum rainfall, are logarithmic. While a linear relationship exists between one day maximum rainfall and consecutive two, three, four, five, six, seven and ten days maximum rainfall. The relationships developed are accurate upto 95% for return period from 2 to 1000 years.

used for determining the design rainfall required at d for planning the various components of water resources and irrigation projects in the region.

6.5 CHARACTERISTICS OF CLIMATIC DATA

Any type of statistical analysis based on the past record would not represent the climate accurately unless the length of the record is adequate. Therefore the rainfall data are tested for the length of records and the results are presented in Table 6.157.

Table 6.157 Length of Records Required for the 73 Raingauge Stations in North Gujarat Agroclimatic Zone

Sr. no.	Name of raingauge station	Available length of record	Length of record required		Annual rainfall	
			Original data	Fitted data	Maximum, mm	Minimum, mm
1	Aslali	48	12	17	1521	141
2	Bareja	38	11	17	1549	143
3	Barejadi	38	11	16	1372	185
4	Chandola	38	12	19	1372	162
5	Dehgam	47	13	18	1474	144
6	Nal Lake	39	13	19	1374	85
7	Sanand	42	11	15	1394	181
8	Wasai	38	11	17	1531	189
9	Ambaji	38	13	27	1801	174
10	Amirgadh	42	13	16	1467	114
11	Bapla	44	14	21	1580	49
12	Chandisar	40	13	18	1213	84
13	Chitrasani	42	13	21	1356	16
14	Danta	46	11	19	1571	95
15	Dantiwada	45	13	18	1357	36
16	Deesa	48	12	18	1189	59
17	Dhanera	48	14	27	1067	7
18	Gadh	38	14	21	1627	30
19	Hadad	41	11	16	1254	214
20	Junisarotri	38	12	18	1447	95
21	Nava	38	15	25	1587	16
22	Palanpur	47	12	24	1374	32
23	Panthawada	42	14	20	1350	41
24	Sanali Ashram	39	11	16	1132	104
25	Wadgam	41	13	20	1701	113
26	Mansa	42	12	17	1469	144
27	Raipur weir	38	11	16	1433	190
28	Balasinor	48	12	16	1547	240
29	Dakor	35	11	16	1439	121

[illegible]	[illegible]	[illegible]	12	15	1671	256
[illegible]	[illegible]	[illegible]	11	19	1433	134
[illegible]	[illegible]	[illegible]	12	15	1905	226
33	Mahemdabad	42	11	15	1596	219
34	Mahisa	39	11	14	1624	103
35	Nadiad	41	12	19	1992	146
36	Pinglaj	42	12	20	1280	119
37	Savli tank	41	11	14	1226	209
38	Vadol	39	12	19	1329	177
39	Vaghroli Tank	36	10	16	1577	232
40	Ambaliyasan	39	12	20	1370	123
41	Kalol	48	13	16	2603	195
42	Dharoi	41	12	15	1898	198
43	Kadi	47	13	23	1966	156
44	Katosan	42	13	19	1324	54
45	Kheralu	42	12	22	1489	140
46	Mehsana	48	15	23	2362	78
47	Ransipur	42	13	19	1519	87
48	Thol	37	12	17	1233	69
49	Unjha	44	13	20	1322	36
50	Vijapur	42	12	18	1593	226
51	Visanagar	48	15	28	2003	91
52	Patan	48	14	22	1713	73
53	Sidhpur	47	13	23	1529	87
54	Wagdod	38	14	25	1535	59
55	Badoli	41	11	17	1526	137
56	Bayad	47	12	15	1758	311
57	Bhiloda	48	11	15	1926	291
58	Dantral	39	11	19	1339	106
59	Himatnagar	39	12	18	1523	106
60	Idar	42	12	17	2077	206
61	Khedbrahma	42	11	17	1669	127
62	Kundlacampo	42	11	17	1793	170
63	Limla dam	38	11	13	1364	197
64	Malpur	47	13	15	2163	299
65	Meghraj	48	11	15	1853	226
66	Modasa	48	11	12	2462	294
67	Pal	46	11	15	1285	161
68	Prantij	42	12	15	1535	220
69	Sabli	36	11	17	1183	165
70	Shamlaji	42	12	17	1699	45
71	Vadgam	48	12	14	1811	250
72	Vijaynagar	42	11	15	1625	91
73	Virpur	38	11	17	1321	245

The annual dataset are analyzed in two ways, first without fitting it to any distribution and secondly by fitting it to the best distribution (Inverse Gaussian). The dataset is fitted to Inverse Gaussian distribution and the probabilities at required return periods of 2 and 100 years are obtained for the analysis. The length of records are determined for both, original and fitted dataset. It is observed that the lengths of record for the fitted data in all case its original form. Hence the adequacy of length of ...ned by fitting the dataset to the best probability distribution. From Table 6.157 it is observed that the length of record available is adequate for statistical analysis. Table 6.158 presents the characteristics of annual rainfall data for 73 raingauge stations of north Gujarat agroclimatic zone.

Table 6.158 Characteristics of Annual Rainfall Data for 73 Raingauge Stations in North Gujarat Agroclimatic Zone

Sr. No.	Name of raingauge station	Sample size	Mean	Standard deviation	Cv	Skewness		Kurtosis	
			mm	mm	%	Statistic	Std. error	Statistic	Std. error
1	Aslali	48	692.49	328.37	47	0.516	0.343	-0.292	0.674
2	Bareja	38	781.12	343.83	44	0.250	0.383	-0.191	0.750
3	Barejadi	38	754.98	306.11	41	0.339	0.383	-0.742	0.750
4	Chandola	38	683.76	325.32	48	0.400	0.383	-0.471	0.750
5	Dehgam	47	647.92	347.37	54	0.598	0.347	-0.487	0.681
6	Nal Lake	39	530.96	291.84	55	0.726	0.378	0.604	0.741
7	Sanand	42	674.92	282.39	42	0.188	0.365	-0.192	0.717
8	Wasai	38	753.87	317.78	42	0.516	0.383	0.139	0.750
9	Ambaji	38	722.93	382.09	53	0.757	0.383	0.236	0.750
10	Amirgadh	42	649.33	359.51	55	0.948	0.365	-0.032	0.717
11	Bapla	44	457.08	293.24	64	1.620	0.357	4.083	0.702
12	Chandisar	40	508.22	275.38	54	0.665	0.374	-0.115	0.733
13	Chitrasani	42	627.99	340.26	54	0.614	0.365	-0.145	0.717
14	Danta	46	756.52	351.72	46	0.503	0.350	-0.338	0.688
15	Dantiwada	45	532.92	286.77	54	0.985	0.354	1.073	0.695
16	Deesa	48	523.40	269.10	51	0.479	0.343	-0.217	0.674
17	Dhanera	48	473.10	280.87	59	0.515	0.343	-0.466	0.674
18	Gadh	38	579.72	342.66	59	1.014	0.383	1.194	0.750
19	Hadad	41	632.98	290.78	46	0.458	0.369	-0.475	0.724
20	Junisarotri	38	657.65	330.66	50	0.671	0.383	0.196	0.750
21	Nava	38	477.60	314.46	66	1.485	0.383	3.323	0.750
22	Palanpur	47	610.71	313.85	51	0.602	0.347	-0.275	0.681
23	Panthawada	42	461.29	290.42	63	1.212	0.365	1.345	0.717
24	Sanali Ashram	39	558.60	243.62	44	0.352	0.378	-0.393	0.741
25	Wadgam	41	644.50	365.80	57	0.943	0.369	0.634	0.724
26	Mansa	42	687.82	338.00	49	0.678	0.365	-0.426	0.717
27	Raipur weir	38	681.00	311.17	46	0.440	0.383	-0.659	0.750
28	Balasinor	48	742.76	349.49	47	0.663	0.343	-0.398	0.674
29	Dakor	35	724.86	312.81	43	0.328	0.398	0.113	0.778
30	Kapadwanj	41	847.29	403.18	48	0.302	0.369	-1.028	0.724
31	Kathlal	40	720.15	323.58	45	0.062	0.374	-0.650	0.733
32	Kheda	38	778.05	362.89	47	0.890	0.383	1.043	0.750
33	Mahemdabad	42	763.03	347.78	46	0.656	0.365	-0.221	0.717

[illegible]	[illegible]	[illegible]	.10	277.16	41	0.933	0.378	2.812	0.741
[illegible]	[illegible]	[illegible]	.07	416.17	52	0.821	0.369	1.507	0.724
[illegible]	[illegible]	[illegible]	.96	303.23	47	0.440	0.365	-0.460	0.717
37	Savli tank	41	667.07	303.83	46	0.307	0.369	-1.218	0.724
38	Vadol	39	671.71	323.42	48	0.586	0.378	-0.501	0.741
39	Vaghroli Tank	36	861.37	343.68	40	0.293	0.393	-0.536	0.768
40	Ambaliyasan	39	616.77	320.57	52	0.550	0.378	-0.322	0.741
41	Kalol	48	729.21	416.76	57	2.251	0.343	7.936	0.674
42	Dharoi	41	755.53	358.96	48	0.850	0.369	1.166	0.724
43	Kadi	47	702.95	374.40	53	1.184	0.347	2.011	0.681
44	Katosan	42	587.18	328.70	56	0.351	0.365	-0.671	0.717
45	Kheralu	42	680.44	355.11	52	0.602	0.365	-0.309	0.717
46	Mehsana	48	623.92	415.03	67	2.012	0.343	6.028	0.674
47	Ransipur	42	633.49	340.41	54	1.035	0.365	0.835	0.717
48	Thol	37	531.42	274.27	52	0.620	0.388	0.208	0.759
49	Unjha	44	470.62	256.51	55	1.367	0.357	2.836	0.702
50	Vijapur	42	751.26	379.20	50	0.463	0.365	-0.906	0.717
51	Visanagar	48	606.09	416.47	69	1.713	0.343	3.179	0.674
52	Patan	48	524.93	320.86	61	1.403	0.343	3.131	0.674
53	Sidhpur	47	581.82	313.21	54	0.920	0.347	0.852	0.681
54	Wagdod	38	540.62	345.18	64	0.986	0.383	1.061	0.750
55	Badoli	41	734.30	308.13	42	0.452	0.369	-0.077	0.724
56	Bayad	47	793.70	369.45	47	0.734	0.347	-0.203	0.681
57	Bhiloda	48	863.60	384.05	44	0.933	0.343	0.593	0.674
58	Dantral	39	663.71	285.90	43	0.190	0.378	-0.416	0.741
59	Himatnagar	39	738.28	344.67	47	0.396	0.378	-0.631	0.741
60	Idar	42	847.78	412.10	49	0.870	0.365	1.124	0.717
61	Khedbrahma	42	740.95	320.96	43	0.589	0.365	0.499	0.717
62	Kundlacampo	42	860.99	361.89	42	0.668	0.365	0.227	0.717
63	Limla dam	38	725.77	336.00	46	0.466	0.383	-0.976	0.750
64	Malpur	47	798.43	420.51	53	1.436	0.347	2.174	0.681
65	Meghraj	48	742.25	334.02	45	0.975	0.343	1.332	0.674
66	Modasa	48	796.64	402.45	51	1.980	0.343	5.753	0.674
67	Pal	46	679.26	283.63	42	0.596	0.350	-0.340	0.688
68	Prantij	42	805.23	379.26	47	0.320	0.365	-1.044	0.717
69	Sabli	36	684.82	277.69	41	0.184	0.393	-0.635	0.768
70	Shamlaji	42	767.08	360.32	47	0.696	0.365	0.550	0.717
71	Vadgam	48	694.79	353.59	51	0.973	0.343	0.719	0.674
72	Vijaynagar	42	742.12	336.09	45	0.469	0.365	0.035	0.717
73	Virpur	38	644.47	297.25	46	0.494	0.383	-0.675	0.750

The mean annual rainfall for the north Gujarat agroclimatic zone ranges from 457.08 mm at Bapla to 863.60 mm at Bhiloda. The standard deviation ranges from 243.62 mm at Sanali ashram to 420.51 mm at Malpur. The annual data for all the 73 raingauges are positively skewed with a range of 0.062 to 2.251. Positive skewness indicates a distribution with an asymmetric tail extending towards more positive values. Values of 2 times standard error of skewness

n) are probably skewed to a significant degree and portions in Table 6.158. 25 stations out of 73 are significantly positively skewed. On a normï referenced test, the existence of skewed distributions as indicated by the skewness statistic is important which may reduce the reliability of the test. Thus for a skewed distribution a criterion referenced test gives desirable results.

The kurtosis ranges from -1.218 to 7.936. Kurtosis characterizes the relative peakedness or flatness of a distribution compared to the normal distribution. Negative kurtosis indicates a relatively flat distribution. Positive kurtosis indicates a relatively peaked distribution. Since a value greater than two times of the standard error indicates significant kurtosis. The existence of flat or peaked distribution indicates violations of the assumption of normality that underlies many of the other statistics like correlation coefficients, t ï tests etc. used to study the validity of the test. The shaded value in Table 6.158 indicates significant kurtosis. 11 stations out of 73 have significant kurtosis.

The coefficient of variation for annual rainfall is greater than the threshold limit of 25% (Singh et al. 2004b), for all the raingauge stations and ranges from 40 % to 67 %, hence not dependable. According to Foster 1949, gauging stations receiving scanty rainfall have greater value of coefficient of variations. Therefore the raingauges situated in north Gujarat agroclimatic zone receives scanty rainfall based on coefficient of variation.

The average annual rainfall for 3 thirty year period (normal rainfall) i.e. first from 1961 to 1990, second from 1971 to 2000 and third from 1981 to 2008, for the different raingauges are calculated and represented in Fig. 6.47. Overall average value for the period from 1961 to 2008 is also depicted in Fig. 6.47. It is observed that the normal rainfall pattern is varied for all the raingauges. No unique pattern can be observed for the study period (1961 to 2008).

Fig. 6.47 Normal and average rainfall for 73 raingauges in north Gujarat agroclimatic zone

w maximum normal rainfall in the first thirty year tions out of 73 show maximum normal rainfall in the second thirty year period (1971-2000). 22 stations out of 73 show maximum normal rainfall in the last twenty eight year period (1981-2008). For the entire region the normal and average rainfalls are within 904 mm. The highest value of 904 mm is observed for the period of 1981 to 2008 at Kapadwanj. It can be seen clearly that Nal Lake, Bapla, Dhanera, Nava, Panthawada and Unjha receives scanty rainfall with normal and average values less than 500 mm.

Box plots provide the scatteredness (or dispersion) of the data values. So in order to get greater insight, the measures of averages must be supported and supplemented by the measures of dispersion, which give the degree by which the numerical data tend to spread about an average value.

From Fig. 6.48 it is observed that Bareja received the highest annual rainfall and Nal Lake received lowest rainfall. The range of dataset for Bareja is more compared to other raingauge stations of the district. While Sanand has least range. Interquartile range is higher for Dehgam and lower for Nal Lake. The first quartile (25 % probability) value is the highest for Bareja and lowest for Nal Lake. The median (2nd quartile, 50 % probability) value for Bareja is the highest while that for Nal Lake is the lowest. The third quartile (75% probability) value is the highest for Barejadi and the lowest for Nal Lake.

If one compares the annual rainfall pattern of the raingauges situated in Ahmedabad district, Bareja raingauge station observes more variation of rainfall with the highest amount while Nal Lake receives less rainfall showing less variation annually. But as determined from the box plot for Dehgam the interquartile range representing 50% data, is the highest. Also from Table 6.158 the coefficient of variation is more for Dehgam compared to Bareja. Based on the altitude of raingauges one can compare that Nal Lake is situated at lowest altitude of 49 m above M.S.L. and Dehgam is situated at the highest elevation of 249 m at M.S.L. While the remaining raingauges are situated between this limit. Thus one can correlate the annual rainfall pattern with the altitude at which it is situated. Greater the altitude greater is the for a set of raingauges into consideration. Similar for the box plots of other districts.

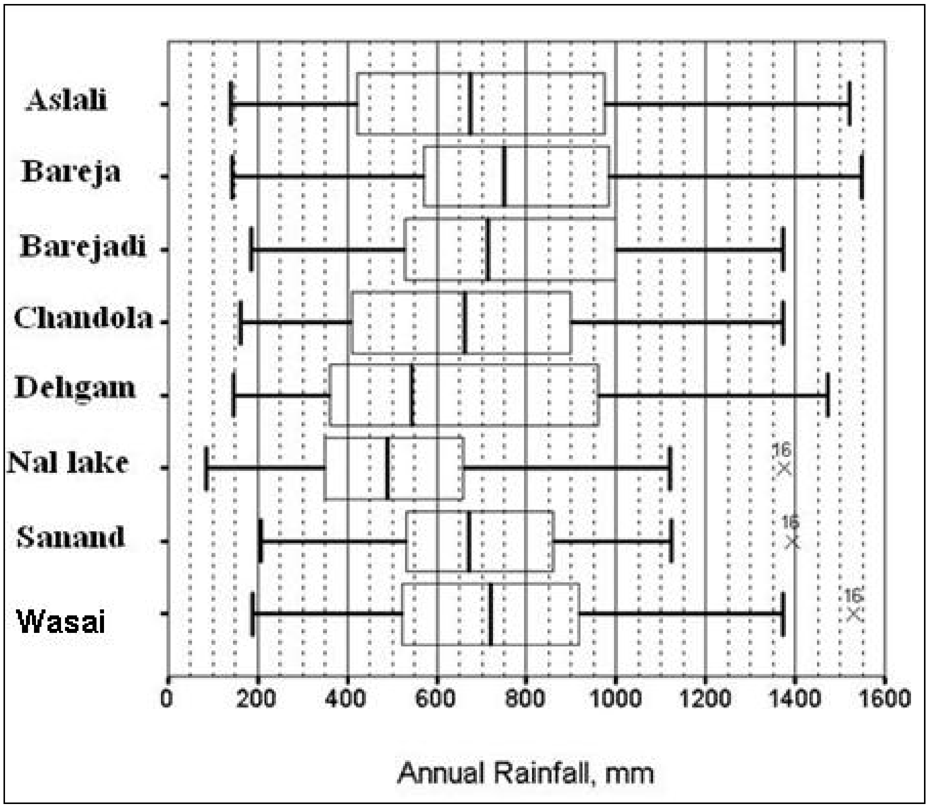


Fig.6.48 Box plot of annual time series of rainfall for raingauge stations situated in Ahmedabad district

If one compares the annual rainfall pattern of the raingauges situated in Ahmedabad district, Bareja raingauge station observes more variation of rainfall with the highest amount while Nal Lake receives less rainfall showing less variation annually. But as determined from the box plot for Dehgam the interquartile range representing 50% data, is the highest. Also from Table 6.158 the coefficient of variation is more for Dehgam compared to Bareja. Based on the altitude of raingauges one can compare that Nal Lake is situated at lowest altitude of 49 m above M.S.L. and Dehgam is situated at the highest elevation of 249 m at M.S.L. While the remaining raingauges are situated between this limit. Thus one can correlate the annual rainfall pattern with the altitude at which it is situated. Greater the altitude greater is the for a set of raingauges into consideration. Similar for the box plots of other districts.

Fig. 6.49 illustrates the box plot for Banaskantha district. It is observed that Ambaji received the highest annual rainfall and Dhanera received lowest rainfall. The range of dataset for Ambaji is more compared to other raingauge stations of the district, with greater variation in annual amounts. Bapla has least range, with lesser variation of annual rainfall. Interquartile range indicating 50% of data are higher for Ambaji and lower for Bapla. The first quartile (25 % probability) value is the highest for Danta which is nearer to Ambaji compared to the lowest observed at Nava. The median (2nd quartile, 50 % probability) value for Ambaji is the highest while that for Panthawada is the lowest. The third quartile (75 % probability) value is the highest for Ambaji and the lowest for Bapla. As discussed earlier for Ahmedabad district, the same is observed for Banaskantha district too. Ambaji is situated at the highest elevation of 1,495 m above M.S.L. compared to the remaining stations in the district. Thus Ambaji observes greater variations in annual rainfall with the highest amounts for all the statistics calculated. Comparing the coefficient of variation values, Bapla, Nava and Panthawada station have higher values of 64 %, 66 % & 63 % respectively, indicating scanty rainfall, showing lesser variations in the statistics determined.

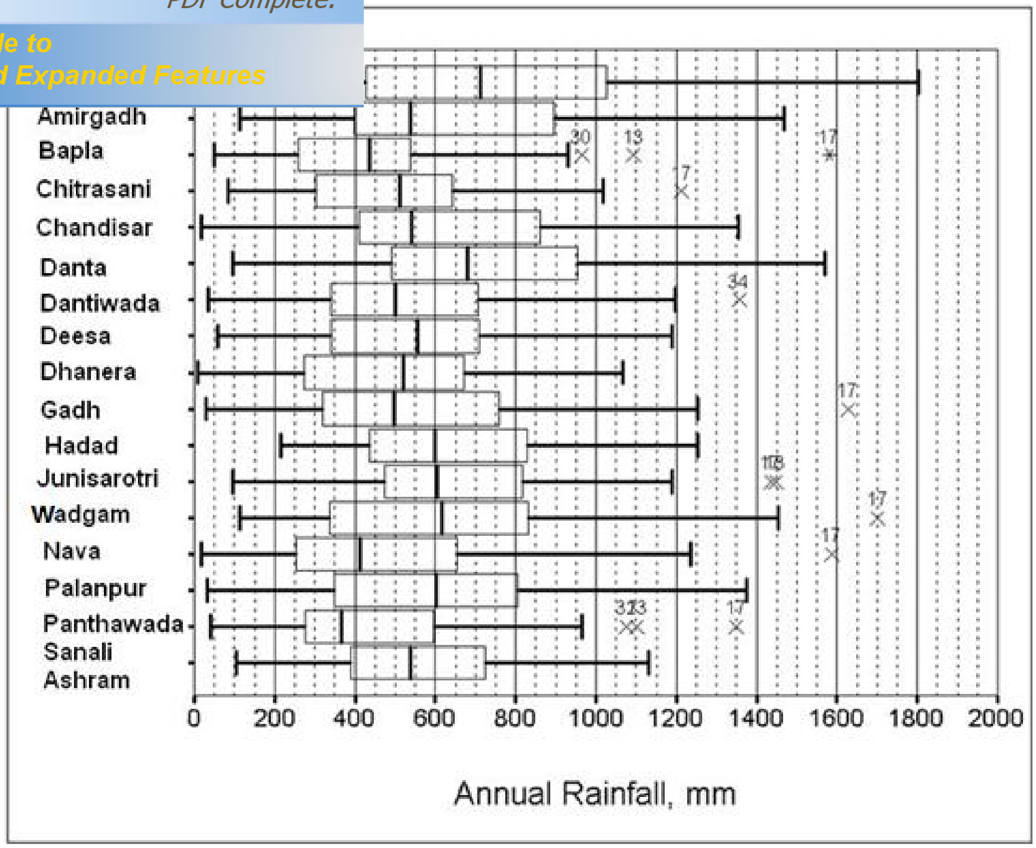


Fig. 6.49 Box plot of annual time series of rainfall for raingauge stations situated in Banaskantha district

For Gandhinagar district there are only two raingauges available for analysis. Fig. 6.50 shows the box plot for Gandhinagar district. Based on the altitude values, Mansa is situated at 338 m and Raipur weir at 215 m above M.S.L. It is observed that Mansa received the highest and lowest annual rainfall. Here the range of dataset is also more than Raipur weir. Interquartile range is higher for Mansa. The first quartile (25 % probability) value is the similar for both the raingauge stations. The second and third quartile value for Mansa is greater than Raipur Weir.

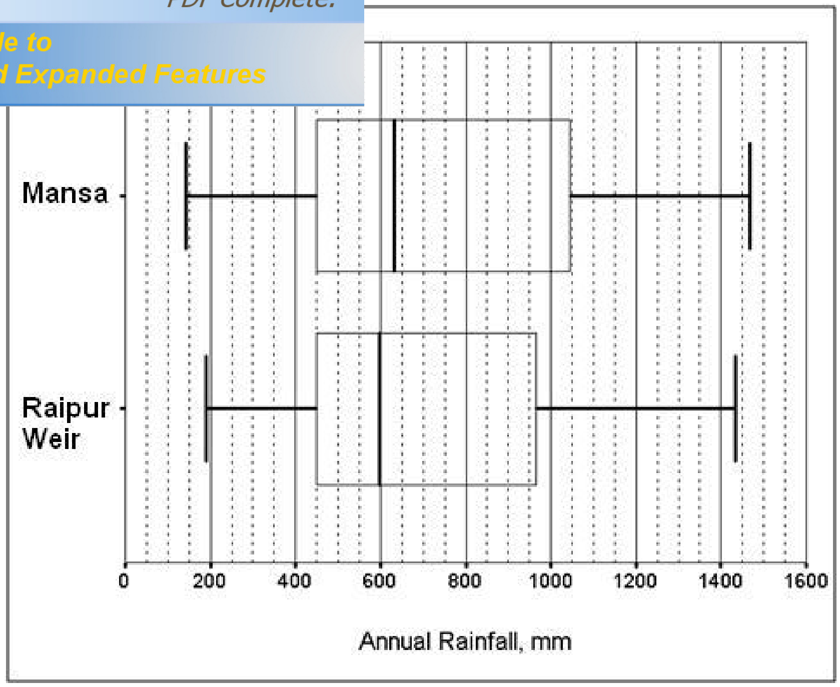


Fig.6.50 Box plot of annual time series of rainfall for raingauge stations situated in Gandhinagar district

Fig. 6.51 shows the box plot for raingauges situated in Kheda district. One can observe that Kapadwanj and Mahisa received the highest and lowest annual rainfall respectively. The range of dataset and interquartile range for Kapadwanj is larger than other raingauge stations in the district. The first quartile (25 % probability) value is the highest for Vaghroli tank and lowest for Savli tank. The median (2^{nd} quartile, 50 % probability) and the third quartile (75 % probability) value for Kapadwanj is the highest while that for Vadol and Mahisa respectively is the lowest. If one recalls the plot of normal rainfalls for 73 raingauge stations then it can be clearly seen that Kapadwanj depicts the highest normal rainfall value of 904 mm for the period from 1981 to 2008. Thus the rainfall for the last 28 years has changed the overall pattern for Kapadwanj raingauge station influencing the rainfall extremes. The altitude of Kapdawanj is 366 m and is the highest amongst the set of raingauges in the district. Thus it shows greater variations in the annual rainfall amounts.

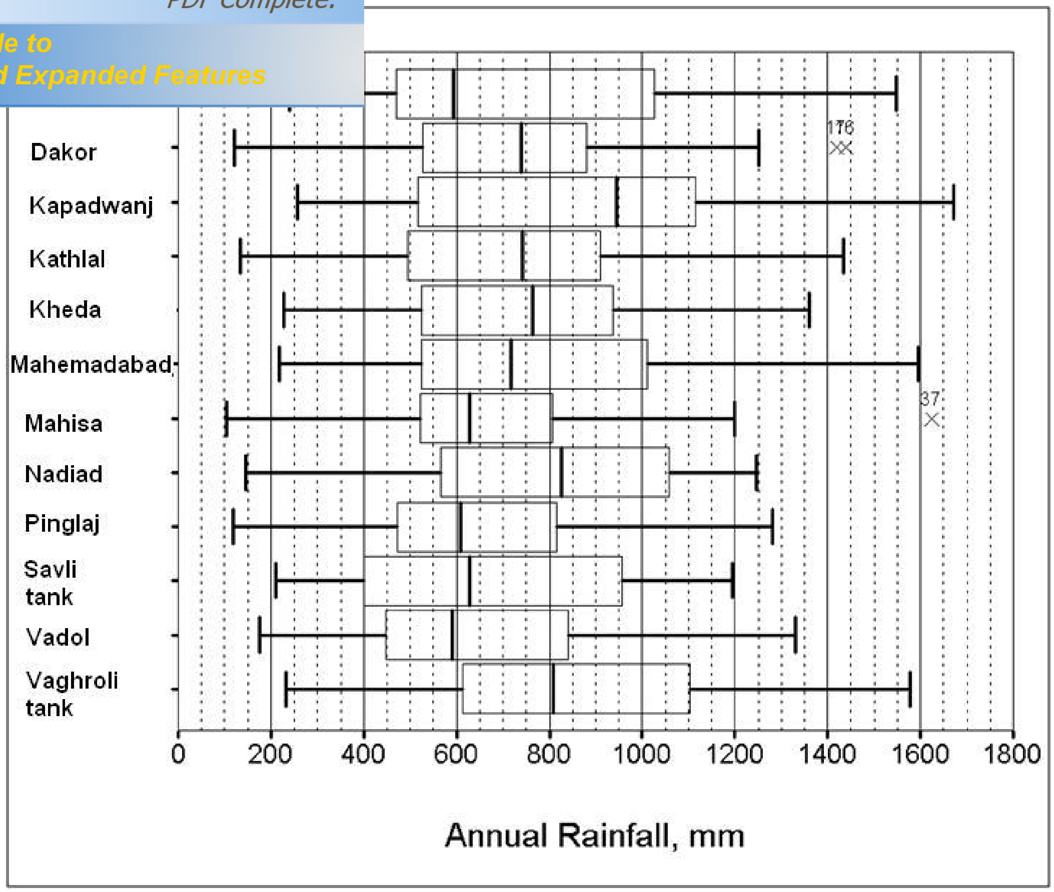


Fig. 6.51 Box plot of annual time series of rainfall for raingauge stations situated in Kheda district

From Fig. 6.52 it is observed that Kadi and Vijapur raingauge station received the highest rainfall and Unjha received lowest rainfall. The range of dataset for Kadi raingauge station is larger than other raingauge stations in the district. Interquartile range is higher for Vijapur. The first quartile (25 % probability) value is the highest for Kalol and lowest for Unjha. The median (2nd quartile, 50 % probability) value for Vijapur and Kadi is the highest while that for Unjha is the lowest. The third quartile (75 % probability) value is the highest for Vijapur and the lowest for Unjha. Here no specific observations can be made based on the altitude of the raingaues. Kheralu is situated at the highest elevation of 557 m above M.S.L. While Kadi and Vijapur observing the variations in annual rainfall values are situated at 512 m and 416 m above M.S.L. Based on the normal rainfall value plot Unjha recieved scanty rainfall throughtout the study period for all the 3 thirty years periods from 1961 to

7. Thus the lowest value for each of the statistics in Unjha. But no specific observations can be made for the highest amounts observed in the district. Though Visnagar, observes the highest one day and consecutive 2 to 7 & 10 days maximum rainfall but it does not influence the annual amounts. Hence overall scenario in case of annual rainfall does not depend on the extreme events observed and on the elevation at which it is measured.

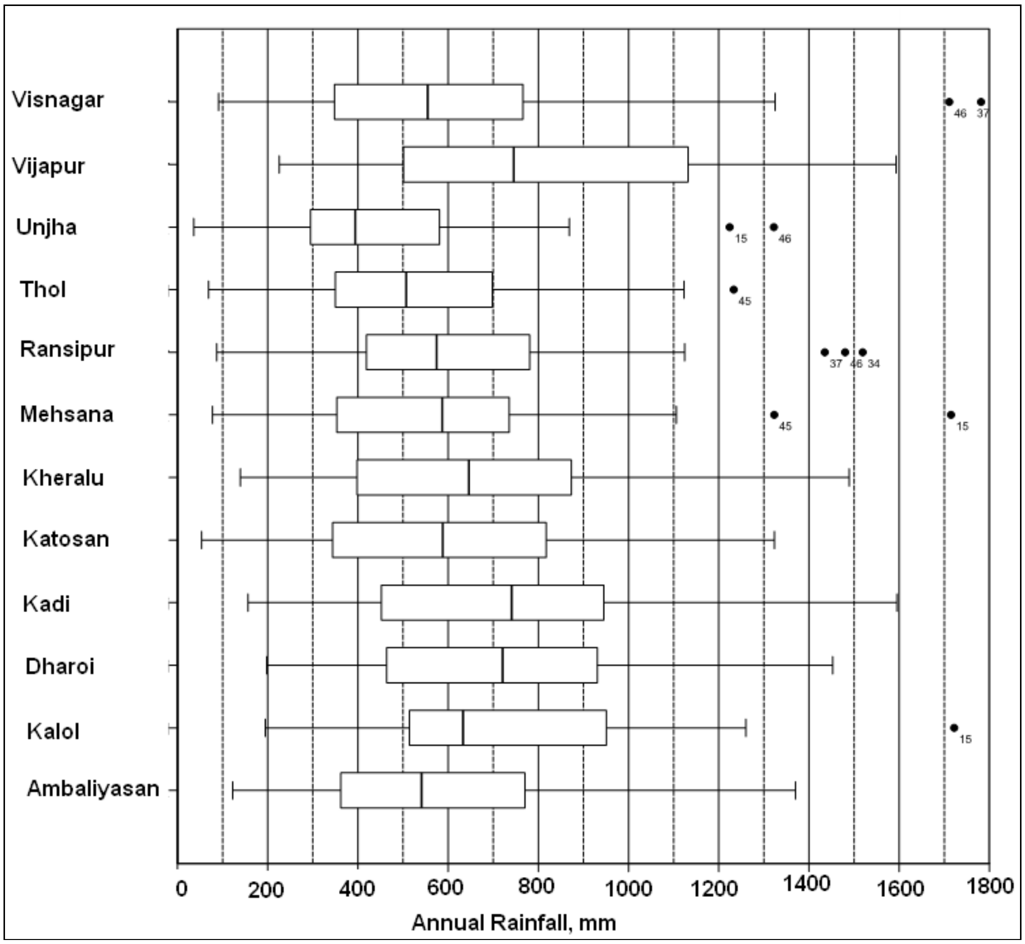


Fig. 6.52 Box plot of annual time series of rainfall for raingauge stations situated in Mehsana district

Fig. 6.53 represents the box plot for raingaguges situated in Patan district. It is observed that Wagdod raingauge station received the highest & lowest annual rainfall. The range of dataset for Wagdod raingauge station is larger than other raingauge stations in the district. The first quartile (25 % probability) value is the highest for Sidhpur and lowest for Patan. The median (2nd

) value for Sidhpur is the highest while that for third quartile (75 % probability) value is the highest for Sidhpur and the lowest for Patan. Sidhpur is situated at the highest elevation of 406 m above M.S.L. Thus for Patan district one can conclude similar observations as seen for previous districts except Mehsana. Sidhpur shows much variation in annual amounts which is influenced by the altitude at which it is situated.

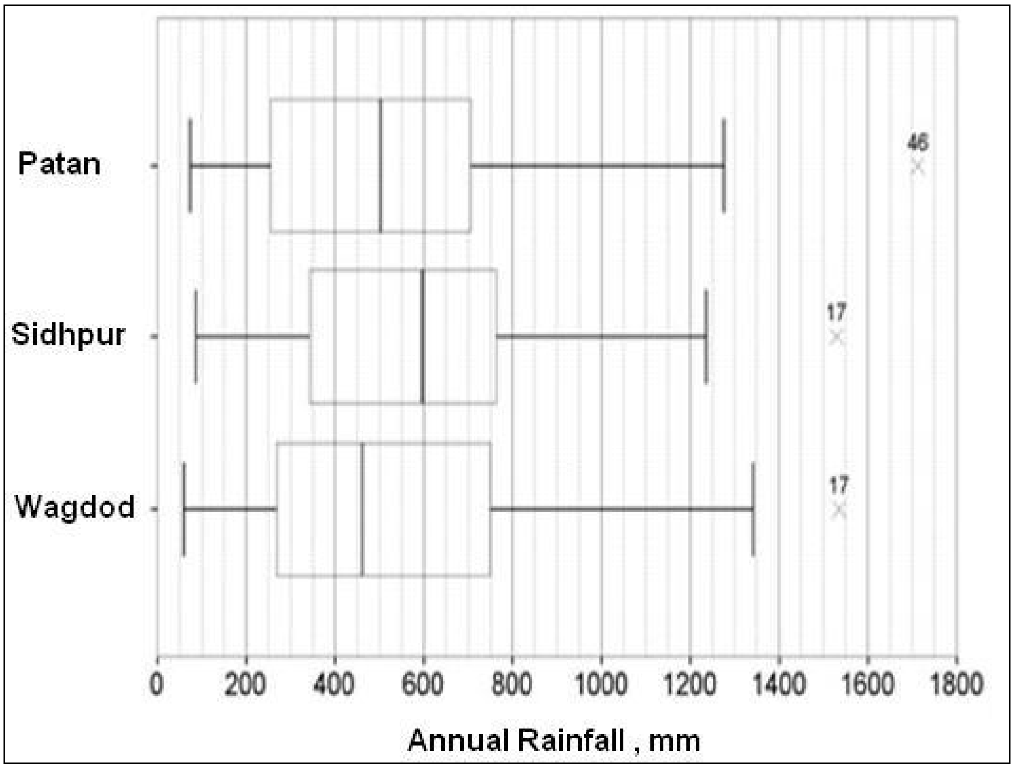


Fig. 6.53 Box plot of annual time series of rainfall for raingauge stations situated in Patan district

Fig. 6.54 shows the box plot for raingauges located at Sabarkantha district. The highest amount of annual rainfall is observed at Shamlaji, while Vijaynagar received lowest rainfall. The range of dataset for Shamlaji raingauge station is larger than other raingauge stations in the district. Interquartile range is higher for Prantij. The first quartile (25 % probability) value is the highest for Idar and lowest for Vadgam. The median (2^{nd} quartile, 50 % probability) value for Kundlacampo is the highest while that for Vadgam is the lowest. The third quartile (75 % probability) value is the highest for

...antral. For the raingauges situated in Sabarkantha ... for annual rainfall is observed with no specific observations to be made with respect to altitude. Kundlacampo observes maximum normal rainfall for the period of 1961 to 1990 which has influenced the highest value obtained for the 50 % of the probability.

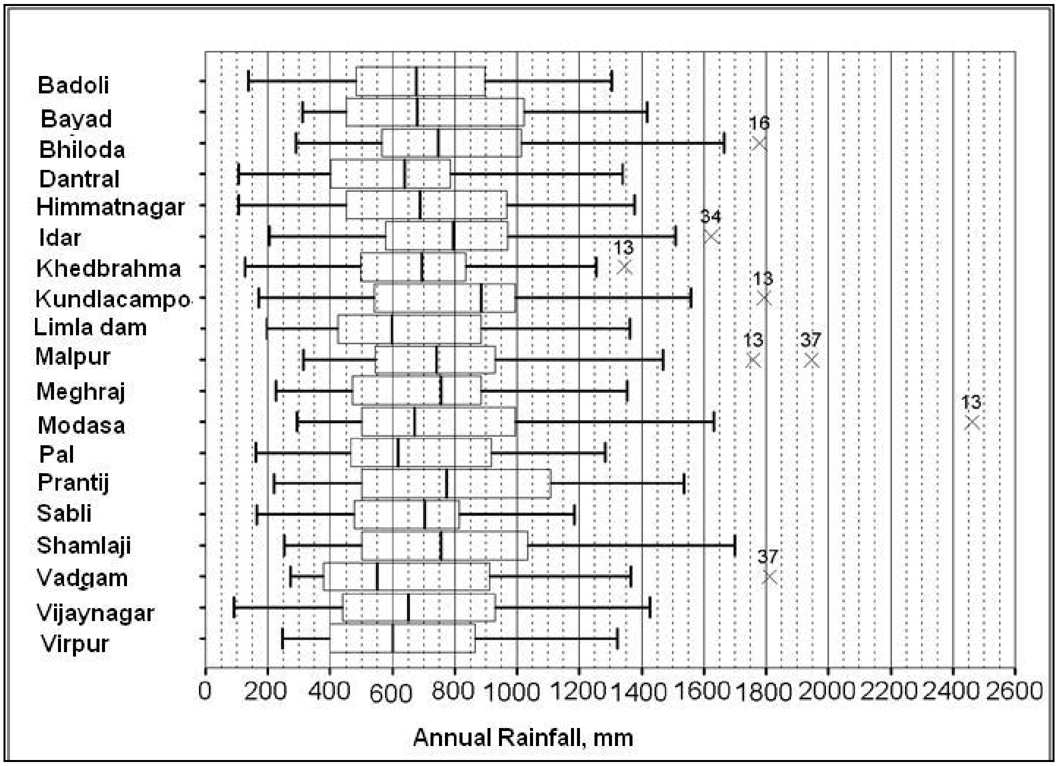


Fig. 6.54 Box plot of annual time series of rainfall for raingauge stations situated in Sabarkantha district

Table 6.159 presents the annual trend of 73 raingauge stations of north Gujarat agroclimatic zone. From Table 6.30 it is observed that an increasing trend is observed for 38 out of 73 (52 %) raingauge stations. The trend value ranges from 0.17 mm / year at Malpur to 9.74 mm / year at Kapadwanj. Rest of the 35 (48%) raingauge stations observe decreasing trend ranging from 0.03 mm / year at Savali tank to 10.25 mm / year at Ambaji. These trend values are significant at Ambaji, Dhanera, Junisarotri and Kapadwanj. The 25 stations having normal rainfall value greater for the period from 1981 to 2008 show positive trends. Thus one can conclude that the rainfall for this period has influenced the trend values indicating a change in the rainfall pattern.

all plots and trend values one can study the pattern ate scenario now a days.

Table 6.159 Annual Trends for 73 Raingague Stations of North Gujarat Agroclimatic Zone.

Sr. no.	Name of raingauge station	Trend mm/ year	Sr. no.	Name of Raingauge station	Trend mm/ year	Sr. no.	Name of raingauge station	Trend mm/ year
1	Aslali	-4.46	25	Sanali Ashram	-4.64	49	Thol	4.08
2	Bareja	3.10	26	Mansa	3.70	50	Unjha	-0.36
3	Barejadi	-2.79	27	Raipur weir	-1.04	51	Vijapur	4.28
4	Chandola	3.01	28	Balasinor	4.43	52	Visanagar	2.32
5	Dehgam	1.96	29	Dakor	-6.03	53	Sidhpur	3.97
6	Nal Lake	4.66	30	Kapadwanj	9.74 +	54	Wagdod	-3.77
7	Sanand	5.46	31	Kathlal	6.30	55	Badoli	-1.76
8	Wasai	-1.53	32	Kheda	3.58	56	Bayad	3.98
9	Ambaji	-10.24 +	33	Mahemdabad	-5.03	57	Bhiloda	1.09
10	Amirgadh	2.00	34	Mahisa	2.23	58	Dantral	-6.99
11	Bapla	-1.73	35	Nadiad	0.66	59	Himatnagar	-1.38
12	Chandisar	-2.26	36	Pinglaj	-1.69	60	Idar	4.21
13	Chitrasani	-0.70	37	Savli tank	-0.03	61	Khedbrahma	-0.53
14	Danta	-2.99	38	Vadol	6.58	62	Kundlacampo	-0.48
15	Dantiwada	-0.62	39	Vaghroli Tank	2.35	63	Limla dam	6.42
16	Deesa	0.95	40	Ambaliyasan	-4.81	64	Malpur	0.17
17	Dhanera	6.44 *	41	Kalol	-1.06	65	Meghraj	2.94
18	Gadh	-2.99	42	Dharoi	-1.18	66	Modasa	1.43
19	Hadad	-1.66	43	Kadi	1.72	67	Pal	-2.53
20	Junisarotri	-7.81 +	44	Katosan	3.56	68	Prantij	2.39
21	Wadgam	0.21	45	Kheralu	2.06	69	Sabli	-2.07
22	Nava	-4.28	46	Mehsana	-3.15	70	Shamlaji	0.76
23	Palanpur	2.04	47	Patan	3.46	71	Vadgam	2.56
24	Panthawada	-0.64	48	Ransipur	3.13	72	Vijaynagar	-0.80
						73	Virpur	-4.23

The descriptive statistics are designed to assist the distributions of the data based on values obtained. Skewness characterizes the degree of asymmetry of a distribution around its mean. Normal distributions produce a skewness statistic of about zero. The characteristics of climate data are also analyzed. Table 6.160 presents the characteristics of Ahmedabad climate station.

From Table 6.160 it is observed that the coefficient of variation is more in case of wind speed and least for maximum temperature. For annual rainfall the coefficient of variation is above the threshold limit of 25 % and hence not dependable. Rainy days, total rainfall, rainfall intensity, maximum temperature, average relative humidity and wind speed are positively skewed which indicate a distribution with an asymmetric tail extending towards more temperature and sunshine hours are negatively bution with an asymmetric tail extending towards more negative values. Values of 2 times standard error of skewness or more (regardless of sign) are probably skewed to a significant degree. Thus the sunshine hours are significantly negatively skewed. Kurtosis characterizes the relative peakedness or flatness of a distribution compared to the normal distribution. Normal distributions produce a kurtosis statistic of about zero called mesokurtic. Positive kurtosis indicates a relatively peaked distribution. Negative kurtosis indicates a relatively flat distribution. Values of 2 times standard errors of kurtosis or more (regardless of sign) probably differ from mesokurtic to a significant degree. Thus rainfall intensity and sunshine hours have significant kurtosis indicating violations of the assumption of normality that underlies many of the other statistics like correlation coefficients, t-tests, etc. used to study test validity. For the other parameters the kurtosis is within the expected range of chance fluctuations in the statistic, which further indicates a distribution with no significant kurtosis problem.

Table 6.160 Characteristics of Climate of Ahmedabad, Ahmedabad District

Parameter	Mean	Minimum	Maximum	C_v	Skewness	Kurtosis	Trend
Rainy days, days / year	30.00	12.00	53.00	35	0.36	-0.51	-0.33
Annual rainfall, mm	749.00	215.00	1284.00	41	0.38	-0.92	-1.67
Rainfall intensity, mm/day	25.05	12.50	48.50	30	1.08*	1.51*	0.05
Minimum temperature, ^{0}C	20.80	3.50	32.80	27	-0.54	-0.90	0.02
Maximum temperature, ^{0}C	34.40	19.40	47.50	14	0.12	-0.61	0.01
Average relative humidity, %	53.80	7.00	100.00	34	0.28	-0.56	-0.07
Wind speed, Kmph	8.67	2.40	36.00	55	0.47	0.57	-0.01***
Sunshine hours, h / day	8.30	1.80	13.40	37	-1.40*	0.97*	-0.01*

Note:- *Significant according to standard error e where,

$$e = \sqrt{\frac{6}{N}} \text{ for skeweness; } \qquad e = \sqrt{\frac{24}{N}} \text{ for kurtosis}$$

N = no. of sample

**Significant at 5% level; ***Significance at 10% level

Fig.6.55 Monthly minimum, maximum and average climate of Ahmedabad, Ahmedabad district

nly minimum, maximum and average values of the ved at Ahmedabad climate station. It is observed that the minimum and maximum temperatures are higher in the month of June and May respectively. The average relative humidity is the highest in the month of July. Also the windspeed observed in the months of May and June is the highest. The sunshine hours are more in the months from March to May indicating higher maximum temperatures and relative humidity. The sunshine hours are lowest in the months of higher rainy days. Thus based on the climate parameters one can correlate the climate of the area and observe its impact on the parameters measured.

Fig. 6.56 illustrates the trend for rainfall and other climatic parameters. Based on trend values obtained it is observed that trend is decreasing for rainy days, total rainfall and wind speed while it is increasing for rainfall intensity, minimum and maximum temperatures. An increasing trend in minimum and maximum temperatures and rainfall can be observed. While decreasing trend is observed for rainy days, total rainfall and wind speed. The average relative humidity and sunshine hours show no significant trend.

All the trend values except for wind speed are non significant at 5% level of significance. Thus increasing rainfall intensity and decreasing rainfall amounts indicate the effect of climate change observed nowï aï days. But for increase in minimum and maximum temperatures, the sunshine hours should also be increased accordingly, which is not much evident from the available data.

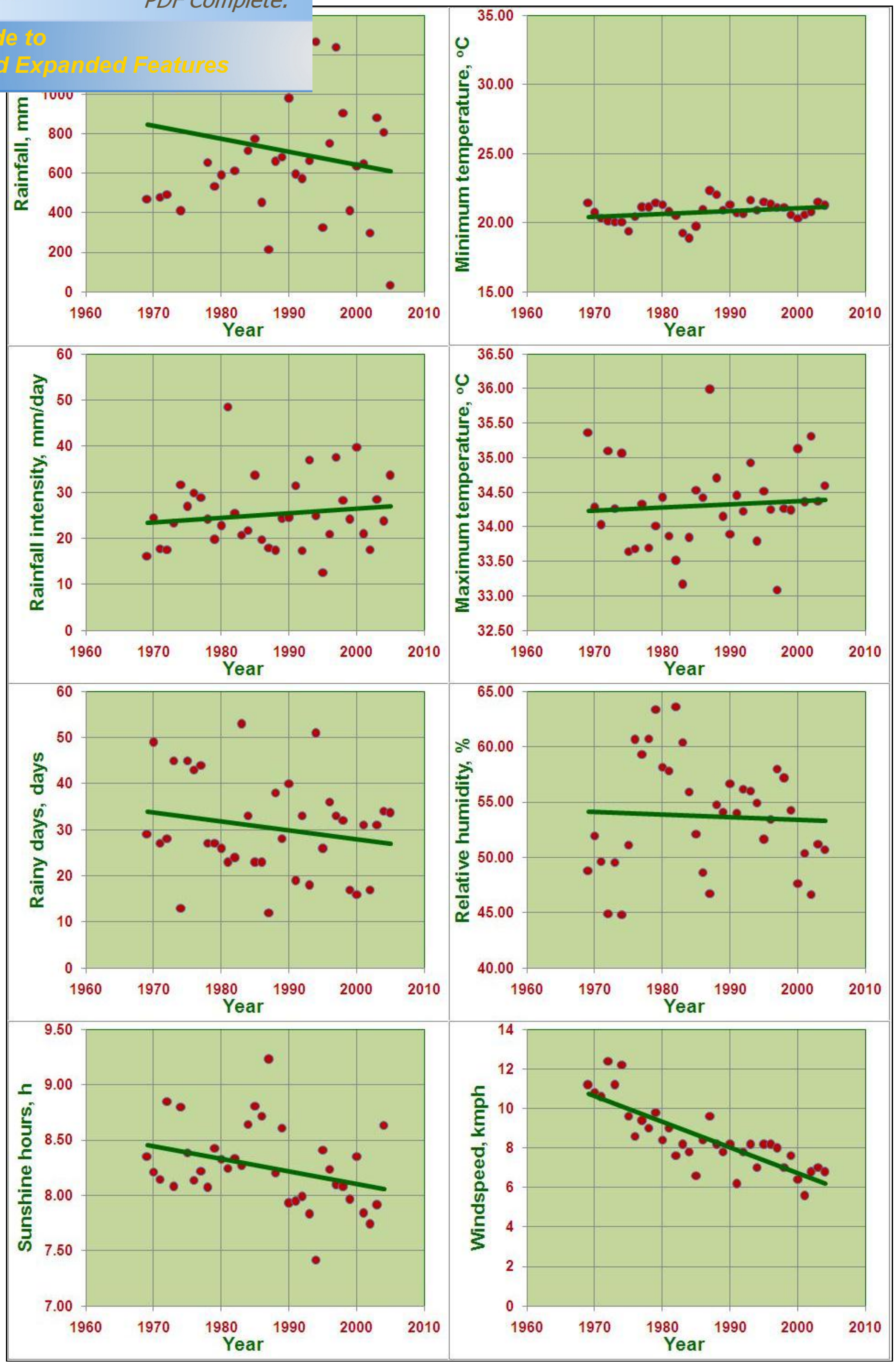


Fig. 6.56 Annual trend of climatic parameters of Ahmedabad, Ahmedabad district

aracteristics of climate of Deesa climate station. It ient of variation is most in case of wind speed and least for maximum temperature. For annual rainfall the coefficient of variation is above the threshold limit of 25 % and hence not dependable. Rainy days, total rainfall, rainfall intensity, average relative humidity and wind speed are positively skewed which indicate a distribution with an asymmetric tail extending towards more positive values. Minimum temperature, maximum temperature and sunshine hours are negatively skewed, indicating a distribution with an asymmetric tail extending towards more negative values. Minimum temperature, maximum temperature, average relative humidity, wind speed and sunshine hours are significantly skewed. Positive kurtosis indicates a relatively peaked distribution. Negative kurtosis indicates a relatively flat distribution. Minimum temperature, maximum temperature, average relative humidity, wind speed and sunshine hours have significant kurtosis indicating violations of the assumption of normality that underlies many of the other statistics like correlation coefficients, t-tests, etc. used to study test validity. Skewness and kurtosis are within the expected range of chance fluctuations in the statistic, which further indicate a distribution with no significant skewness or kurtosis problem.

Table 6.161 Characteristics of Climate of Deesa, Banaskantha District

Parameter	Mean	Minimum	Maximum	C_v	Skewness	Kurtosis	Trend
Rainy days, days / year	22.00	4.00	41.00	41.98	0.17	-0.42	-0.125
Annual rainfall, mm	472.48	50.10	1010.80	55.98	0.29	-0.81	-1.968
Rainfall intensity, mm/day	21.42	4.94	50.52	43.18	0.65	1.47	0.065
Minimum temperature, ^{0}C	19.42	5.10	29.20	30.79	-0.47*	-1.06*	0.003
Maximum temperature, ^{0}C	33.98	22.00	44.40	13.23	-0.11*	-0.71*	0.031***
Average relative humidity, %	53.56	19.00	95.00	28.08	0.46*	-0.29*	0.022
Wind speed, kmph	4.70	2.40	21.60	66.14	0.65*	1.11*	-0.135***
Sunshine hours, hours/day	9.25	3.10	14.00	23.34	-0.86*	0.42*	0.018

Note:- *Significant according to standard error e where,

$$e = \sqrt{\frac{6}{N}} \quad \text{for skeweness;} \qquad e = \sqrt{\frac{24}{N}} \quad \text{for kurtosis}$$

N = no. of sample; **Significant at 5% level; *** Significant at 10% level minimum, maximum and average values of the ed at Deesa climate station. It is observed that the minimum and maximum temperatures are higher in the month of June and May respectively. The average relative humidity is the highest in the month of August. Also the windspeed observed in the month of June is the highest. The sunshine hours are more in the month of March. When the sunshine hours are lowest, for those months the rainfall is observed.

Here one can say that the increasing trend in sunshine hours may tend to increase the trend of maximum and minimum temperatures which can be seen from Fig. 6.56. Also the decrease in rainfall and rainy day indicates that the rainfall for the area is decreasing with increase in sunshine hours and daytime temperatures.

Fig. 6.58 represents the trend for the climatic parameters. One can observe the increasing trend in minimum & maximum temperatures, sunshine hours and relative humidity. Decreasing trend in rainy days, rainfall and wind speed are observed. According to Mann Kendall test maximum temperature and wind speed have significant trend value at 10 % significance level.

Fig.6.57 Monthly minimum, maximum and average climate of Deesa, Banaskantha district

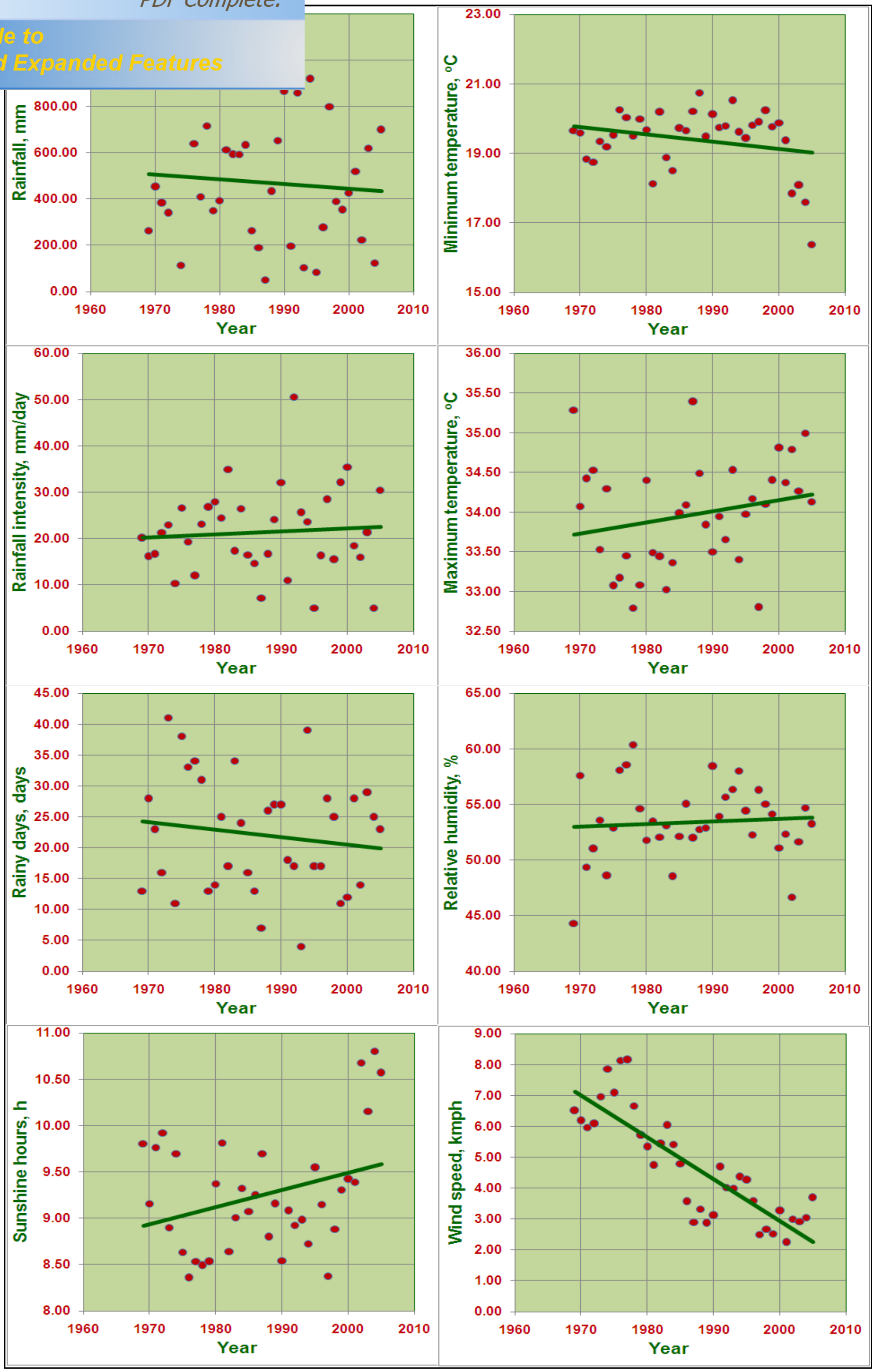


Fig. 6.58 Annual trend of climatic parameters of Deesa, Banaskantha district

...e characteristics of Dantiwada climate station. The ...ost in case of rainfall intensity & wind speed and least for maximum temperature. For annual rainfall the coefficient of variation is above the threshold limit of 25 % and hence not dependable. Rainy days, minimum and maximum temperatures and sunshine hours are negatively skewed which indicate a distribution with an asymmetric tail extending towards more negative values. Annual rainfall, rainfall intensity, average relative humidity and wind speed are positively skewed, indicating a distribution with an asymmetric tail extending towards more positive values. Rainy days and annual rainfall are within the expected range of chance fluctuations in the statistic for skewness and kurtosis, which further indicates a distribution with no significant skewness or kurtosis problem. Thus other parameters except the annual rainfall and rainy days, have significant skewness and kurtosis indicating violations of the assumption of normality that underlies many of the other statistics like correlation coefficients, t-tests, etc. used to study test validity.

Table 6.162 Characteristics of Climate of Dantiwada, Banaskantha District

Parameter	**Mean**	**Minimum**	**Maximum**	**C_v**	**Skewness**	**Kurtosis**	**Trend**
Rainy days, days / year	19.00	2.00	32.00	41.60	-0.30	-0.61	0.249
Annual rainfall, mm	522.00	36.00	1357.00	59.47	1.00	1.04	2.800
Rainfall intensity, mm/day	29.39	11.36	101.81	71.98	2.57*	6.59*	-0.300
Minimum temperature,^{0}C	19.05	5.90	36.90	34.38	-0.40*	-1.08*	0.011
Maximum temperature,^{0}C	33.84	10.10	47.20	13.91	-0.18*	-0.45*	-0.005
Average relative humidity, %	54.13	7.80	100.00	30.34	0.21*	-0.24*	0.134
Wind speed, kmph	5.59	2.40	36.00	71.60	1.31*	1.80*	-0.015
Sunshine hours, hours/day	8.32	1.30	39.20	34.74	-1.28*	2.46*	-0.079***

Note:- *Significant according to standard error e where,

$$e = \sqrt{\frac{6}{N}} \quad \text{for skeweness;} \quad e = \sqrt{\frac{24}{N}} \quad \text{for kurtosis}$$

N = no. of sample

Significant at 5% level; * Significant at 10% level

Fig. 6.59 Monthly minimum, maximum and average climate of Dantiwada, Banaskantha district

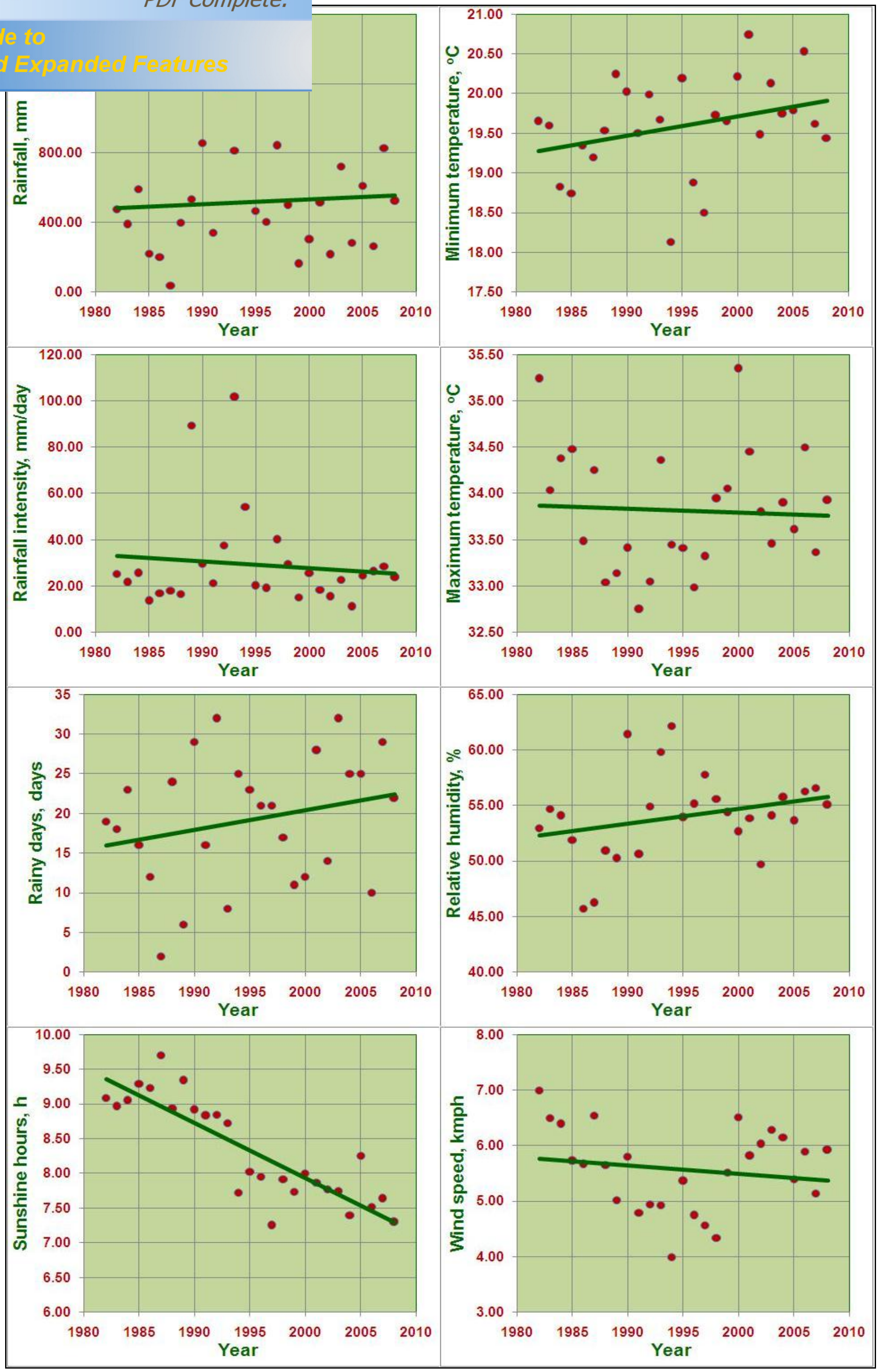


Fig. 6.60 Annual trend of climatic parameters of Dantiwada, Banaskantha district

nly minimum, maximum and average values of the ed at Dantiwada climate station. It is observed that the minimum and maximum temperatures are higher in the month of June and May respectively. The average relative humidity is the highest in the month of June. Also the highest windspeed is observed in the month of June. The sunshine hours are higher in the month of May. It is observed that when the sunshine hours are lowest the rainfalls are observed in those months.

Fig. 6.60 represents the trend for rainfall and other climatic parameters. One can observe the opposite scenario for the annual averages for this station compared to the other two discussed earlier. An increasing trend in minimum temperature, relative humidity, rainy days and rainfall amounts is observed. Decreasing trend in maximum temperature, sunshine hours, wind speed and rainfall intensity are observed. According to Mann Kendall test these trend values are not significant except for sunshine hours. The period of average calculation considered is from 1982 to 2008 which may be one of the reasons. While for other stations it is averaged over the period from 1969 to 2005.

From Table 6.163 it is observed that the coefficient of variation is most in case of wind speed and least for maximum temperature. For annual rainfall the coefficient of variation is above the threshold limit of 25 % and hence not dependable. Rainy days, rainfall, rainfall intensity, maximum temperatures, average relative humidity and wind speed are positively skewed which indicates a distribution with an asymmetric tail extending towards more positive values. Minimum temperature and sunshine hours are negatively skewed, indicating a distribution with an asymmetric tail extending towards more negative values. Annual rainfall, rainfall intensity and rainy days are within the expected range of chance fluctuations in the statistic for skewness and kurtosis, which further indicates a distribution with no significant skewness or kurtosis problem. Thus other parameters except the annual rainfall, rainfall intensity and rainy days, have significant skewness and kurtosis indicating violations of the assumption of normality that underlies many of the other statistics like correlation coefficients, t-tests, etc. used to study test validity.

cs of Climate of Vallabh Vidyanagar, Kheda District

[illegible]	[illegible]	[illegible]	Maximum	C_v	Skewness	Kurtosis	Trend
Rainy days, days / year	29.00	8.00	53.00	35.77	0.07	0.09	-0.008
Annual rainfall, mm	752.34	226.35	1,904.80	48.00	1.07	1.59	-3.294
Rainfall intensity, mm/day	25.78	11.93	51.49	32.08	0.89	1.20	-0.086
Minimum temperature,^{0}C	19.57	7.40	28.60	22.52	-0.60*	-0.24*	0.011
Maximum temperature,^{0}C	33.40	22.50	41.10	10.48	0.33*	0.25*	0.021
Average relative humidity, %	62.90	28.50	97.00	21.67	0.11*	0.08*	0.150**
Wind speed, kmph	3.57	0.51	14.40	63.06	0.73*	1.45*	-0.098***
Sunshine hours, hours/day	8.70	1.30	14.30	24.97	-0.57*	0.07*	0.017**

Note:- *Significant according to standard error e where,

$$e = \sqrt{\frac{6}{N}} \quad \text{for skeweness;} \qquad e = \sqrt{\frac{24}{N}} \quad \text{for kurtosis}$$

N = no. of sample

Significant at 5% level; * Significance at 10% level

Fig. 6.61 represents monthly minimum, maximum and average values of the climate parameters observed at Vallabh Vidyanagar climate station. It is observed that the minimum & maximum temperatures and sunshine hours are the highest in the month of May. The average relative humidity is the highest in the month of July. Also the windspeed observed for the month of June is the highest. The highest rainfall is observed in the month of July where the numbers of rainy days are also more.

Fig. 6.62 represents the trend for rainfall and other climatic parameters. An increasing trend in minimum and maximum temperatures and relative humidity, sunshine hours is observed. Decreasing trends for rainfall and wind speed are observed. The data for rainfall intensity and rainy days are not available, hence not plotted. According to Mann Kendall test these trend values are significant for average relative humidity, wind speed and sunshine hours at 5 %, 10 % & 5 % significance level respectively.

Fig. 6.61 Monthly minimum, maximum and average climate of Vallabh Vidyanagar, Kheda district

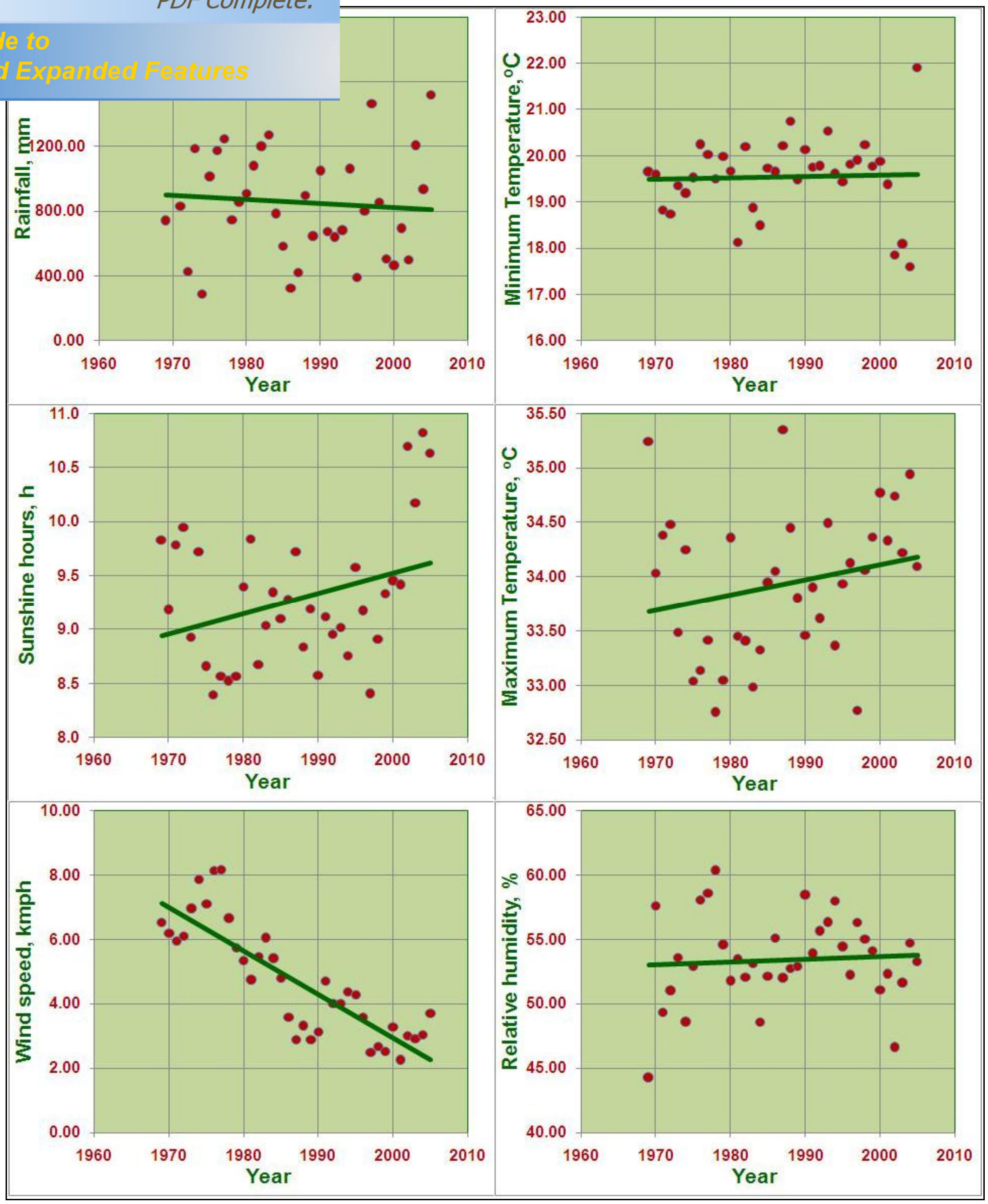


Fig. 6.62 Annual trend of climatic parameters of Vallabh Vidyanagar, Kheda district

Table 6.164 illustrates the characteristics of Idar climate station. It is observed that the coefficient of variation is most in case of rainfall and least for maximum temperature. Rainy days, rainfall, maximum temperature, wind speed and sunshine hours are positively skewed which indicate a distribution with an asymmetric tail extending towards more positive values. Rainfall ature and average relative humidity are negatively bution with an asymmetric tail extending towards more negative values. Minimum temperature is within chance of fluctuation for skewness. Rainy days, rainfall, rainfall intensity and maximum temperature have negative kurtosis indicating relatively flat distribution. Other parameters show positive kurtosis indicating peaked distribution. Minimum temperature is within the acceptable chance of fluctuation for kurtosis.

Table 6.164 Characteristics of Climate of Idar, Sabarkantha District

Parameter	**Mean**	**Minimum**	**Maximum**	**C_v**	**Skewness**	**Kurtosis**	**Trend**
Rainy days, days / year	32.00	14.00	58.00	34.00	0.44*	-0.28*	-0.12
Annual rainfall, mm	797.00	205.00	1,065.00	44.00	0.29*	-0.14*	-2.29
Rainfall intensity, mm/day	24.00	12.00	37.00	27.00	-0.02*	-0.73*	-0.07
Minimum temperature,^{0}C	21.00	17.00	22.00	5.00	-1.72	6.20	0.01
Maximum temperature,^{0}C	34.00	33.00	36.00	2.00	0.36*	-0.51*	0.04**
Average relative humidity, %	46.00	37.00	56.00	10.00	-0.12*	0.22*	0.08
Wind speed, kmph	2.66	2.40	16.80	38.97	4.68*	3.55*	-0.01
Sunshine hours, hours/day	8.36	7.44	10.35	6.00	1.18*	4.39*	0.01

Note:- *Significant according to standard error e where,

$$e = \sqrt{\frac{6}{N}} \text{ for skeweness; } \quad e = \sqrt{\frac{24}{N}} \text{ for kurtosis}$$

N = no. of sample

**Significant at 5% level

Fig. 6.63 represents the trend for rainfall and other climatic parameters. One can observe the increasing trend in minimum and maximum temperatures, average relative humidity and sunshine hours and decreasing trend for rainy days, total rainfall, rainfall intensity and wind speed. Based on trend values obtained it is observed that trend is decreasing for rainy days, total rainfall amount and rainfall intensity while it is increasing for minimum and maximum temperatures, average relative humidity and sunshine hours.

Fig. 6.63 Monthly minimum, maximum and average climate of Idar, Sabarkantha district

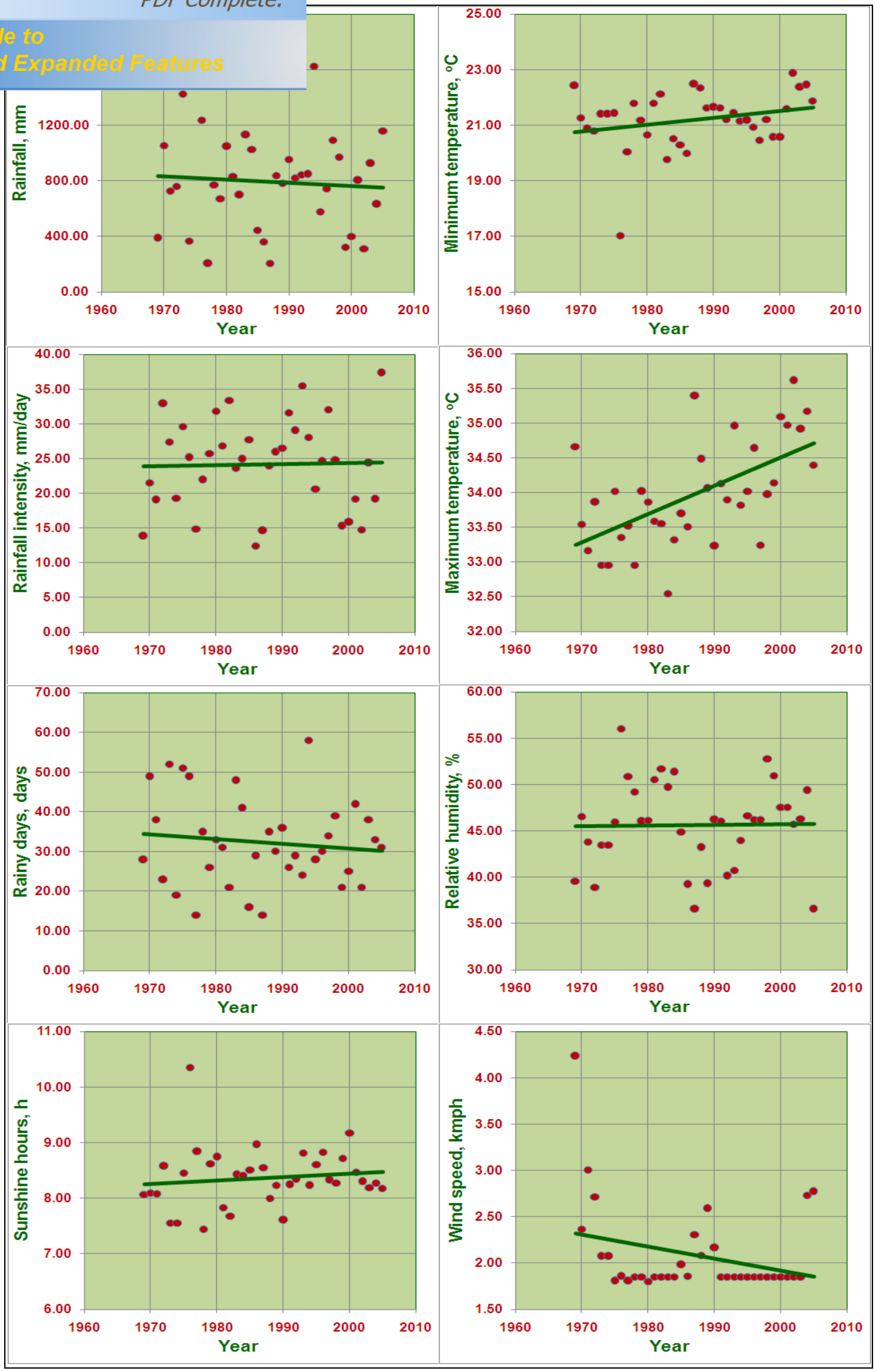


Fig. 6.64 Annual trend of climatic parameters of Idar, Sabarkantha district

nd values except for maximum rainfall are non gnificance. Thus while relating the rainfall and other climate parameters one can say that as the other climate parameter values increase for given annual time series for Idar, the rainfall intensity decrease. This is due to the climatic changes because of global warming effect. Further variation effects can be achieved if one explores the climate data if available at each raingauge network.

From the statistics obtained for all the five climate stations general observations can be made. The findings relate to the study funded by NASA indicating the amount of solar radiation the sun emits, during times of quiet sunspot activity, has increased since 1970ôs with a rate of 0.05 percent per decade.(http://www.nasa.gov/home/hqnews/2003/mar/HP_news_03106. html) Richard Willson, a researcher affiliated with NASA's Goddard Institute for Space Studies and Columbia University's Earth Institute, New York said that this trend was important because, if sustained over many decades, it could cause significant climate change. He was the lead author of the study recently published in Geophysical Research Letters. Historical records of solar activity indicated that solar radiation has been increasing since the late 19th century. He mentioned that if a trend, comparable to the one found in his study, persisted throughout the 20th century, it would had provided a significant component of the global warming the Intergovernmental Panel on Climate Change reports to have occurred over the past 100 years.

In order to study the heterogeneity of rainfall amounts over an area, a modified version of Oliverôs (1980) Precipitation Concentration Index (PCI) is used as explained in the methodology. The PCI for 73 raingaguge stations have been calculated and presented in Figs. 6.65 to 6.70. Fig. 6.65 presents the plot for Ahmedabad district and the remaining plots are provided in Figs. 6.66 to 6.71 for Banaskantha, Gandhinagar, Kheda, Mehsana, Patan and Sabarkantha districts, which are given in CD. For all the raingauge stations the Precipitation Concentration Index (PCI) values are above 20 which correspond to climates with substantial monthly variability. The average PCI

nd 40 %. Thus for the north Gujarat agroclimatic
s substantially variable.

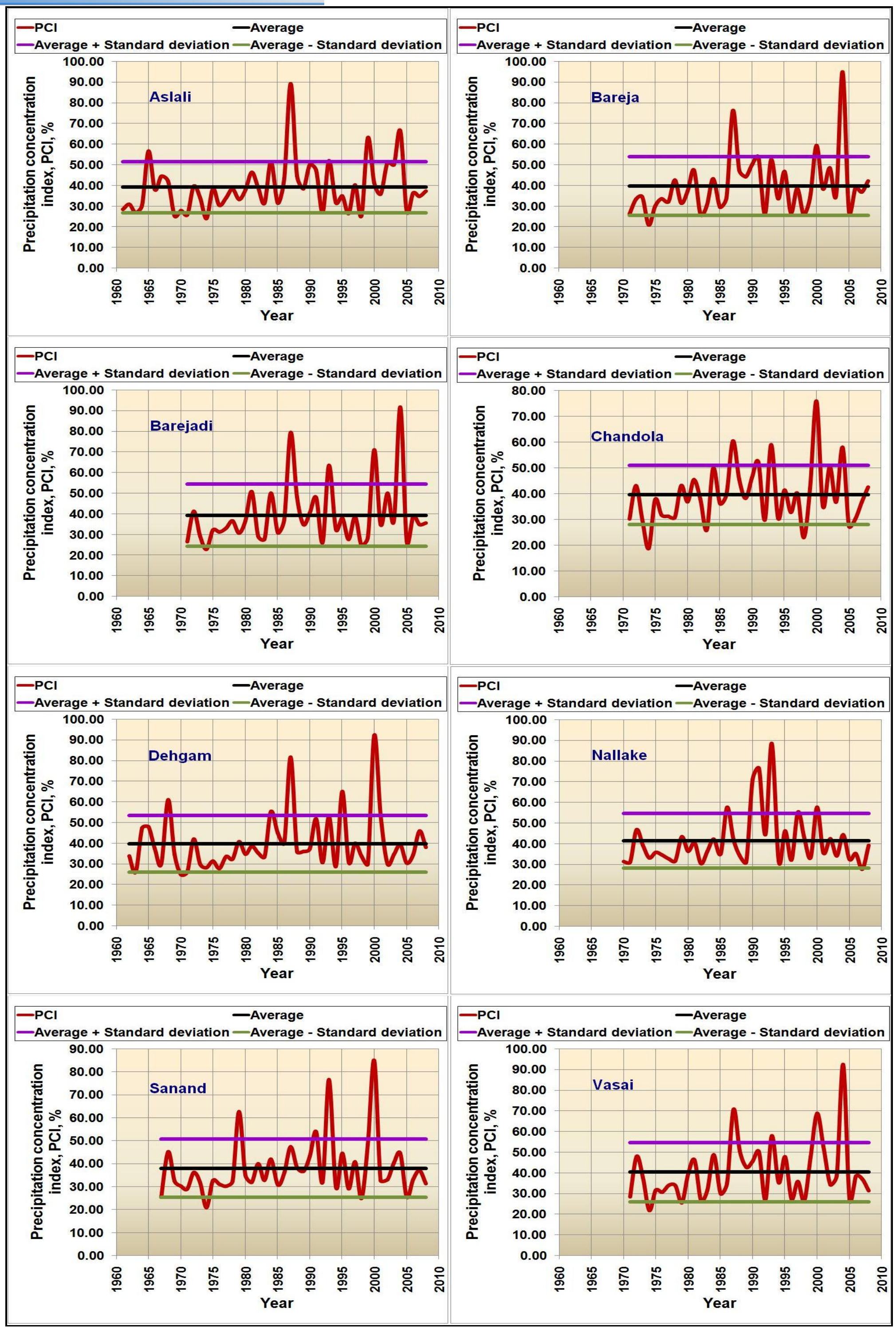


Fig. 6.65 PCI for raingauge stations in Ahmedabad district

ferent statistical characteristics of the climate ... can conclude that the climate of the present study area is varying and needs to be analyzed in detail for planning the water resources and agricultural activities.

6.6 REGIONALIZATION BASED ON SPATIAL AND TEMPORAL RAINFALL PATTERNS

The concentration indices (COIN) for 73 raingauges, the constants a & b and the percentage of rainfall amount for 25 % of rainiest days are presented in Table 6.165. From Table 6.165 it can be observed that if one considers a period of 48 years from 1961 to 2008 then more than 60% of the total rain fell in 25% of rainiest days in the region. During the past 48 years, Prantij has experienced maximum of 77 % of total rainfall within 25 % of rainiest days. While Mahisa has experienced 63 % of total rainfall within 25 % of rainiest days. It can be observed that Mahisa, Savli tank and Vadol have minimum COIN of 0.54 while Dharoi and Prantij have maximum COIN of 0.66 and the average COIN for north Gujarat agroclimatic zone is 0.60. The COIN value for 73 raingauge stations in north Gujarat agroclimatic zone varies from 0.54 to 0.66 with standard deviation of 0.03. This 12% variation is significant according to Kolmogrov Smirnov one sample test statistic at 0.01 significance level. Fig. 6.69 illustrates the distribution of the concentration of rainfall in the study area.

…aingauge Stations and Percentage of Total Rainfall
…ays Observed in North Gujarat Agroclimatic Zone

Sr. no.	Name of raingauge station	a	b	COIN	Percentage of total rainfall amount for 25% of rainiest days
1	Aslali	0.0589	0.0275	0.56	65
2	Bareja	0.0678	0.0258	0.55	66
3	Barejadi	0.0506	0.0287	0.58	68
4	Chandola	0.0584	0.0272	0.57	67
5	Dehgam	0.0406	0.0309	0.60	70
6	Nal Lake	0.0627	0.0267	0.56	65
7	Sanand	0.0330	0.0331	0.61	71
8	Wasai	0.0707	0.0254	0.55	67
9	Ambaji	0.0593	0.0271	0.57	67
10	Amirgadh	0.0345	0.0323	0.62	72
11	Bapla	0.0504	0.0285	0.59	69
12	Chandisar	0.0415	0.0304	0.61	70
13	Chitrasani	0.0474	0.0291	0.60	70
14	Danta	0.0438	0.0300	0.60	70
15	Dantiwada	0.0292	0.0339	0.63	73
16	Deesa	0.0242	0.0358	0.65	75
17	Dhanera	0.0308	0.0335	0.63	72
18	Gadh	0.0429	0.0300	0.61	71
19	Hadad	0.0393	0.0311	0.61	71
20	Junisarotri	0.0366	0.0318	0.61	72
21	Nava	0.0670	0.0261	0.55	65
22	Palanpur	0.0417	0.0302	0.61	72
23	Panthawada	0.0396	0.0309	0.61	72
24	Sanali Ashram	0.0478	0.0293	0.59	69
25	Wadgam	0.0532	0.0281	0.58	68
26	Mansa	0.0344	0.0323	0.62	66
27	Raipur Weir	0.0574	0.0276	0.56	73
28	Balasinor	0.0414	0.0309	0.59	69
29	Dakor	0.0425	0.0308	0.59	68
30	Kapadwanj	0.0528	0.0285	0.57	67
31	Kathlal	0.0452	0.0300	0.59	68
32	Kheda	0.0458	0.0298	0.59	69
33	Mahemadabad	0.0317	0.0332	0.63	73
34	Mahisa	0.0685	0.0260	0.54	63
35	Nadiad	0.0360	0.0318	0.62	72
36	Pinglaj	0.0632	0.0264	0.57	68
37	Savli tank	0.0690	0.0260	0.54	64
38	Vadol	0.0766	0.0247	0.54	64
39	Vaghroli	0.0678	0.0258	0.55	65
40	Ambaliyasan	0.0415	0.0306	0.60	70
41	Dharoi	0.0201	0.0378	0.66	75
42	Kadi	0.0374	0.0313	0.62	72
43	Kalol	0.0373	0.0316	0.61	72

[illegible]	[illegible]	.0416	0.0305	0.60	70
[illegible]	[illegible]	.0387	0.0309	0.62	72
[illegible]	[illegible]	.0363	0.0315	0.63	73
47	Ransipur	0.0498	0.0287	0.59	70
48	Thol	0.0508	0.0286	0.58	68
49	Unjha	0.0517	0.0286	0.58	67
50	Vijapur	0.0306	0.0334	0.63	73
51	Visnagar	0.0381	0.0310	0.62	73
52	Patan	0.0369	0.0314	0.62	73
53	Sidhpur	0.0396	0.0307	0.62	72
54	Wagdod	0.0528	0.0281	0.59	68
55	Badoli	0.0407	0.0308	0.60	70
56	Bayad	0.0308	0.0335	0.63	73
57	Bhiloda	0.0321	0.0330	0.63	73
58	Dantral	0.0406	0.0300	0.63	71
59	Himmatnagar	0.0323	0.0330	0.62	72
60	Idar	0.0437	0.0301	0.60	70
61	Khebhrama	0.0348	0.0323	0.62	72
62	Kundlacampo	0.0474	0.0292	0.59	69
63	Limladam	0.0439	0.0301	0.60	70
64	Malpur	0.0246	0.0355	0.65	75
65	Meghraj	0.0341	0.0327	0.61	73
66	Modasa	0.0292	0.0339	0.63	74
67	Pal	0.0602	0.0270	0.56	66
68	Prantij	0.0181	0.0388	0.66	77
69	Sabli	0.0480	0.0292	0.59	69
70	Shamlaji	0.0373	0.0314	0.62	72
71	Vadgam	0.0317	0.0334	0.62	72
72	Vijaynagar	0.0476	0.0295	0.58	68
73	Virpur	0.0427	0.0304	0.60	70

Fig. 6.72 indicates the COIN for north Gujarat agroclimatic zone. It is observed that the overall concentration of rainfall in most of the region is nearer to the average value of 0.600 indicated by the green colour. The average value obtained, divides the area into two different parts indicating higher and lower concentration of rainfall with reference to the average value obtained. Also there are some of the closed contours observed in the area. If one observes the lower portion of the area the COIN value builds up from lower to higher and achieves peak at 0.595. Further moving from the peak the COIN value decreases forming depression cones near the Nal Lake, Wasai, Savali tank, Vaghroli tank and Mahisa areas.

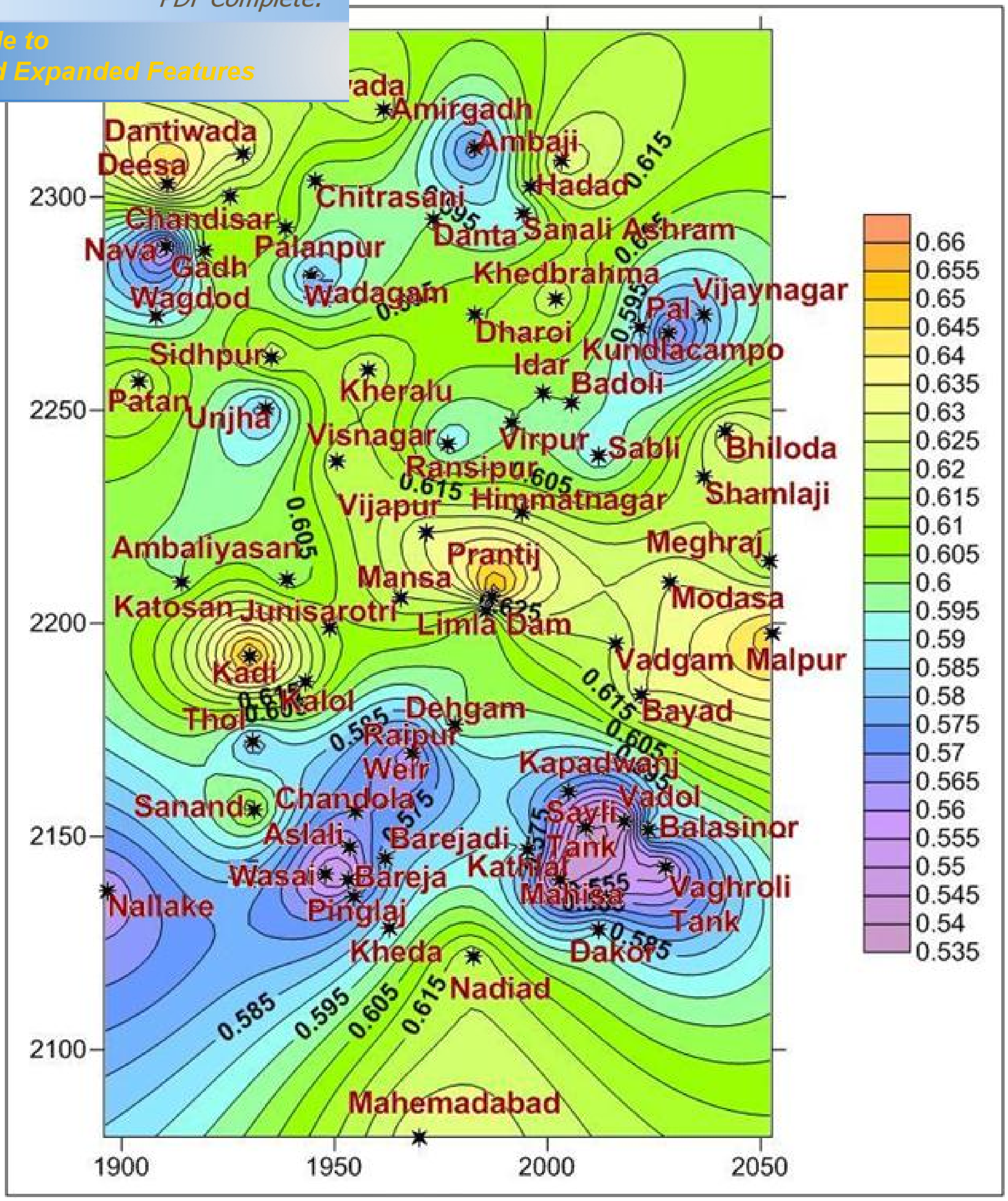


Fig. 6.72 Isopleth map of COIN for north Gujarat agroclimatic zone.

Observing the satellite images from the google maps, the terrain is somewhat flatter at and around these areas. Observing the google earth images the depression areas are less dense compared to the other area, although Nal Lake is situated nearer to the water body. Thus one may say that it is not necessary to believe that the concentration of rainfall is more nearer to the water bodies.

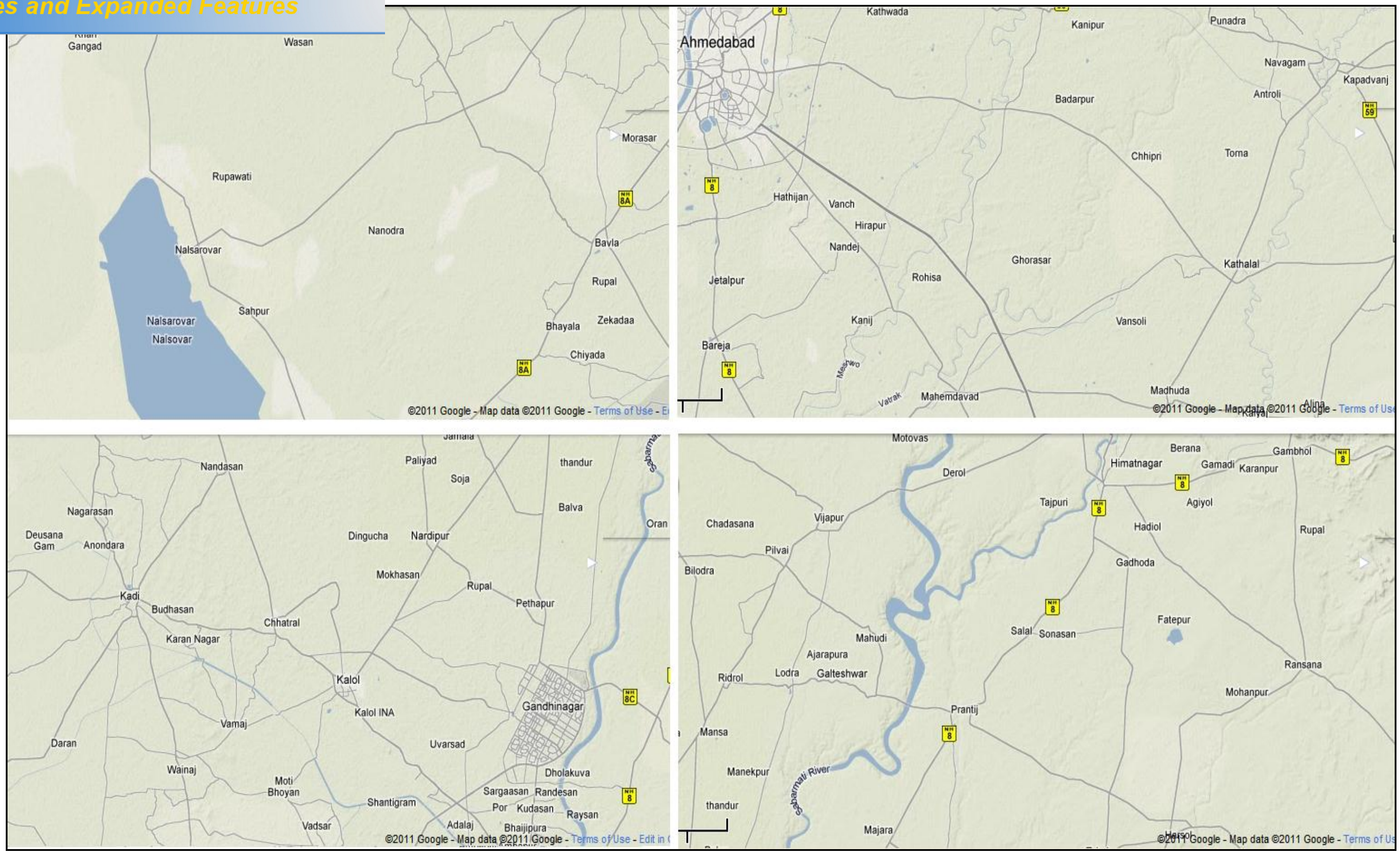


Fig. 6.73 Satellite images for the lower portion of the area consisting of Bareja, Kathlal, Kheda, Mehmadabad, Nal Lake (Nal sarovar), Kadi, Kalol, Prantij, Vijapur, etc. .

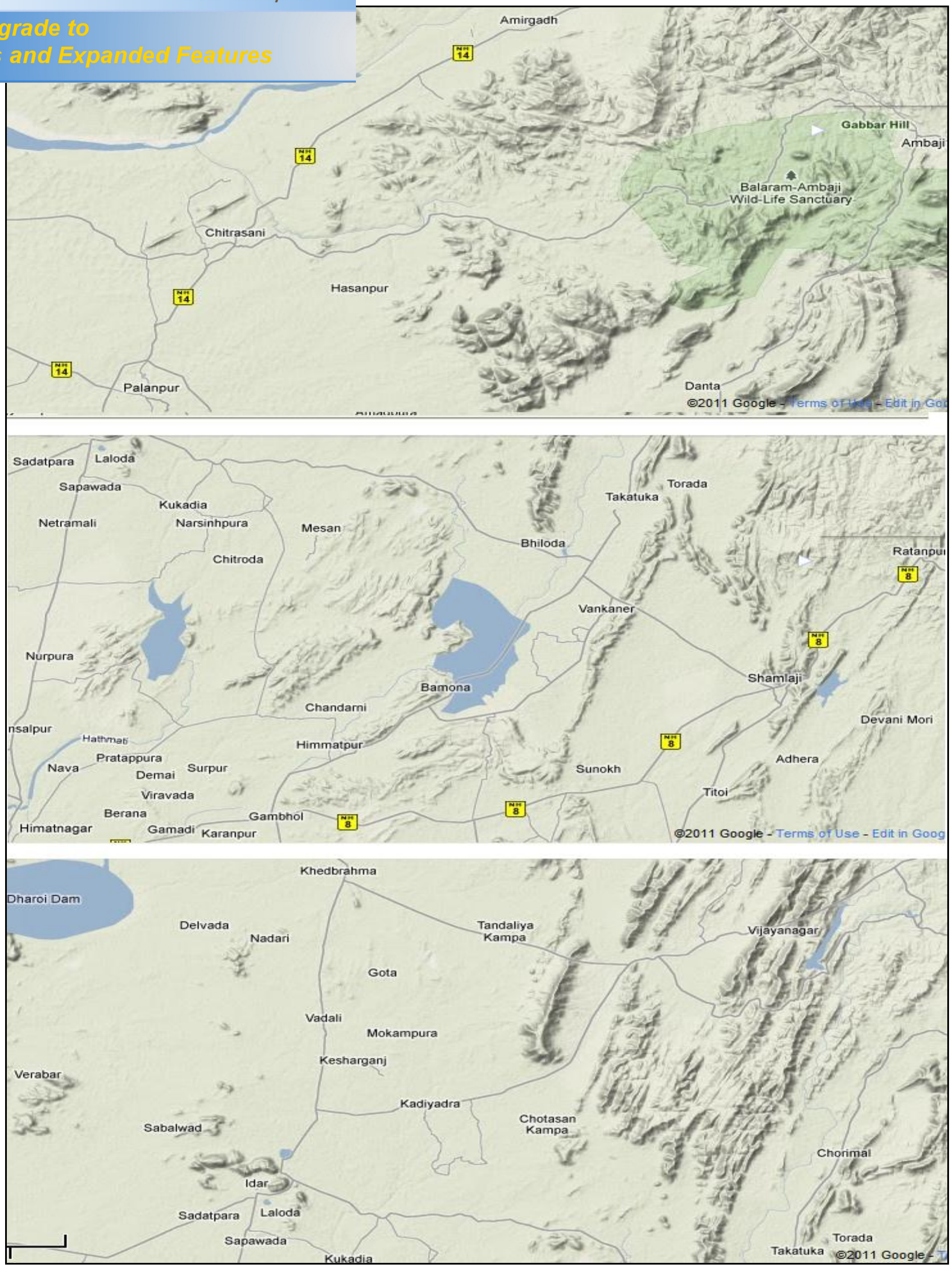


Fig. 6.74 Satellite images for the upper portion of the region consisting of Ambaji, Amirgadh, Chandisar, Danta, Dantiwada, Shamlaji, Bhiloda, Prantij, Vijaynagar, etc.

y build up away from the water body which may be at which it is situated. While it is known by now that many changes in the environment have their impact on climate. But at least one can study the behaviour spatial variability of rainfall by the concentration indices and plan for the water resources and agricultural management. Fig. 6.73 shows the satellite images of the lower portion of the study area consisting of lower concentration compared to the upper portion of the area.

As one observes the upper portion of the area, the concentration of the rainfall is at or above the average value of 0.60 except at Ambaji, Wadgam and Nava. If one observes the satellite images available from the google maps, the area is surrounded by mountainous regions. Hence the concentration of rainfall is higher due to the hilly region attracting more rains. Most of the central portion too observes the same scenario of average or above average concentration of rainfall with closed increasing contours at Kadi, Prantij and Malpur. Fig. 6.74 shows the satellite images of the upper portion of the study area consisting of higher concentration compared to the lower portion. The distribution of rainfall varies spatially in the region dividing the region into two parts with higher and lower concentrations with respect to the mean value. Hence as one moves from north towards south the variability of rainfall decreases. Most of the areas within the region observes greater variability with respect to the concentration of daily rainfall amount as the COIN value in any case is not more than 0.66 (as the COIN value of 1.00 gives the most uniform amount of rainfall for uniform number of rainy days).

The region receives most of the rainfall with fewer rainy days indicating the higher intensity of the rainfall. From the agriculture point of view, higher intensity of rainfall is less useful compared to the lesser intensity of rainfall. The high intensity of rainfall is incapable to fully infiltrate the soil due to lesser time of concentration resulting in more runoff. Thus the water harvesting (runoff harvesting) structures must be planned for storage of heavy rains which can be long dry spell periods, which are often observed in the further studies on dry spell analysis carried out for the region.

6.7 DESIGN STORM FOR HATHMATI CATCHMENT AREA

Nine raingauge stations fall in the Hathmati catchment area. This stations are Badoli, Bhiloda, Idar, Kundlacampo, Modasa, Pal, Sabli,Shamlaji and Vijaynagar. The aerial rainfall is determined using Theissen polygon formed using the other adjacent raingauge stations. The annual rainfall for the Hathmati catchment area is as represented in Fig. 6.75. The maximum value of 1573 mm is observed in 2006. Lowest annual rainfall of 202 mm is observed in 1987. The average rainfall over the catchment is 740 mm. The trend line indicated by black colour in the Fig. 6.75 do not show any increase or decrease in the annual rainfall amounts.

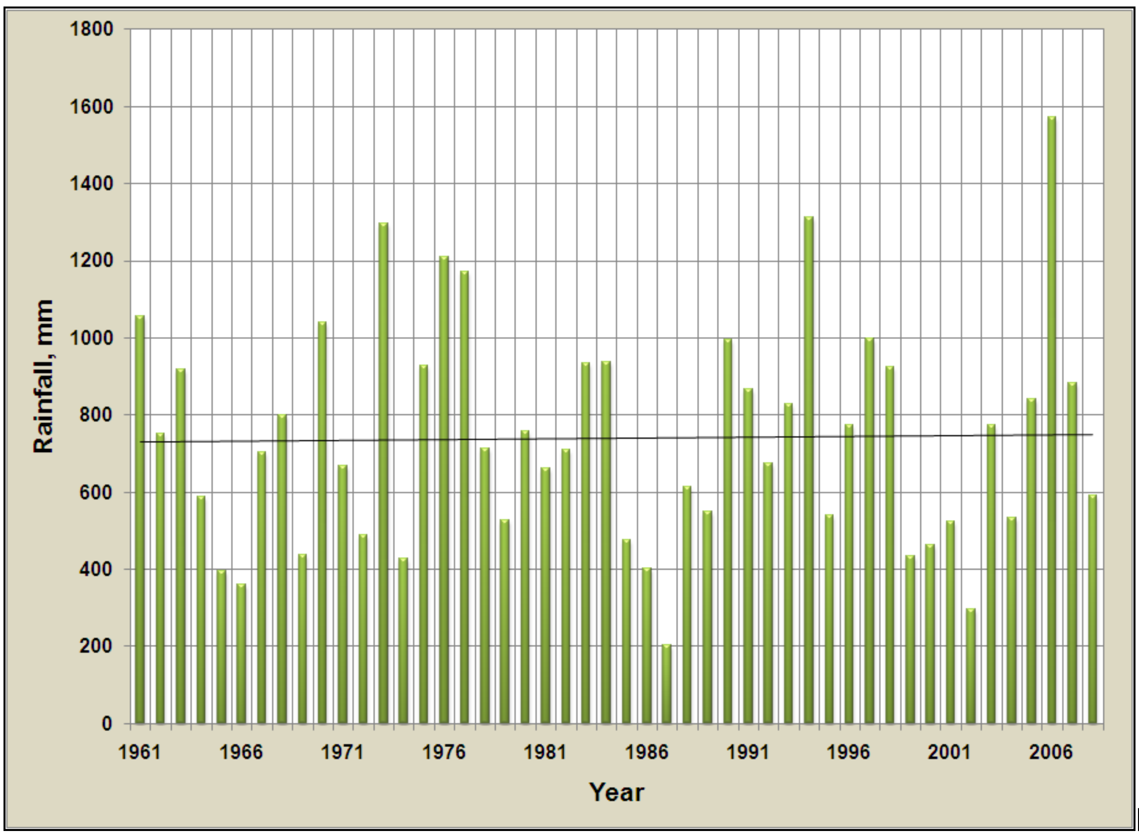


Fig. 6.75 Annual rainfall over the Hathmati catchment area

nspells which affected the Hathmati catchment are aerial rainfalls during each of these 48 rainstorms have been worked out and among them 10 severe rainstorms are given in Table 6.166. The maximum rainfalls for 1 to 5 days durations have been determined from the Table 6.166.

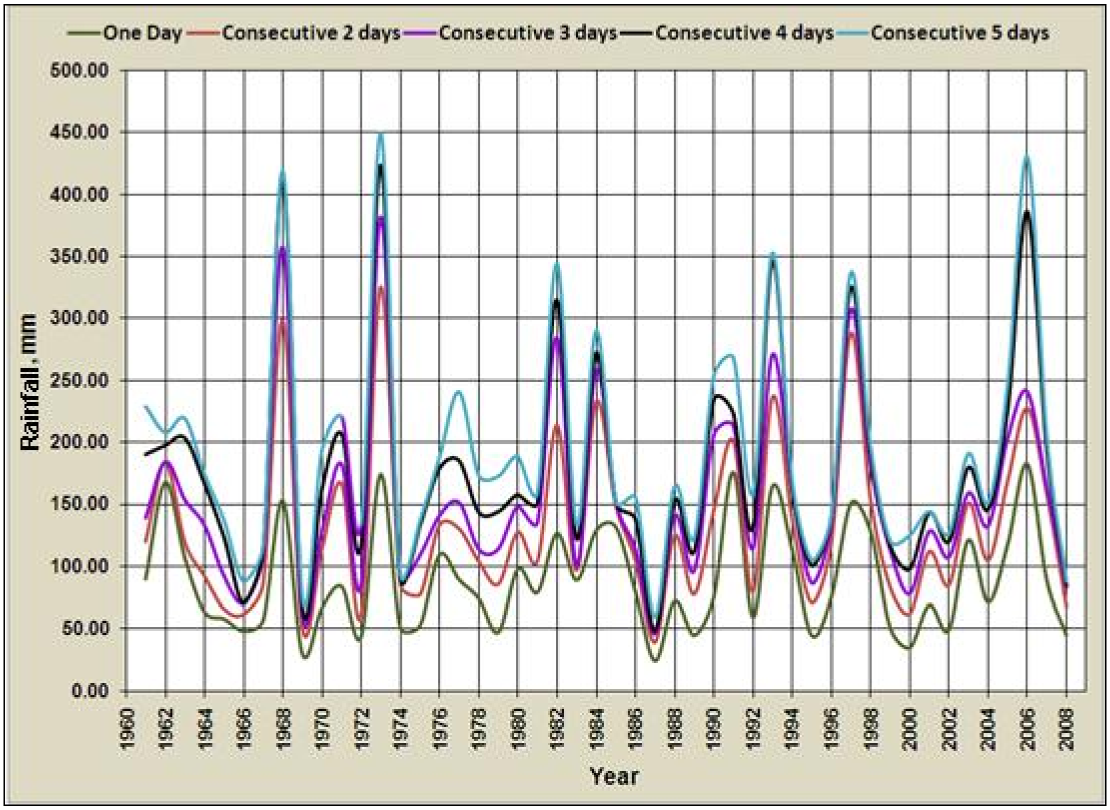


Fig. 6.76 Actual maximum rainfall observed at Hathmati catchment area

Table 6.166 Severe Rainstorms Observed at Hathmati Catchment Area

Sr. No.	Date of rainstorm	Daily rainfall, mm					Total Mm
		1	2	3	4	5	
1	29 Augï 2 Sep 1973	25.45	56.46	151.16	174.30	41.84	449.21
2	16 Augï 20 Aug 2006	182.83	44.58	2.79	156.45	43.28	429.94
3	30 Jul ï 3 Aug 1968	57.58	153.14	145.67	58.48	3.67	418.55
4	8 Julï 11 Jul 1993	76.08	151.71	41.72	77.31	---	346.82
5	23 Julï 27 Jul 1982	70.48	86.90	126.79	31.13	28.69	344.00
6	24 Junï 27 Jun 1997	18.27	150.99	137.09	19.11	---	325.46
7	3 Augï 6 Aug 1984	25.65	103.57	129.22	14.16	---	272.60
8	22 Julï 26 Jul 1991	44.71	57.52	13.77	62.92	89.23	268.15
9	3 Julï 7 Jul 1990	28.74	69.45	75.80	60.49	19.06	253.54
10	17 Julï 18 Jul 1993	71.69	164.90	---	---	---	236.59

...ns over the catchment, the raindepths for 1,2,3,4 and ... as depth-duration (DD) curves (see Fig. 6.77). DD analysis has shown that the catchment received as high as 182.83 mm, 236.59 mm, 356.39 mm, 414.87 mm and 449.21 mm in 1, 2,3,4 and 5 day durations respectively as depicted in Table 6.167

Table 6.167 Observed One Day to Consecutive 2 to 5 Days Raindepths for Hathmati Catchment Area

Sr. no.	Year	1D	C2D	C3D	C4D	C5D
1	1973	25.45	81.91	233.07	407.37	**449.21**
2	2006	**182.83**	227.41	230.20	386.65	429.93
3	1968	57.58	210.72	**356.39**	**414.87**	418.54
4	1993	76.08	227.79	269.51	346.82	346.82
5	1982	70.48	157.38	284.17	315.30	343.99
6	1997	18.27	169.26	306.35	325.46	325.46
7	1984	25.65	129.22	258.44	272.60	272.60
8	1991	44.71	102.23	116.00	178.92	268.15
9	1990	28.74	98.19	173.99	234.48	253.54
10	1993	71.69	**236.59**	236.59	236.59	236.59

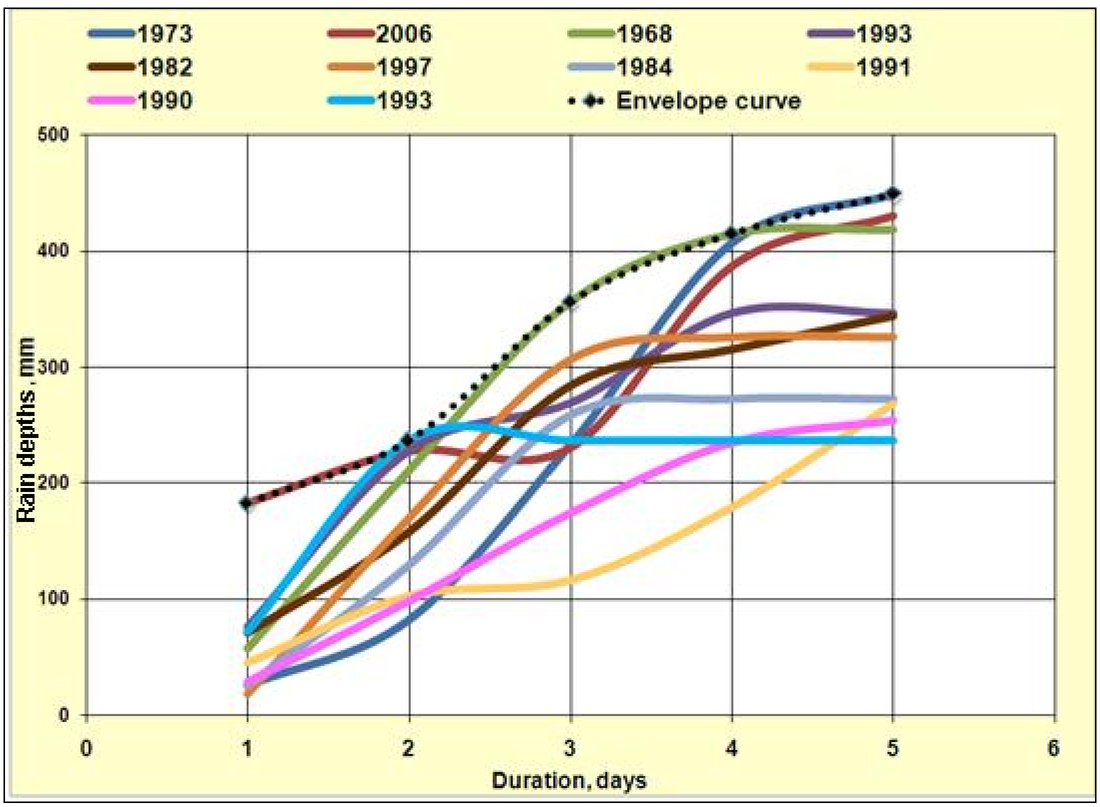


Fig. 6.77 Depth duration (DD) and envelope curve for Hathmati catchment area

method

In order to determine the design raindepths by the statistical method, the annual maximum catchment raindepths for the 48 years period (1961ï 2008) for 1,2,3,4 and 5 day durations have been subjected to the best fitted Inverse Gaussian distribution. Table 6.168 gives the design storm rainfalls for 1,2,3,4 and 5 day durations for return period from 2 to 1000 years. This Table shows that the highest raindepths obtained by DD method (Table 6.167) for 1ï day (182.83 mm) is close to 23 years, 2ï day is close to 14 years, 3ï day is close to 60 years, 4ï day is close to 54 years and 5ï day is close to 60 years.

Table 6.168 1,2,3,4 and 5 Day Rainfall at Different Return Period for Hathmati Water Resources Project

Return period Years	1–day mm	2–day mm	3–day mm	4–day mm	5–day mm
2	78	116	138	159	174
5	119	175	202	236	255
10	149	216	246	289	310
20	177	256	289	341	364
50	215	309	345	408	434
60	223	320	356	422	448
70	229	329	365	433	459
80	235	336	373	443	470
90	240	343	380	451	479
100	244	349	387	459	487
500	312	443	484	578	608
750	329	466	508	607	639
1000	341	483	526	629	661

In evaluating the probable maximum precipitation (PMP) for the Hathmati catchment, the envelope curve obtained by DD method are maximized with the moisture maximization factors (MMFs). The MMF is a ratio of the highest amount of moisture recorded over the catchment during the period when the rainstorm occurred to that recorded in the rainstorm. The moisture in an air mass from which large precipitation occurs, can be estimated from the surface dew points decreasing with height at a the pseudo-adiabatic lapse rate.

the maximum 24 hour persisting dew point value is fore been worked out on the basis of maximum persisting rainstorm and the maximum persisting dew point for the catchement. The maximum 24 hour persisting dew point temperature for the catchment in July and August months have been observed.

The maximum 12 hours persisting dew point temperature for the Hathmati Catchment has been found to be 27.6 ^{0} C. The storm dew point temperatures for the selected 10 rainstorms have been obtained. The elevation of the catchment is 202 m. The dew point temperatures obtained above are reduced to the mean sea level from Fig. 5.5. Table 6.169 gives the values of parameters used for evaluating the MMFs where the dew points are expressed in their 1000 mb equivalents using Fig. 5.6.

Table 6.169 Parameters used for Working out MMFs

Rainstorm period	Storm dew point ^{0} C		Precipitable water mm	Maximum dew point for the Hathmati catchment ^{0} C	Precipitable water mm	MMF
	Observed	Reduced to mean sea level				
29 Augï 2 Sep 1973	24.8	25.2	88	28.5	94	1.07
16 Augï 20 Aug 2006	---	---	---	28.5	94	---
30 Julï 3 Aug 1968	---	---	---	28.5	94	---
8 Julï 11 Jul 1993	23.2	24.0	60	28.5	94	1.56
23 Julï 27 Jul 1982	24.8	25.2	88	28.5	94	1.07
24 Junï 27 Jun 1997	---	---	---	28.5	94	---
3 Augï 6 Aug 1984	25.0	25.8	74	28.5	94	1.27
22 Julï 26 Jul 1991	25.0	25.8	74	28.5	94	1.27
3Julï 7 Jul 1990	23.7	24.2	66	28.5	94	1.42
17 Julï 18 Jul 1993	23.2	24.0	60	28.5	94	1.56

The MMFs obtained for the 10 severe rainstorms have been found and presented in Table 6.169. A maximum value of 1.56 is observed for two severe rainstorms analyzed. Thus a value of 1.56 is the obtained MAF for determining the PMPs for the catchment.

The following estimates of PMP have been obtained by adjusting the DD rain depths by the appropriate MMFs factors:

		Equivalent to Return period calculated by statistical method, years
1ï day	$= 183 \times 1.56 \approx 285 \text{mm}$	250
2ï day	$= 237 \times 1.56 \approx 370 \text{mm}$	145
3ï day	$= 356 \times 1.56 \approx 555 \text{mm}$	1530
4ï day	$= 415 \times 1.56 \approx 647 \text{mm}$	1220
5ï day	$= 449 \times 1.56 \approx 700 \text{mm}$	1750

The estimates of PMP for 1,2,3,4 and 5 day durations for the Hathmati catchment have been found to be 285 mm, 370 mm, 555 mm, 647 mm and 700 mm respectively. These PMP raindepths can be used for calculation of the PMF hydrograph for the Hathmati dam.

From the design storm analysis of the Hathmati Water Resources Project following results have been emerged:

The average annual rainfall in the catchment is about 74 cm with a standard deviation of 29 cm.

The coefficient of variability of annual rainfall is about 39%. July month has the lowest variability of 51% among the four months while June has about 100%, August has about 61% and September has about 105% variability of rainfall.

10 severe rainstorms have occurred over the catchment during the 48 year period. Out of these 10 rainstorms, 5 were observed in July, 4 in August and 1 in June. The heavy intensity of storms were observed in the years 1968, 1973, 1982, 1984, 1990, 1991, 1993, 1997 and 2006.

ment rain depths for the 48 year period for 1,2,3,4 been subjected to best fitted Inverse Gaussian distribution. The highest observed rain depths obtained by DD method for 1-day duration (i.e. 182.83 mm) is close to 23 years, 2ï day duration (i.e. 236.59 mm) is close to 14 years, 3ï day duration (i.e. 356.39 mm) is close to 60 years, 4ï day duration (i.e. 414.87 mm) is close to 54 years and 5ï day duration (i.e. 449.21 mm) is close to 60 year return period estimated by statistical (probability distribution) method.

The estimates of PMP using hydrometeorological method, for 1,2,3,4 and 5 day durations for the Hathmati catchment have been found to be 285 mm, 370 mm, 555 mm, 647 mm and 700 mm respectively. This PMP estimates are equivalent to 250, 145, 1530, 1220 and 1750 years of return period estimated by statistical (probability distribution) method.

The findings above can be supported by the study carried out by Mistry (1988) emphasizing the review of design floods for some of the major river valley projects in Gujarat state. He mentioned that the hydrological aspects, viz., availability of water, design flood, etc. were estimated on the basis of a few years observed discharge data available at that time or by using the rational empirical formulae for runoff and floods. The design floods for the projects were estimated by applying suitable factor of safety, to the observed maximum flood at the site or at nearby site on the same stream depending on the judgement of the designer. Attemps were also made to estimate the magnitude of the design flood by using the slope area method and observed flood marks of the highest experienced flood from local inquiry. All these above mentioned methods were based on the past available records of floods in the concerned regions. At the time of preparing the project report, the design flood derived by the above methods is based on the data available, then the design flood may be subjected to revision.

The construction of Hathmati dam was completed in Year 1971. Mistry (1988) has mentioned in his report that unprecedented floods occurred in the year 1973 lso it should be noted that the year 2006 observed n be observed from the analysis carried out. This necessitated the revision of design flood study carried out in past. Keeping the devastating effects of the floods in view, an attempt was made for revision of the design flood which will be useful in the planning and design of new water resources projects as well as in reï examining the spillways of the existing water control devices.

The design discharge capacity of spillway of existing Hathmati dam is 2,943 m^3/s. Its catchment area is 595 km^2. Based on the hydrometerological method the design raindepth over the catchment observed for one day is 285 mm. Therefore the design flood considering 85 % runoff, comes out to be 1,668.27 m^3/s. When one considers the statistical frequency distribution method, then 1000 year return period rainfall depth is considered for spillway designs. The rainfall depth using statistical method obtained is 341 mm and the design flood calculated is 1,996.07 m^3/s. Thus the design flood obtained for the period from 1961 to 2008 is reduced to 43 % and 32 % in case for hydrometerological and statistical method respectively, than the design discharge of the existing spillway capacity. This design discharge capacity of 2,943 m^3/s was determined considering the maximum flood observed in 1927. If in case for further analysis period in future a need may arise to re-examining the design storm the statistical method can be recommended. In case of Kadana dam, it was completed in 1979 with main spillway capacity of 31,400 m^3/s. Considering the rainfall in 1973 the design discharge was revised and an additional spillway of 18,097 m^3/s was constructed.

Overall it can be said that probable maximum precipitation estimates by statistical method are well comparable with values obtained by the hydrometeorological method for different durations. As the hydrometeorological method involves additional data for dew point temperatures and lengthy al method can be easily used with appropriate return

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6.8 DROUGHT ANALYSIS

By using the monthly rainfall data of 73 raingauge stations, standardized precipitation index (SPI) values are calculated for 4, 12 and 24 months period. Based on AIC and BIC the best distribution fitted to the dataset of 4 months, 12 months and 24 months rainfall for all the raingauge stations obtained is inverse Gaussian and hence used for further analysis. The drought intensity is classified as discussed in methodology using Table 5.9 and the results are presented in Tables 6.70 to 6.176 The number of events and percentage out of total number of years of analysis is calculated for all the three types of data viz. original one (O), gamma fitted (G) and best fitted inverse Gaussian (I).

From Table 6.170 it is observed that the total drought events for 4 month time scale using gamma and inverse Gaussian distribution are equal for Bareja, Chandola, Dehgam, Sanand and Nal Lake raingauge stations in Ahmedabad district. For 12 month time scale (SPI12) Aslali, Barejadi, Sanand and Nal Lake have same drought events for gamma and inverse Gaussian while it is more for gamma distribution in case for Bareja, Chandola, Dehgam and Vasai. For 24 months time scale (SPI24) all the raingauges give equal events except Dehgam. The total drought events for SPI4, SPI12 and SPI24 using original dataset are less than or equal to the gamma and inverse Gaussian distributions. Though the total drought events for most of the stations are equal for gamma and inverse Gaussian distribution, the later predicts more extreme drought events.It is observed that for smaller time scales the gamma and inverse Gaussian gives similar results. But as the time scale increases the results may vary. Thus extreme events are more categorized by the best fitted inverse Gaussian distribution.

…ity Classification Events (Percentages) for SPI4, SPI12 and SPI24 in Ahmedabad

Rain - gauge Station	Type	Moderate drought						Severe drought						Extreme drought						Total drought					
		SPI4		SPI12		SPI24		SPI4		SPI12		SPI24		SPI4		SPI12		SPI24		SPI4		SPI12		SPI24	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Aslali	O	8	17	7	15	6	13	3	6	3	6	4	9	1	2	1	2	0	0	12	25	11	23	10	21
	G	6	13	6	13	5	11	6	13	5	10	7	15	1	2	1	2	0	0	13	27	12	25	12	26
	I	4	8	5	10	5	11	5	10	3	6	5	11	3	6	4	8	2	4	12	25	12	25	12	26
Bareja	O	4	11	3	8	2	5	2	5	3	8	3	8	2	5	2	5	1	3	8	21	8	21	6	16
	G	3	8	3	8	6	16	4	11	3	8	2	5	2	5	3	8	2	5	9	24	9	24	10	27
	I	3	8	2	5	6	16	2	5	1	3	1	3	4	11	5	13	3	8	9	24	8	21	10	27
Barejadi	O	7	18	5	13	5	14	1	3	3	8	3	8	1	3	1	3	1	3	9	24	9	24	9	24
	G	7	18	4	11	5	14	4	11	4	11	4	11	0	0	1	3	0	0	11	29	9	24	9	24
	I	4	11	4	11	5	14	4	11	4	11	3	8	1	3	1	3	1	3	9	24	9	24	9	24
Chandola	O	6	16	7	18	7	19	3	8	3	8	1	3	0	0	0	0	1	3	9	24	10	26	9	24
	G	6	16	7	18	9	24	4	11	1	3	2	5	1	3	3	8	0	0	11	29	11	29	11	30
	I	6	16	5	13	6	16	4	11	2	5	3	8	1	3	3	8	1	3	11	29	10	26	10	27
Dehgam	O	6	13	5	11	5	11	3	6	4	9	3	7	0	0	0	0	2	4	9	19	9	19	10	22
	G	2	4	6	13	5	11	8	17	6	13	4	9	0	0	0	0	2	4	10	21	12	26	11	24
	I	2	4	5	11	5	11	7	15	4	9	2	4	1	2	2	4	4	9	10	21	11	23	11	24
Nal Lake	O	6	15	4	10	7	18	3	8	4	10	0	0	0	0	0	0	1	3	9	23	8	21	8	21
	G	3	8	0	0	5	13	4	10	6	15	2	5	2	5	2	5	1	3	9	23	8	21	8	21
	I	3	8	0	0	4	11	2	5	4	10	3	8	4	10	4	10	1	3	9	23	8	21	8	21
Sanand	O	2	5	4	10	4	10	5	12	3	7	1	2	2	5	2	5	2	5	9	21	9	21	7	17
	G	1	2	1	2	4	10	5	12	5	12	2	5	3	7	3	7	3	7	9	21	9	21	9	22
	I	1	2	1	2	4	10	3	7	3	7	2	5	5	12	5	12	3	7	9	21	9	21	9	22
Wasai	O	4	11	2	5	5	14	1	3	3	8	1	3	2	5	1	3	1	3	7	18	6	16	7	19
	G	5	13	6	16	6	16	3	8	1	3	3	8	2	5	3	8	1	3	10	26	10	26	10	27
	I	4	11	5	13	5	14	2	5	0	0	2	5	3	8	4	11	2	5	9	24	9	24	9	24

for different timescales using inverse Gaussian auge station, Ahmedabad district. Remaining 72 raingauge stations plots are presented from Figs 6.79 to to 6.150 and enclosed in CD.

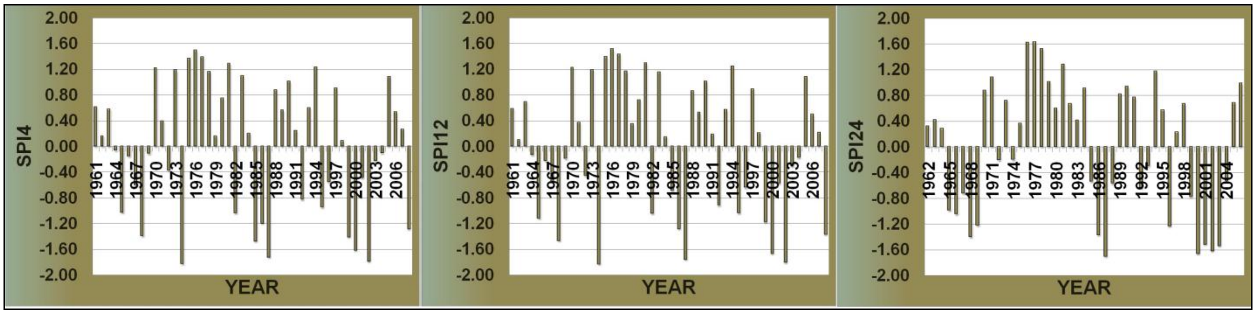

Fig. 6.78 SPI4, SPI12, SPI24 for Aslali raingauge station, Ahmedabad district

For shorter period of 4 months the switching of SPI between positive and negative values are more frequent. In longer periods it is seen that the duration of wet or dry periods are longer. Both of these situations can be interpreted in different approaches according to different water users. For example, the soil moisture is influenced much during the 4 months base period and agricultural studies must be carried with more caution. Longer periods of drought affect the ground water and river flows. In the planning of water resources these aspects should also be considered

While analyzing the different time scales of SPI values, it is observed that when the timescale increases from 4 to 24 months the drought intensity events decrease for all the stations. As observed from the results of Tables 6.169 to 6.175 for original data, gamma fitted data and best fitted (inverse Gaussian) data, one can say that the total events observed for most of the raingauge stations is almost same. But for the extreme events the number observed in case for best fitted distribution are more compared to the original and gamma fitted data. The same is observed for all the other districts too.

…sification Events (Percentages) for SPI4, SPI12 and SPI24 in Banaskantha District

Rain gauge station		…ought						Severe drought						Extreme drought						Total drought					
		SPI4		SPI12		SPI24		SPI4		SPI12		SPI24		SPI4		SPI12		SPI24		SPI4		SPI12		SPI24	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Ambaji	**O**	5	13	7	18	9	24	3	8	1	3	1	3	0	0	0	0	1	3	8	21	8	21	11	30
	G	5	13	6	16	7	19	5	13	5	13	4	11	0	0	0	0	0	0	10	26	11	29	11	30
	I	3	8	4	11	7	19	3	8	4	11	4	11	2	5	1	3	0	0	8	21	9	24	11	30
Amirgadh	**O**	6	14	6	14	5	12	1	2	1	2	2	5	0	0	0	0	1	2	7	17	7	17	8	20
	G	7	17	6	14	8	20	5	12	5	12	4	10	0	0	0	0	0	0	12	29	11	26	12	29
	I	6	14	4	10	6	15	3	7	5	12	4	10	2	5	1	2	1	2	11	26	10	24	11	27
Bapla	**O**	6	14	6	14	3	7	2	5	2	5	2	5	0	0	0	0	1	2	8	18	8	18	6	14
	G	5	11	6	14	4	9	4	9	3	7	4	9	2	5	2	5	2	5	11	25	11	25	10	23
	I	4	9	4	9	3	7	4	9	3	7	3	7	3	7	3	7	3	7	11	25	10	23	9	21
Chandisar	**O**	6	15	8	20	3	7	3	8	2	5	1	2	0	0	0	0	2	5	9	23	10	25	6	15
	G	5	13	5	13	3	7	4	10	5	13	2	5	1	3	1	3	3	7	10	25	11	28	8	20
	I	3	8	3	8	2	5	4	10	5	13	1	2	3	8	2	5	4	10	10	25	10	25	7	17
Chitrasani	**O**	4	10	5	12	2	5	2	5	2	5	3	7	1	2	1	2	2	5	7	17	8	19	7	17
	G	6	14	3	7	3	7	1	2	4	10	4	10	3	7	2	5	2	5	10	24	9	21	9	22
	I	2	5	3	7	3	7	0	0	1	2	2	5	4	10	3	7	4	10	6	14	7	17	9	22
Danta	**O**	5	11	6	13	5	11	3	7	2	4	2	4	1	2	1	2	2	4	9	20	9	20	9	20
	G	6	13	8	17	7	16	3	7	2	4	2	4	2	4	2	4	3	7	11	24	12	26	12	27
	I	5	11	5	11	7	16	1	2	3	7	1	2	4	9	3	7	4	9	10	22	11	24	12	27
Dantiwada	**O**	4	9	6	13	1	2	2	4	1	2	3	7	1	2	1	2	1	2	7	16	8	18	5	11
	G	3	7	4	9	2	5	3	7	4	9	0	0	3	7	2	4	4	9	9	20	10	22	6	14
	I	2	4	3	7	2	5	3	7	3	7	0	0	3	7	3	7	4	9	8	18	9	20	6	14
Deesa	**O**	9	19	9	19	4	9	1	2	1	2	2	4	2	4	2	4	3	6	12	25	12	25	9	19
	G	8	17	7	15	6	13	2	4	2	4	1	2	3	6	3	6	5	11	13	27	12	25	12	26
	I	7	15	6	13	6	13	2	4	3	6	1	2	3	6	3	6	5	11	12	25	12	25	12	26
Dhanera	**O**	6	13	8	17	5	11	4	8	2	4	2	4	0	0	1	2	2	4	10	21	11	23	9	19
	G	5	10	7	15	5	11	3	6	3	6	2	4	3	6	2	4	3	6	11	23	12	25	10	21
	I	4	8	4	8	4	9	1	2	1	2	1	2	4	8	4	8	4	9	9	19	9	19	9	19

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3	8	2	5	2	5	2	5	0	0	0	0	1	3	7	18	7	18	6	16
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	5	2	5	2	5	4	11	2	5	2	5	2	5	8	21	11	29	8	22
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	3	0	0	1	3	3	8	4	11	3	8	3	8	7	18	7	18	7	19
Hadad	**O**	6	15	6	15	6	15	4	10	4	10	1	3	0	0	0	0	2	5	10	24	10	24	9	23
	G	2	5	2	5	3	8	8	20	8	20	4	10	0	0	0	0	2	5	10	24	10	24	9	23
	I	2	5	2	5	2	5	7	17	6	15	5	13	1	2	2	5	2	5	10	24	10	24	9	23
Junisarotri	**O**	5	13	4	11	4	11	3	8	2	5	2	5	1	3	1	3	1	3	9	24	7	18	7	19
	G	4	11	3	8	1	3	4	11	4	11	6	16	2	5	2	5	1	3	10	26	9	24	8	22
	I	2	5	2	5	0	0	3	8	2	5	5	14	4	11	4	11	2	5	9	24	8	21	7	19
Nava	**O**	6	16	6	16	2	5	1	3	1	3	2	5	0	0	0	0	1	3	7	18	7	18	5	14
	G	4	11	5	13	2	5	4	11	4	11	2	5	1	3	1	3	3	8	9	24	10	26	7	19
	I	3	8	3	8	2	5	3	8	3	8	1	3	2	5	2	5	4	11	8	21	8	21	7	19
Palanpur	**O**	5	11	9	19	4	9	2	4	1	2	3	7	1	2	1	2	2	4	8	17	11	23	9	20
	G	7	15	7	15	4	9	5	11	5	11	4	9	1	2	1	2	2	4	13	28	13	28	10	22
	I	4	9	5	11	4	9	3	6	3	6	3	7	3	6	3	6	3	7	10	21	11	23	10	22
Panthawada	**O**	4	10	6	14	3	7	2	5	1	2	2	5	0	0	0	0	1	2	6	14	7	17	6	15
	G	6	14	6	14	4	10	1	2	3	7	2	5	2	5	1	2	2	5	9	21	10	24	8	20
	I	1	2	1	2	4	10	3	7	3	7	1	2	3	7	3	7	3	7	7	17	7	17	8	20
Sanali Ashram	**O**	7	18	6	15	3	8	2	5	2	5	1	3	1	3	1	3	2	5	10	26	9	23	6	16
	G	5	13	4	10	3	8	4	10	4	10	3	8	1	3	1	3	2	5	10	26	9	23	8	21
	I	3	8	4	10	3	8	4	10	2	5	3	8	3	8	3	8	2	5	10	26	9	23	8	21
Wadgam	**O**	6	15	9	22	3	7	2	5	1	2	2	5	0	0	0	0	1	2	8	20	10	24	6	15
	G	8	20	8	20	5	12	4	10	4	10	4	10	0	0	0	0	0	0	12	29	12	29	9	22
	I	8	20	7	17	4	10	1	2	3	7	3	7	3	7	1	2	2	5	12	29	11	27	9	22

Table 6.172 Drought Intensity Classification Events (Percentages) for SPI4, SPI12 and SPI24 in Gandhinagar District

Rain - gauge station	Type	Moderate drought						Severe drought						Extreme drought						Total drought					
		SPI4		SPI12		SPI24		SPI4		SPI12		SPI24		SPI4		SPI12		SPI24		SPI4		SPI12		SPI24	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Mansa	**O**	7	17	6	14	2	5	2	5	1	2	6	15	0	0	0	0	0	0	9	21	7	17	8	20
	G	5	12	7	17	1	2	5	12	4	10	7	17	0	0	0	0	0	0	10	24	11	26	8	20
	I	3	7	4	10	1	2	5	12	5	12	7	17	1	2	1	2	0	0	9	21	10	24	8	20
Raipur Weir	**O**	6	16	7	18	4	11	3	8	2	5	3	8	0	0	0	0	1	3	9	24	9	24	8	22
	G	5	13	3	8	4	11	5	13	6	16	4	11	0	0	0	0	1	3	10	26	9	24	9	24
	I	3	8	3	8	3	8	6	16	4	11	3	8	1	3	2	5	3	8	10	26	9	24	9	24

…sification Events (Percentages) for SPI4, SPI12 and SPI24 in Kheda District

Rain - gauge station	Type	drought						Severe drought						Extreme drought						Total drought					
		SPI4		SPI12		SPI24		SPI4		SPI12		SPI24		SPI4		SPI12		SPI24		SPI4		SPI12		SPI24	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Balasinor	**O**	5	10	8	17	9	19	4	8	2	4	1	2	0	0	0	0	0	0	9	19	10	21	10	21
	G	3	6	7	15	7	15	7	15	6	13	5	11	0	0	0	0	0	0	10	21	13	27	12	26
	I	3	6	7	15	7	15	7	15	6	13	5	11	0	0	0	0	0	0	10	21	13	27	12	26
Dakor	**O**	6	17	1	3	3	9	1	3	5	14	1	3	1	3	1	3	1	3	8	23	7	20	5	15
	G	1	3	1	3	5	15	6	17	6	17	2	6	1	3	1	3	1	3	8	23	8	23	8	24
	I	1	3	0	0	5	15	6	17	3	9	2	6	1	3	4	11	1	3	8	23	7	20	8	24
Kapadwanj	**O**	7	17	8	20	5	13	4	10	3	7	4	10	0	0	0	0	0	0	11	27	11	27	9	23
	G	7	17	7	17	3	8	6	15	5	12	7	18	0	0	0	0	0	0	13	32	12	29	10	25
	I	5	12	6	15	2	5	6	15	5	12	6	15	0	0	0	0	1	3	11	27	11	27	9	23
Kathlal	**O**	1	3	2	5	5	13	6	15	5	13	1	3	1	3	1	3	2	5	8	20	8	20	8	21
	G	2	5	4	10	4	10	7	18	5	13	3	8	1	3	2	5	2	5	10	25	11	28	9	23
	I	0	0	2	5	4	10	3	8	2	5	2	5	5	13	5	13	3	8	8	20	9	23	9	23
Kheda	**O**	5	13	5	13	6	16	3	8	3	8	3	8	0	0	0	0	0	0	8	21	8	21	9	24
	G	6	16	7	18	6	16	4	11	4	11	5	14	0	0	0	0	0	0	10	26	11	29	11	30
	I	5	13	7	18	6	16	4	11	2	5	4	11	1	3	2	5	1	3	10	26	11	29	11	30
Mahemadabad	**O**	8	19	6	14	5	12	2	5	3	7	2	5	0	0	0	0	1	2	10	24	9	21	8	20
	G	6	14	8	19	4	10	5	12	4	10	6	15	0	0	0	0	1	2	11	26	12	29	11	27
	I	5	12	5	12	3	7	4	10	5	12	6	15	2	5	1	2	1	2	11	26	11	26	10	24
Mahisa	**O**	4	10	3	8	2	5	3	8	2	5	2	5	1	3	1	3	2	5	8	21	6	15	6	16
	G	2	5	2	5	2	5	3	8	2	5	4	11	3	8	3	8	2	5	8	21	7	18	8	21
	I	2	5	1	3	2	5	2	5	2	5	3	8	4	10	3	8	3	8	8	21	6	15	8	21
Nadiad	**O**	5	13	7	18	9	24	3	8	1	3	1	3	0	0	0	0	1	3	8	21	8	21	11	30
	G	5	13	6	16	7	19	5	13	5	13	4	11	0	0	0	0	0	0	10	26	11	29	11	30
	I	3	8	4	11	7	19	3	8	4	11	4	11	2	5	1	3	0	0	8	21	9	24	11	30
Pinglaj	**O**	2	5	5	12	5	12	5	12	3	7	3	7	2	5	1	2	0	0	9	21	9	21	8	20
	G	1	2	5	12	4	10	5	12	3	7	7	17	3	7	2	5	0	0	9	21	10	24	11	27
	I	1	2	4	10	4	10	3	7	2	5	7	17	5	12	4	10	0	0	9	21	10	24	11	27
Savli tank	**O**	8	20	8	20	6	15	2	5	3	7	4	10	1	2	0	0	1	3	11	27	11	27	11	28
	G	9	22	9	22	5	13	4	10	4	10	6	15	0	0	0	0	1	3	13	32	13	32	12	30
	I	6	15	7	17	5	13	5	12	6	15	6	15	1	2	0	0	1	3	12	29	13	32	12	30

					13	2	5	1	3	3	8	4	11	2	5	0	0	1	3	7	18	8	21	7	18
					10	1	3	3	8	5	13	1	3	2	5	0	0	5	13	9	23	9	23	7	18
					8	1	3	2	5	4	10	1	3	3	8	2	5	5	13	8	21	9	23	7	18
Vaghroli tank	**O**	3	8	4	11	6	17	3	8	2	6	1	3	1	3	1	3	2	6	7	19	7	19	9	26
	G	4	11	6	17	4	11	3	8	2	6	3	9	1	3	1	3	2	6	8	22	9	25	9	26
	I	4	11	4	11	4	11	0	0	1	3	3	9	4	11	3	8	2	6	8	22	8	22	9	26

Table 6.174 Drought Intensity Classification Events (Percentages) for SPI4, SPI12 and SPI24 in Mehsana District

Rain - gauge station	Type	Moderate drought						Severe drought						Extreme drought						Total drought					
		SPI4		SPI12		SPI24		SPI4		SPI12		SPI24		SPI4		SPI12		SPI24		SPI4		SPI12		SPI24	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Ambaliyasan	**O**	4	10	6	15	4	11	4	10	3	8	2	5	0	0	0	0	1	3	8	21	9	23	7	18
	G	4	10	5	13	5	13	6	15	5	13	1	3	0	0	0	0	2	5	10	26	10	26	8	21
	I	3	8	4	10	4	11	2	5	3	8	1	3	4	10	3	8	3	8	9	23	10	26	8	21
Dharoi	**O**	6	15	9	22	4	10	3	7	1	2	3	8	0	0	0	0	1	3	9	22	10	24	8	20
	G	6	15	6	15	6	15	7	17	7	17	3	8	0	0	0	0	2	5	13	32	13	32	11	28
	I	5	12	5	12	6	15	6	15	6	15	2	5	1	2	1	2	3	8	12	29	12	29	11	28
Kadi	**O**	7	15	7	15	6	13	2	4	2	4	2	4	0	0	0	0	0	0	9	19	9	19	8	17
	G	5	11	4	9	6	13	7	15	6	13	5	11	0	0	1	2	1	2	12	26	11	23	12	26
	I	3	6	4	9	6	13	5	11	3	6	5	11	3	6	4	9	1	2	11	23	11	23	12	26
Kalol	**O**	9	19	6	13	6	13	2	4	1	2	3	6	0	0	0	0	0	0	11	23	7	15	9	19
	G	8	17	4	8	6	13	6	13	6	13	6	13	0	0	1	2	0	0	14	29	11	23	12	26
	I	8	17	4	8	6	13	6	13	5	10	5	11	0	0	2	4	1	2	14	29	11	23	12	26
Katosan	**O**	5	12	4	10	1	2	5	12	5	12	2	5	0	0	0	0	3	7	10	24	9	21	6	15
	G	6	14	4	10	4	10	5	12	6	14	1	2	1	2	1	2	4	10	12	29	11	26	9	22
	I	2	5	2	5	3	7	5	12	2	5	0	0	3	7	5	11	5	12	10	24	9	21	8	20
Kheralu	**O**	7	17	7	17	5	12	3	7	2	5	1	2	0	0	0	0	2	5	10	24	9	21	8	20
	G	4	10	6	14	2	5	6	14	6	14	5	12	0	0	0	0	1	2	10	24	12	29	8	20
	I	4	10	6	14	2	5	3	7	4	10	3	7	3	7	2	5	3	7	10	24	12	29	8	20
Mehsana	**O**	6	13	7	15	5	11	1	2	1	2	3	6	0	0	0	0	0	0	7	15	8	17	8	17
	G	4	8	5	10	3	6	4	8	3	6	5	11	2	4	2	4	2	4	10	21	10	21	10	21
	I	4	8	4	8	3	6	1	2	2	4	4	9	5	10	4	8	3	6	10	21	10	21	10	21
Ransipur	**O**	6	14	5	12	7	17	1	2	2	5	1	2	0	0	0	0	1	2	7	17	7	17	9	22
	G	4	10	4	10	3	7	5	12	4	10	6	15	1	2	1	2	1	2	10	24	9	21	10	24
	I	3	7	4	10	3	7	4	10	2	5	6	15	2	5	3	7	1	2	9	21	9	21	10	24

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5	14	3	8	3	8	3	8	1	3	1	3	1	3	7	18	8	22	9	24
Thol	G	4	11	4	11	8	22	2	5	3	8	4	11	4	11	2	5	0	0	10	26	9	24	12	32
	I	2	5	2	5	6	16	1	3	2	5	6	16	4	11	4	11	0	0	7	18	8	22	12	32
Unjha	O	5	11	6	14	4	9	3	7	1	2	1	2	0	0	1	2	2	5	8	18	8	18	7	16
	G	4	9	5	11	4	9	2	5	3	7	1	2	3	7	2	5	3	7	9	20	10	23	8	19
	I	3	7	1	2	4	9	1	2	5	11	1	2	4	9	2	5	3	7	8	18	8	18	8	19
Vijapur	O	9	21	8	19	3	7	1	2	3	7	3	7	0	0	0	0	3	7	10	24	11	26	9	22
	G	7	17	7	17	3	7	5	12	4	10	4	10	0	0	0	0	3	7	12	29	11	26	10	24
	I	5	12	2	5	2	5	6	14	9	21	4	10	0	0	0	0	3	7	11	26	11	26	9	22
Visnagar	O	9	19	8	17	4	9	0	0	0	0	2	4	0	0	0	0	0	0	9	19	8	17	6	13
	G	9	19	5	10	9	19	5	10	6	13	2	4	0	0	1	2	0	0	14	29	12	25	11	23
	I	5	10	4	8	9	19	5	10	6	13	3	6	3	6	2	4	1	2	13	27	12	25	13	28

Table 6.175 Drought Intensity Classification Events (Percentages) for SPI4, SPI12 and SPI24 in Patan District

Rain - gauge station	Type	Moderate drought						Severe drought						Extreme drought						Total drought					
		SPI4		SPI12		SPI24		SPI4		SPI12		SPI24		SPI4		SPI12		SPI24		SPI4		SPI12		SPI24	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Patan	O	7	15	8	17	2	4	3	6	3	6	4	9	0	0	0	0	0	0	10	21	11	23	6	13
	G	6	13	4	8	2	4	3	6	5	10	1	2	3	6	3	6	4	9	12	25	12	25	7	15
	I	6	13	1	2	0	0	3	6	7	15	2	4	3	6	3	6	4	9	12	25	11	23	6	13
Sidhpur	O	5	10	6	13	2	4	2	4	2	4	3	6	1	2	1	2	2	4	8	17	9	19	7	15
	G	6	13	8	17	6	13	2	4	2	4	2	4	3	6	3	6	3	6	11	23	13	27	11	23
	I	3	6	4	8	6	13	1	2	0	0	0	0	4	8	4	8	5	11	8	17	8	17	11	23
Wagdod	O	5	13	6	16	3	8	3	8	2	5	4	11	0	0	0	0	0	0	8	21	8	21	7	19
	G	6	16	7	18	2	5	3	8	3	8	3	8	1	3	1	3	3	8	10	26	11	29	8	22
	I	4	11	3	8	1	3	0	0	2	5	2	5	4	11	4	11	4	11	8	21	9	24	7	19

...sification Events (Percentages) for SPI4, SPI12 and SPI24 in Sabarkantha District

Rain - gauge Station	Type	Moderate drought						Severe drought						Extreme drought						Total drought					
		SPI4		SPI12		SPI24		SPI4		SPI12		SPI24		SPI4		SPI12		SPI24		SPI4		SPI12		SPI24	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Badoli	O	2	5	5	12	2	5	4	10	2	5	3	8	1	2	1	2	2	5	7	17	8	20	7	18
	G	2	5	5	12	3	8	5	12	5	12	2	5	2	5	1	2	3	8	9	22	11	27	8	20
	I	1	2	4	10	3	8	4	10	3	7	2	5	3	7	3	7	3	8	8	20	10	24	8	20
Bayad	O	13	28	13	28	6	13	1	2	1	2	4	9	0	0	0	0	0	0	14	30	14	30	10	22
	G	12	26	12	26	5	11	4	9	4	9	7	15	0	0	0	0	0	0	16	34	16	34	12	26
	I	9	19	11	23	4	9	6	13	5	11	8	17	0	0	0	0	0	0	15	32	16	34	12	26
Bhiloda	O	9	19	9	19	6	13	2	4	2	4	2	4	0	0	0	0	2	4	11	23	11	23	10	21
	G	7	15	9	19	8	17	5	10	4	8	3	6	0	0	0	0	2	4	12	25	13	27	13	28
	I	6	13	6	13	8	17	5	10	5	10	3	6	1	2	2	4	2	4	12	25	13	27	13	28
Dantral	O	6	15	8	21	4	11	3	8	1	3	2	5	1	3	0	0	0	0	10	26	9	23	6	16
	G	6	15	5	13	8	21	4	10	4	10	2	5	1	3	1	3	0	0	11	28	10	26	10	26
	I	5	13	4	10	8	21	2	5	2	5	0	0	4	10	3	8	2	5	11	28	9	23	10	26
Himmatnagar	O	5	13	7	18	7	18	3	8	1	3	2	5	1	3	1	3	1	3	9	23	9	23	10	26
	G	5	13	5	13	5	13	4	10	4	10	5	13	1	3	1	3	1	3	10	26	10	26	11	29
	I	4	10	5	13	5	13	2	5	3	8	5	13	3	8	2	5	1	3	9	23	10	26	11	29
Idar	O	6	14	5	12	4	10	3	7	3	7	1	2	0	0	1	2	2	5	9	21	9	21	7	17
	G	1	2	1	2	3	7	6	14	6	14	3	7	2	5	2	5	3	7	9	21	9	21	9	22
	I	1	2	1	2	3	7	3	7	4	10	3	7	5	12	4	10	3	7	9	21	9	21	9	22
Khedbrahma	O	3	7	4	10	5	12	3	7	2	5	3	7	1	2	1	2	1	2	7	17	7	17	9	22
	G	2	5	4	10	5	12	6	14	4	10	3	7	1	2	2	5	3	7	9	21	10	24	11	27
	I	1	2	2	5	4	10	4	10	3	7	3	7	3	7	3	7	3	7	8	19	8	19	10	24
Kundlacampo	O	7	17	8	19	5	12	1	2	1	2	2	5	1	2	1	2	1	2	9	21	10	24	8	20
	G	6	14	10	24	6	15	4	10	2	5	3	7	1	2	1	2	1	2	11	26	13	31	10	24
	I	5	12	9	21	5	12	3	7	2	5	4	10	2	5	2	5	1	2	10	24	13	31	10	24
Limla dam	O	8	21	8	21	3	8	2	5	2	5	3	8	0	0	0	0	1	3	10	26	10	26	7	19
	G	3	8	2	5	4	11	6	16	6	16	0	0	2	5	2	5	4	11	11	29	10	26	8	22
	I	3	8	2	5	3	8	8	21	8	21	1	3	0	0	0	0	4	11	11	29	10	26	8	22
Malpur	O	8	17	9	19	7	15	0	0	0	0	3	7	0	0	0	0	0	0	8	17	9	19	10	22
	G	11	23	8	17	5	11	3	6	5	11	6	13	0	0	0	0	0	0	14	30	13	28	11	24
	I	10	21	8	17	4	9	4	9	5	11	7	15	0	0	0	0	0	0	14	30	13	28	11	24

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13	8	17	2	4	2	4	3	6	0	0	0	0	0	0	10	21	8	17	11	23
	[illegible]	[illegible]	[illegible]	[illegible]	17	7	15	4	8	6	13	6	13	1	2	0	0	0	0	15	31	14	29	13	28
	[illegible]	[illegible]	[illegible]	[illegible]	15	6	13	4	8	5	10	7	15	2	4	2	4	0	0	15	31	14	29	13	28
Modasa	**O**	6	13	9	19	7	15	1	2	0	0	2	4	0	0	0	0	0	0	7	15	9	19	9	19
	G	8	17	9	19	6	13	4	8	4	8	6	13	0	0	0	0	0	0	12	25	13	27	12	26
	I	6	13	8	17	5	11	4	8	5	10	7	15	2	4	0	0	0	0	12	25	13	27	12	26
Pal	**O**	4	9	7	15	5	11	1	2	2	4	4	9	2	4	1	2	1	2	7	15	10	22	10	22
	G	9	19	8	17	6	13	4	9	1	2	6	13	0	0	2	4	0	0	13	28	11	24	12	27
	I	8	17	8	17	6	13	2	4	0	0	5	11	3	6	3	7	1	2	13	28	11	24	12	27
Prantij	**O**	6	14	6	14	3	7	4	10	3	7	3	7	0	0	0	0	1	2	10	24	9	21	7	17
	G	4	10	6	14	3	7	6	14	5	12	7	17	0	0	0	0	0	0	10	24	11	26	10	24
	I	4	10	3	7	3	7	4	10	5	12	3	7	2	5	2	5	4	10	10	24	10	24	10	24
Sabli	**O**	6	17	5	14	2	6	2	6	2	6	0	0	1	3	2	6	2	6	9	25	9	25	4	11
	G	5	14	5	14	2	6	4	11	3	8	2	6	1	3	2	6	2	6	10	28	10	28	6	17
	I	3	8	4	11	2	6	4	11	3	8	0	0	2	6	2	6	4	11	9	25	9	25	6	17
Shamlaji	**O**	5	12	7	17	2	5	2	5	1	2	2	5	1	2	1	2	2	5	8	19	9	21	6	15
	G	9	21	9	21	4	10	1	2	2	5	4	10	3	7	2	5	2	5	13	31	13	31	10	24
	I	5	12	6	14	3	7	1	2	2	5	2	5	3	7	2	5	4	10	9	21	10	24	9	22
Vadgam	**O**	11	23	10	21	4	9	1	2	0	0	5	11	0	0	0	0	0	0	12	25	10	21	9	19
	G	7	15	6	13	4	9	5	10	6	13	7	15	0	0	0	0	0	0	12	25	12	25	11	23
	I	5	10	6	13	3	6	7	15	6	13	3	6	0	0	0	0	4	9	12	25	12	25	10	21
Vijaynagar	**O**	8	19	8	19	5	12	1	2	1	2	1	2	2	5	2	5	3	7	11	26	11	26	9	22
	G	7	17	7	17	7	17	2	5	2	5	2	5	2	5	2	5	3	7	11	26	11	26	12	29
	I	7	17	7	17	7	17	1	2	1	2	2	5	3	7	3	7	3	7	11	26	11	26	12	29
Virpur	**O**	8	21	7	18	1	3	2	5	2	5	4	11	0	0	0	0	2	5	10	26	9	24	7	19
	G	8	21	9	24	2	5	6	16	5	13	5	14	0	0	0	0	2	5	14	37	14	37	9	24
	I	6	16	8	21	1	3	6	16	5	13	4	11	0	0	0	0	3	8	12	32	13	34	8	22

s in number observed for moderate, severe and hree types of data analyzed. As one already knows that any statistical data are rarely following normal distribution and the commonly used gamma distribution is not the best fitted one for the present data analyzed, thus the discussion related to the results obtained based on inverse Gaussian distribution is dealt with.

The most obvious characteristics of the drought events observed in all the Figures are that drought category changes as the time scale changes. At longer time scales drought becomes less frequent and of longer duration. For all the stations it is observed that the total drought events are more than 20% for the period under study. Thus based on SPI analysis the area can be categorized as drought affected according to the IMD classification. Observing the moderate, severe and extreme drought events the most frequently affected years observing all the 73 raingauge stations is presented in Fig. 6.151.

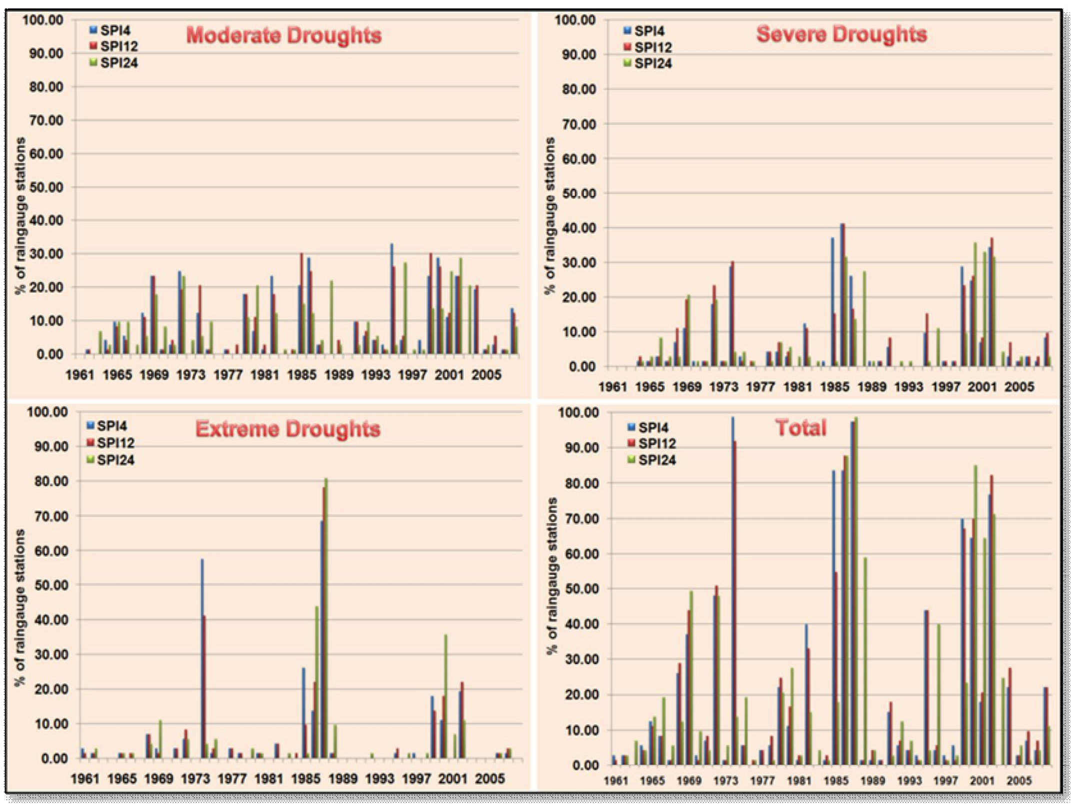

Fig. 6.151 Percentage of raingauge stations experiencing drought in north Gujarat agroclimatic zone during the study period (1961 to 2008)

say that the year 1987 observed extreme drought out of 73) raingauge stations for SPI24 which is the highest. Observing the moderate, severe and extreme drought events for all the 73 raingauge stations, years 1974, 1985 to 1988 and 1999 to 2002 are the most droughts affected one. The frequency of extreme drought is higher for all over north Gujarat agroclimatic zone. One can observe that almost every year with only few exceptions the region experiences drought of different magnitudes and time scales.

The study carried out by Gore and Sinha Ray (2002), using aridity index for drought classification for Gujarat state for the period of 1901 to 1999, is in accordance with the findings obtained by using the modified SPI classification. Aridity index used by the authors categorized 27 drought years as worst droughts when the area affected by it exceeded 50% of the total area. For the period from 1961 to 1999, the years 1962, 1966, 1968, 1972, 1974, 1982, 1985, 1986, 1987, 1991, 1995 and 1999 are the worst droughts mentioned. Similar results are obtained using SPI too for the present study region.

The above results obtained can also be confirmed by the study carried out by Chopra (2006). The author stated that the drought of 1987 was one of the worst in the century. The monsoon rainfall was normal only in 14 out of 35 meteorological subï division in the country (India). Also Gujarat was one such state where drought occurred with unfailing regularity. All India and Gujarat state drought years were analysed and presented in Table 6.177 referring the study by Gore and Ponkshe (2004). In addition, drought index results agree with the historical record for the duration of drought (12ï 24 month) with some exceptions.

Table 6.177 All India and Gujarat State Drought Years Analyzed by Gore and Ponkshe (2004)

1961-1970	**1971-1980**	**1981-1990**	**1991-2000**
Gujarat state			
1962, 1963, 1965, 1966,1968	1972, 1973, 1974	1982, 1985, 1986, 1987, 1990	1991, 1993, 1995, 1998, 1999
All India			
1965, 1966, 1968	1972, 1974, 1979	1982, 1987	

concludes that the inverse Gaussian distribution is ta in the study area for different time scales of 4, 12 and 24 months. The total drought events are nearly same for gamma and best fitted distribution. The original data gives less drought events compared to the gamma and inverse Gaussian distributions. It can be concluded that inverse Gaussian can be used for further studies for classifying the drought intensities for the region. Further the area is drought prone as more than 20% years the drought is experienced during the study period from 1961 to 2008. The SPI values show that when time scale increases drought occurs less frequently but has longer duration. Also when the time scale is short the shift between positive and negative values are seen more frequently and when the time scale increases it is observed that the SPI values respond to the varying precipitation conditions slower.

In a nutshell drought analysis carried out by the standardized precipitation index is vital for the study area experiencing frequent drought events.

6.9 Crop Planning for Rainfed Agriculture

6.9.1 Climate classification

Climate classification analysis is carried out for the five climate stations and analysed for crop planning. The distribution of these 5 climate stations among the 73 raingauge stations are performed using Theissen polygon method. Table 6.178 represents the moisture availability index (MAI) for monsoon season (June to September). Based on the climate classification the MAI for all the years is is greater than or equal to 1.33 for atleast 1 or 2 months. Thus the cilmate is either arid or somewhat wet (as per Table 5.11). The MAI values are satisfactory for crop production for two months in a year i.e. July and August receiving major amount of total rainfall. The same was supported by the climate data analysis presented in section 6.4.

ification Based on MAI for North Gujarat

Sr. No.	Name of raingauge station	MAI				Climate classification
		June	July	August	September	
1	Aslali	0.17	1.39	1.35	0.13	Somewhat wet
2	Bareja	0.28	1.41	1.56	0.14	Somewhat wet
3	Barejadi	0.24	1.40	1.68	0.07	Somewhat wet
4	Chandola	0.23	1.67	1.27	0.04	Somewhat wet
5	Dehgam	0.21	1.39	0.97	0.08	Somewhat wet
6	Nal Lake	0.11	0.87	0.61	0.00	Arid
7	Sanand	0.32	1.36	0.98	0.17	Somewhat wet
8	Vasai	0.18	1.35	1.22	0.12	Somewhat wet
9	Ambaji	0.22	1.18	0.82	0.19	Arid
10	Amirgadh	0.17	1.20	0.86	0.10	Arid
11	Bapla	0.05	0.89	0.62	0.08	Arid
12	Chandisar	0.02	0.79	0.73	0.04	Arid
13	Chitrasani	0.13	1.01	0.67	0.16	Arid
14	Danta	0.07	1.52	1.18	0.13	Somewhat wet
15	Dantiwada	0.03	0.88	0.67	0.05	Arid
16	Deesa	0.07	0.83	0.50	0.11	Arid
17	Dhanera	0.06	0.60	0.52	0.10	Arid
18	Gadh	0.09	0.88	0.58	0.04	Arid
19	Hadad	0.09	1.18	1.03	0.17	Arid
20	Junisarotri	0.01	1.59	0.58	0.17	Somewhat wet
21	Nava	0.06	0.62	0.50	0.00	Arid
22	Palanpur	0.13	1.27	0.72	0.21	Arid
23	Panthawada	0.02	0.90	0.48	0.00	Arid
24	Sanali Ashram	0.10	1.10	0.84	0.19	Arid
25	Wadgam	0.16	1.16	0.71	0.15	Arid
26	Mansa	0.12	1.40	1.15	0.05	Somewhat wet
27	Raipurweir	0.19	1.43	1.33	0.05	Somewhat wet
28	Balasinor	0.22	1.20	0.94	0.13	Arid
29	Dakor	0.25	1.03	1.66	0.00	Somewhat wet
30	Kapadwanj	0.15	1.92	1.41	0.17	Somewhat wet
31	Kathlal	0.04	1.00	1.09	0.03	Arid
32	Kheda	0.14	1.49	1.84	0.07	Somewhat wet
33	Mahemdabad	0.37	1.15	1.29	0.18	Arid
34	Mahisa	0.14	1.16	1.30	0.01	Arid
35	Nadiad	0.29	1.05	1.20	0.08	Arid
36	Pinglaj	0.07	1.14	1.35	0.20	Somewhat wet
37	Savli tank	0.19	1.19	0.96	0.00	Arid
38	Vadol	0.09	0.93	1.12	0.13	Arid
39	Vaghroli Tank	0.33	1.24	1.28	0.12	Arid
40	Ambaliyasan	0.13	1.11	0.91	0.10	Arid
41	Dharoi	0.26	1.41	1.15	0.15	Somewhat wet
42	Kadi	0.28	1.47	0.96	0.10	Somewhat wet
43	Kalol	0.14	1.59	0.97	0.08	Somewhat wet
44	Katosan	0.18	1.08	0.45	0.00	Arid
45	Kheralu	0.13	0.99	1.06	0.15	Arid
46	Mehsana	0.11	1.14	0.94	0.05	Arid
47	Ransipur	0.13	1.10	0.96	0.07	Arid
48	Thol	0.08	0.79	0.92	0.00	Arid
49	Unjha	0.00	1.10	0.44	0.00	Arid
50	Vijapur	0.22	1.25	1.08	0.11	Arid
51	Visnagar	0.21	1.03	0.61	0.08	Arid

[illegible]	[illegible]	0.04	0.57	0.43	0.05	Arid
[illegible]	[illegible]	0.10	1.02	0.74	0.01	Arid
[illegible]	[illegible]	0.06	0.59	0.41	0.00	Arid
55	Badoli	0.14	1.40	1.27	0.26	Somewhat wet
56	Bayad	0.31	1.47	1.35	0.20	Somewhat wet
57	Bhiloda	0.35	1.86	1.79	0.39	Somewhat wet
58	Dantral	0.25	1.22	1.16	0.04	Arid
59	Himatnagar	0.15	1.29	1.06	0.13	Arid
60	Idar	0.35	1.30	1.26	0.22	Arid
61	Khedbrahma	0.15	1.34	1.35	0.31	Somewhat wet
62	Kundlacampo	0.19	1.69	1.48	0.15	Somewhat wet
63	Limla dam	0.08	1.38	0.98	0.08	Somewhat wet
64	Malpur	0.28	1.25	1.41	0.16	Somewhat wet
65	Meghraj	0.22	1.44	1.32	0.16	Somewhat wet
66	Modasa	0.35	1.12	1.25	0.24	Arid
67	Pal	0.18	1.33	1.29	0.27	Arid
68	Prantij	0.22	1.56	1.26	0.07	Somewhat wet
69	Sabli	0.09	1.07	1.15	0.04	Arid
70	Shamlaji	0.20	1.50	1.66	0.18	Somewhat wet
71	Vadgam	0.15	1.08	1.02	0.05	Arid
72	Vijaynagar	0.26	1.53	1.37	0.08	Somewhat wet
73	Virpur	0.13	1.27	1.17	0.13	Arid

If one analyzes the climate in the region, it is mostly arid except few stations observing somewhat wet climate. 29 out of 73 stations observed somewhat wet climate. Most of these stations are situated in Ahmedabad and Sabarkantha districts, which are situated at the southern and south east portions of the region. Therefore one can conclude that the region is experiencing two types of climate. The arid climate is experienced mostly over the region baring certain areas of southern and south east portions experiencing somewhat wet climate.

Arid climate has limited suitability for rainfed agriculture, which has to be therefore planned for optimum utilization of rainfall. Somewhat wet climate requires natural or artificial drainage for good production. It can be said that though the raingauge stations are situated in one agroclimatic zone, two different types of climate are observed.

6.9.2 Dry Spell

Markov chain model is investigated for predicting the behaviour of dry spells for the monsoon season. The fitted model is used to estimate the risk of long dry spell lengths. Data of 73 raingauge stations are analyzed and the probability of dry spell is obtained. According to IMD classification, a day with fall is considered to be a rainy day. Table 6.179 rainy days observed during the period from 1961 to 2008 for 73 raingauges in the region.

Table 6.179 Details of Rainy Days Observed from 1961 to 2008 for 73 Raingauges in the North Gujarat Agroclimatic Zone

Sr. No.	Station	Rainy Days			% of Wet Days
		Maximum	Minimum	Average	
1	Aslali	50	6	27	22.13
2	Bareja	48	7	29	23.77
3	Barejadi	44	7	27	22.13
4	Chandola	44	9	26	21.31
5	Dehgam	54	9	27	22.13
6	Sanand	39	7	26	21.31
7	Nal Lake	34	6	21	17.21
8	Vasai	49	10	27	22.13
9	Ambaji	67	13	32	26.23
10	amirgadh	49	10	25	20.49
11	Bapla	43	3	19	15.57
12	Chandisar	45	5	22	18.03
13	Chitrasani	50	1	25	20.49
14	Danta	62	9	31	25.41
15	Dantiwada	43	2	21	17.21
16	Deesa	48	6	22	18.03
17	Dhanera	38	1	19	15.57
18	Gadh	44	2	23	18.85
19	Hadad	56	10	29	23.77
20	Junisarotri	51	11	26	21.31
21	Nava	41	2	20	16.39
22	Palanpur	56	5	26	21.31
23	Panthawada	43	3	20	16.39
24	Sanali Ashram	48	8	27	22.13
25	Wadgam	55	8	26	21.31
26	mansa	49	8	26	21.31
27	Raipur weir	43	9	24	19.67
28	Balasinor	57	11	30	24.59
29	Dakor	50	3	27	22.13
30	Kapadwanj	52	7	29	23.77
31	Kathlal	50	6	26	21.31
32	Kheda	53	8	30	24.59
33	Mahemdabad	49	12	29	23.77
34	Mahisa	48	4	27	22.13
35	Nadiad	54	7	31	25.41
36	Pinglaj	54	8	26	21.31
37	Savli tank	44	6	25	20.49
38	Vadol	48	11	26	21.31
39	Vaghroli Tank	54	10	29	23.77
40	Ambaliyasan	46	6	25	20.49
41	Kalol	53	10	27	22.13
42	Dharoi	55	12	29	23.77
43	Kadi	46	11	26	21.31
44	Katosan	41	5	21	17.21
45	Kheralu	51	8	28	22.95

[illegible]	[illegible]	63	5	26	21.31
[illegible]	[illegible]	65	10	26	21.31
[illegible]	[illegible]	44	2	21	17.21
49	Unjha	38	3	17	13.93
50	Vijapur	47	11	27	22.13
51	Visanagar	50	4	26	21.31
52	Patan	42	6	22	18.03
53	Sidhpur	53	9	25	20.49
54	Wagdod	41	6	18	14.75
55	Badoli	53	11	30	24.59
56	Bayad	49	12	30	24.59
57	Bhiloda	56	15	33	27.05
58	Dantral	55	7	31	25.41
59	Himmatnagar	48	10	29	23.77
60	Idar	58	12	32	26.23
61	Khedbhrama	51	10	31	25.41
62	Kundlacampo	61	16	37	30.33
63	Limla dam	46	11	26	21.31
64	Malpur	51	15	30	24.59
65	Meghraj	55	14	32	26.23
66	Modasa	52	14	31	25.41
67	Pal	56	8	32	26.23
68	Prantij	50	10	30	24.59
69	Sabli	52	14	29	23.77
70	Shamlaji	64	4	32	26.23
71	Vadgam	52	13	28	22.95
72	Vijaynagar	64	4	33	27.05
73	Virpur	49	13	28	22.95

The percentage of wet days is calculated considering 122 days (June to September) of monsoon season. It is observed that the percentage of wet days ranges from 13.93 to 30.33 i.e. corresponding to 17 and 37 days respectively. The lowest value is observed at Unjha and highest at Kundlacampo.

Analysis of 48 years of rainfall showing the fitted probability of an event in case of zero, first and second orders of Markov chain from 15th June to 14th October is presented in Table 6.180. From Table 6.180 one can say that the highest probability of a day being wet is 36% for the period from 30th July to 6th August (day 212 to 219). The highest probability of a day being wet given the previous day is wet (Rain & Rain) is 62% for the period from 12th July to 22nd July (day 194 to 204). The highest probability of a day being wet given the previous two days are wet (Rain, Rain & Rain) is 63% from 19th June to 23rd June (161 to 175). Thus as the order of the Markov chain increases the probability also increases. In case of zero order as it does not depend on any ility is less compared to the first and second order onsideration increases the probability value.

The probability of day being dry is one minus the probability of day being wet. Thus for period having 36% probability of wet has 64% probability of day being dry. Similarly from the probability of day being wet given the previous day being dry is obtained as one minus the probability of day being dry given the previous day is wet and so on for third order results.

Table 6.180 Fitted Probability of Occurrence of Event from 15th June to 14th October for Aslali, Ahmedabad District, with 2.5 mm Threshold Value

Date	Probability of occurrence of an event						
	Zero order	First order		Second order			
	Rain	Rain & dry	Rain & rain	Rain, dry & dry	Rain, dry & rain	Rain, rain & dry	Rain, rain & rain
15-Jun	0.09	0.06	0.29	0.05	0.08	0.30	0.62
16-Jun	0.09	0.06	0.31	0.06	0.08	0.32	0.62
17-Jun	0.09	0.07	0.32	0.06	0.09	0.33	0.62
18-Jun	0.10	0.07	0.34	0.06	0.10	0.35	0.62
19-Jun	0.11	0.07	0.36	0.06	0.11	0.36	0.63
20-Jun	0.11	0.08	0.37	0.07	0.12	0.38	0.63
21-Jun	0.12	0.08	0.39	0.07	0.13	0.39	0.63
22-Jun	0.12	0.08	0.40	0.07	0.14	0.41	0.63
23-Jun	0.13	0.09	0.42	0.08	0.15	0.42	0.63
24-Jun	0.14	0.09	0.44	0.08	0.16	0.44	0.62
25-Jun	0.14	0.09	0.45	0.08	0.17	0.45	0.62
26-Jun	0.15	0.10	0.47	0.08	0.18	0.47	0.62
27-Jun	0.16	0.10	0.48	0.09	0.19	0.48	0.62
28-Jun	0.16	0.11	0.50	0.09	0.20	0.50	0.62
29-Jun	0.17	0.11	0.51	0.10	0.21	0.51	0.62
30-Jun	0.18	0.12	0.52	0.10	0.22	0.52	0.62
1-Jul	0.19	0.12	0.54	0.10	0.23	0.53	0.61
2-Jul	0.19	0.12	0.55	0.11	0.24	0.54	0.61
3-Jul	0.20	0.13	0.56	0.11	0.25	0.55	0.61
4-Jul	0.21	0.13	0.57	0.11	0.26	0.56	0.61
5-Jul	0.22	0.14	0.58	0.12	0.27	0.57	0.61
6-Jul	0.23	0.14	0.59	0.12	0.28	0.58	0.60
7-Jul	0.23	0.15	0.59	0.12	0.29	0.59	0.60
8-Jul	0.24	0.15	0.60	0.13	0.30	0.59	0.60
9-Jul	0.25	0.15	0.60	0.13	0.31	0.60	0.60
10-Jul	0.26	0.16	0.61	0.14	0.32	0.61	0.59
11-Jul	0.26	0.16	0.61	0.14	0.32	0.61	0.59
12-Jul	0.27	0.17	0.62	0.14	0.33	0.61	0.59
13-Jul	0.28	0.17	0.62	0.15	0.34	0.62	0.59
14-Jul	0.29	0.17	0.62	0.15	0.34	0.62	0.58
15-Jul	0.29	0.18	0.62	0.15	0.35	0.62	0.58
16-Jul	0.30	0.18	0.62	0.16	0.36	0.62	0.58
17-Jul	0.31	0.19	0.62	0.16	0.36	0.62	0.58

[illegible]	[illegible]	[illegible]	0.62	0.16	0.36	0.62	0.57
[illegible]	[illegible]	[illegible]	0.62	0.16	0.37	0.62	0.57
[illegible]	[illegible]	[illegible]	0.62	0.17	0.37	0.62	0.57
21-Jul	0.33	0.20	0.62	0.17	0.38	0.62	0.57
22-Jul	0.33	0.20	0.62	0.17	0.38	0.62	0.57
23-Jul	0.34	0.20	0.61	0.17	0.38	0.62	0.56
24-Jul	0.34	0.20	0.61	0.17	0.38	0.62	0.56
25-Jul	0.34	0.21	0.61	0.18	0.39	0.61	0.56
26-Jul	0.35	0.21	0.60	0.18	0.39	0.61	0.56
27-Jul	0.35	0.21	0.60	0.18	0.39	0.61	0.56
28-Jul	0.35	0.21	0.60	0.18	0.39	0.60	0.56
29-Jul	0.35	0.21	0.59	0.18	0.39	0.60	0.55
30-Jul	0.36	0.21	0.59	0.18	0.39	0.60	0.55
31-Jul	0.36	0.21	0.58	0.18	0.39	0.59	0.55
1-Aug	0.36	0.21	0.58	0.18	0.39	0.59	0.55
2-Aug	0.36	0.21	0.57	0.18	0.38	0.58	0.55
3-Aug	0.36	0.21	0.57	0.18	0.38	0.58	0.55
4-Aug	0.36	0.21	0.56	0.18	0.38	0.58	0.55
5-Aug	0.36	0.21	0.56	0.18	0.38	0.57	0.55
6-Aug	0.36	0.21	0.56	0.18	0.38	0.57	0.55
7-Aug	0.35	0.20	0.55	0.17	0.37	0.57	0.55
8-Aug	0.35	0.20	0.55	0.17	0.37	0.56	0.55
9-Aug	0.35	0.20	0.54	0.17	0.37	0.56	0.55
10-Aug	0.35	0.20	0.54	0.17	0.36	0.55	0.55
11-Aug	0.34	0.19	0.54	0.17	0.36	0.55	0.55
12-Aug	0.34	0.19	0.53	0.16	0.36	0.55	0.55
13-Aug	0.34	0.19	0.53	0.16	0.35	0.54	0.55
14-Aug	0.33	0.19	0.53	0.16	0.35	0.54	0.55
15-Aug	0.33	0.18	0.53	0.16	0.34	0.54	0.55
16-Aug	0.32	0.18	0.53	0.15	0.34	0.54	0.56
17-Aug	0.32	0.17	0.52	0.15	0.33	0.54	0.56
18-Aug	0.31	0.17	0.52	0.15	0.33	0.53	0.56
19-Aug	0.30	0.17	0.52	0.14	0.32	0.53	0.56
20-Aug	0.30	0.16	0.52	0.14	0.32	0.53	0.56
21-Aug	0.29	0.16	0.52	0.14	0.31	0.53	0.56
22-Aug	0.28	0.15	0.52	0.13	0.31	0.53	0.56
23-Aug	0.28	0.15	0.52	0.13	0.30	0.53	0.56
24-Aug	0.27	0.15	0.52	0.12	0.30	0.53	0.57
25-Aug	0.26	0.14	0.52	0.12	0.29	0.52	0.57
26-Aug	0.25	0.14	0.53	0.12	0.29	0.52	0.57
27-Aug	0.25	0.13	0.53	0.11	0.28	0.52	0.57
28-Aug	0.24	0.13	0.53	0.11	0.28	0.52	0.57
29-Aug	0.23	0.12	0.53	0.11	0.27	0.52	0.57
30-Aug	0.22	0.12	0.53	0.10	0.26	0.52	0.57
31-Aug	0.22	0.11	0.53	0.10	0.26	0.52	0.58
1-Sep	0.21	0.11	0.54	0.09	0.25	0.52	0.58
2-Sep	0.20	0.11	0.54	0.09	0.25	0.52	0.58
3-Sep	0.19	0.10	0.54	0.09	0.24	0.52	0.58
4-Sep	0.18	0.10	0.54	0.08	0.24	0.52	0.58
5-Sep	0.18	0.09	0.55	0.08	0.23	0.52	0.58
6-Sep	0.17	0.09	0.55	0.08	0.23	0.52	0.58
7-Sep	0.16	0.09	0.55	0.07	0.22	0.52	0.58
8-Sep	0.15	0.08	0.55	0.07	0.22	0.52	0.58
9-Sep	0.15	0.08	0.55	0.07	0.21	0.51	0.58
10-Sep	0.14	0.07	0.55	0.06	0.21	0.51	0.58
11-Sep	0.13	0.07	0.55	0.06	0.20	0.51	0.58

[illegible]	[illegible]	[illegible]	0.55	0.06	0.20	0.51	0.58
[illegible]	[illegible]	[illegible]	0.55	0.06	0.19	0.50	0.58
[illegible]	[illegible]	[illegible]	0.55	0.05	0.19	0.50	0.58
15-Sep	0.11	0.06	0.55	0.05	0.18	0.50	0.58
16-Sep	0.10	0.06	0.55	0.05	0.18	0.49	0.58
17-Sep	0.10	0.05	0.55	0.05	0.17	0.49	0.58
18-Sep	0.09	0.05	0.54	0.04	0.17	0.48	0.58
19-Sep	0.09	0.05	0.54	0.04	0.16	0.47	0.57
20-Sep	0.08	0.05	0.54	0.04	0.16	0.47	0.57
21-Sep	0.08	0.04	0.53	0.04	0.15	0.46	0.57
22-Sep	0.07	0.04	0.53	0.04	0.15	0.45	0.56
23-Sep	0.07	0.04	0.52	0.03	0.15	0.45	0.56
24-Sep	0.07	0.04	0.51	0.03	0.14	0.44	0.56
25-Sep	0.06	0.04	0.50	0.03	0.14	0.43	0.55
26-Sep	0.06	0.03	0.49	0.03	0.13	0.42	0.55
27-Sep	0.06	0.03	0.48	0.03	0.13	0.41	0.54
28-Sep	0.05	0.03	0.47	0.03	0.13	0.40	0.54
29-Sep	0.05	0.03	0.46	0.02	0.12	0.39	0.53
30-Sep	0.05	0.03	0.45	0.02	0.12	0.37	0.52
1-Oct	0.04	0.03	0.44	0.02	0.11	0.36	0.51
2-Oct	0.04	0.02	0.42	0.02	0.11	0.35	0.51
3-Oct	0.04	0.02	0.41	0.02	0.11	0.34	0.50
4-Oct	0.04	0.02	0.39	0.02	0.10	0.33	0.49
5-Oct	0.03	0.02	0.38	0.02	0.10	0.31	0.48
6-Oct	0.03	0.02	0.36	0.02	0.10	0.30	0.47
7-Oct	0.03	0.02	0.35	0.02	0.09	0.29	0.46
8-Oct	0.03	0.02	0.33	0.02	0.09	0.28	0.45
9-Oct	0.03	0.02	0.31	0.02	0.09	0.27	0.44
10-Oct	0.03	0.02	0.30	0.01	0.08	0.25	0.42
11-Oct	0.02	0.02	0.28	0.01	0.08	0.24	0.41
12-Oct	0.02	0.02	0.26	0.01	0.08	0.23	0.40
13-Oct	0.02	0.01	0.25	0.01	0.07	0.22	0.39
14-Oct	0.02	0.01	0.23	0.01	0.07	0.21	0.37

The three different orders of Markov chain models are evaluated based on the AIC & BIC as calculated using the Eqs. 5.2 & 5.4. The fitted model consists of 8 parameters in case of zero order, and 6 each in case of first and second order. Table 6.181 depicts the results obtained. The sample size (N) is 366 as daily probabilities are calculated considering the 29th February.

Table 6.181 AIC and BIC Values for Model Fit

Sr. No.	Model order	RSS	N	k	AIC	BIC
1	Zero	0.44	366	5	-1409.75	-2417.01
2	First	0.75	366	5	-1262.37	-2277.43
3	Second	0.68	366	6	-1253.25	-2268.31

…on with Akaike Weights

		Δi	Exp(-0.5 x Δi)	Weight
1	Zero	0.00 $\{=\lvert -1409.75-(-1409.75)\rvert\ \}$	1.00	1.00
2	First	147.38 $\{=\lvert -1409.75-(-1262.37)\rvert\ \}$	0.00	0.00
3	Second	156.50 $\{=\lvert -1409.75-(-1253.25)\rvert\ \}$	0.00	0.00
			Sum = 1.00	

The AIC and the BIC values in case of zero order model are less compared to first and second orders. Further applying Akaike weights as depicted in Table 6.182 for selection between models; zero order is 100 times better than the first and second orders. Based on the AIC and BIC values zero order model is the best fitted one and therefore considered for further analysis. Fig. 6.152 shows the model fit for zero order Markov chain. Fig. 6.153 depicts the dry spell length for 7 to 14 days using 2.5 mm of threshold value.

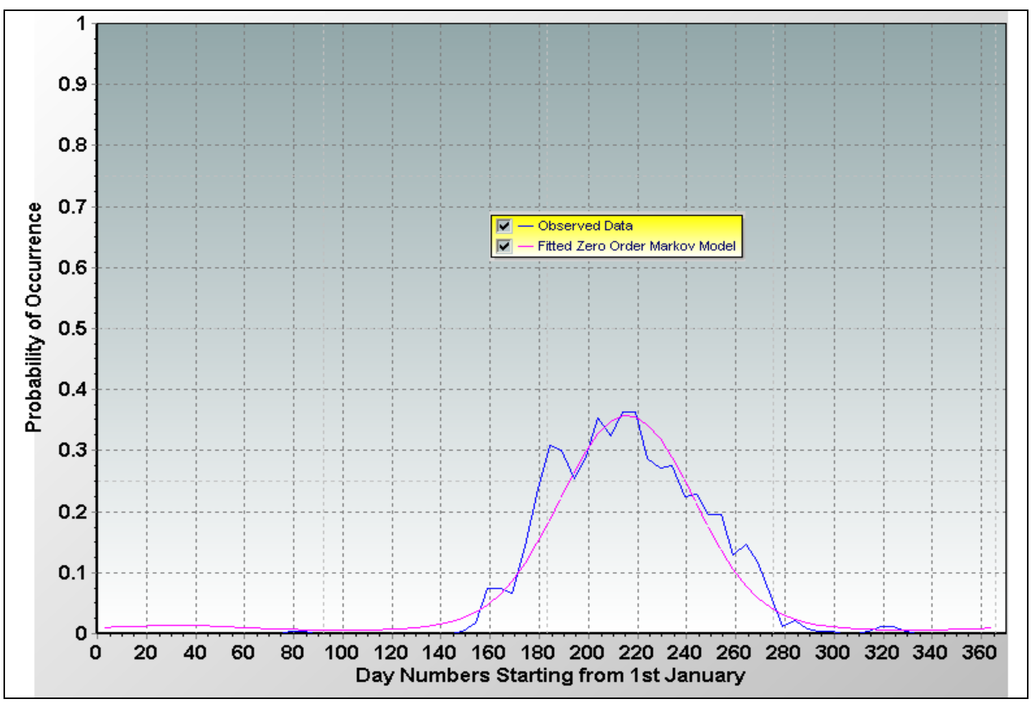

FIG. 6.152 Zero order Markov model fitted to rain event with 2.5 mm threshold rainfall

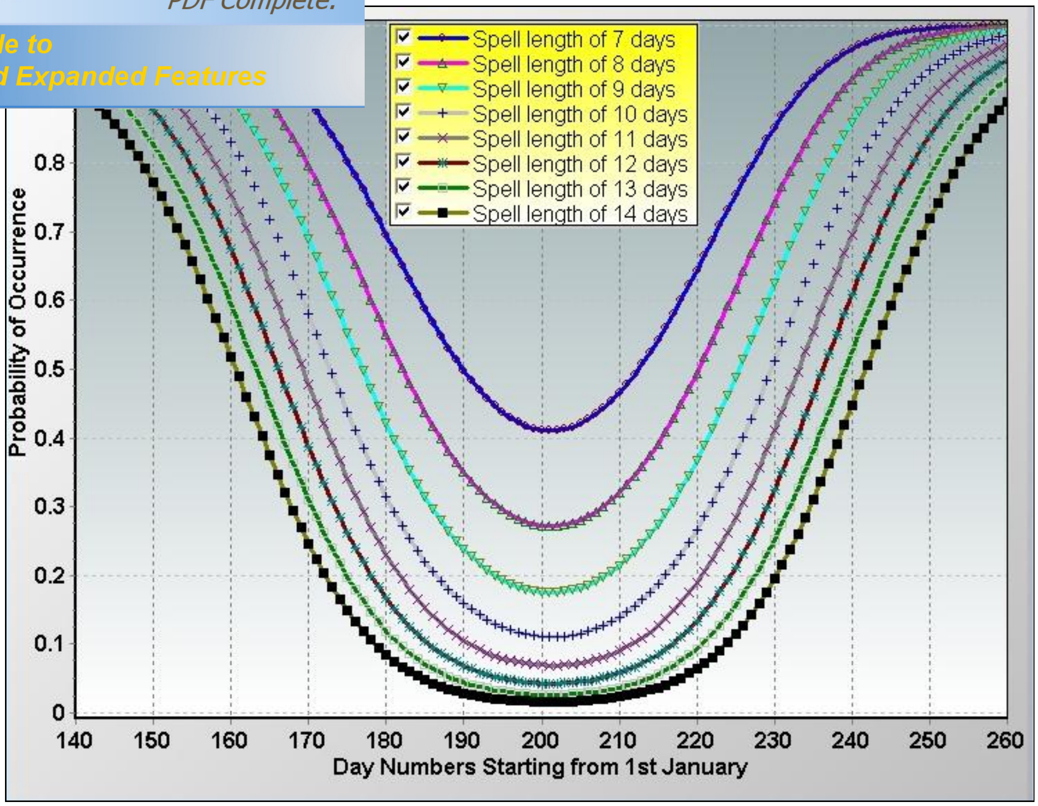

Fig. 6.153 Probability of dry spell length of 7 to 14 days using zero order Markov model with 2.5 mm threshold rainfall

The spell lengths of 7 to 14 days over periods of 30 days are calculated & given in Table 6.153. The results show that the probability of a dry spell of 7 days, within the 30 days following sowing, has dropped to 0.5 by 7th July (day 189). Similarly, for a dry spell of 10 days within the 30 days following sowing, has dropped to 0.5 by 20th June (day 172). For a dry spell of 14 days within the 30 days following sowing, has dropped to 0.5 by 14th June (day 166). This information in correlation with the onset dates will be most important for agricultural planning.

Similar analysis is carried out for threshold value of 8 mm in view for agricultural planning. Table 6.183 presents the probabilities for zero, first and second order Markov models. Fig. 6.154 shows the model fit for zero order Markov chain.

lity of Occurrence of the Event from 15th June to
edabad District, with 8 mm Threshold Value

	robability of occurrence of an event						
Date	Zero order	First order		Second order			
	rain	Rain & dry	Rain & rain	Rain, dry & dry	Rain, dry & rain	Rain, rain & dry	Rain, rain & rain
15-Jun	0.05	0.04	0.26	0.02	0.21	0.41	0.60
16-Jun	0.06	0.04	0.27	0.03	0.22	0.41	0.59
17-Jun	0.06	0.04	0.28	0.03	0.22	0.41	0.59
18-Jun	0.07	0.05	0.29	0.03	0.23	0.40	0.58
19-Jun	0.07	0.05	0.31	0.03	0.23	0.40	0.58
20-Jun	0.07	0.05	0.32	0.03	0.23	0.40	0.57
21-Jun	0.08	0.05	0.33	0.03	0.24	0.40	0.57
22-Jun	0.08	0.06	0.34	0.04	0.24	0.40	0.56
23-Jun	0.09	0.06	0.36	0.04	0.24	0.40	0.56
24-Jun	0.09	0.06	0.37	0.04	0.25	0.40	0.55
25-Jun	0.10	0.07	0.38	0.04	0.25	0.40	0.54
26-Jun	0.10	0.07	0.39	0.05	0.25	0.40	0.54
27-Jun	0.11	0.08	0.41	0.05	0.25	0.40	0.53
28-Jun	0.11	0.08	0.42	0.05	0.26	0.40	0.53
29-Jun	0.12	0.08	0.43	0.05	0.26	0.40	0.52
30-Jun	0.13	0.09	0.44	0.06	0.26	0.40	0.51
1-Jul	0.13	0.09	0.45	0.06	0.26	0.41	0.51
2-Jul	0.14	0.10	0.46	0.06	0.26	0.41	0.50
3-Jul	0.15	0.10	0.47	0.07	0.26	0.41	0.50
4-Jul	0.15	0.11	0.48	0.07	0.26	0.41	0.49
5-Jul	0.16	0.11	0.48	0.08	0.26	0.42	0.48
6-Jul	0.17	0.12	0.49	0.08	0.26	0.42	0.48
7-Jul	0.18	0.12	0.50	0.08	0.26	0.42	0.47
8-Jul	0.18	0.13	0.50	0.09	0.26	0.43	0.47
9-Jul	0.19	0.13	0.51	0.09	0.26	0.43	0.46
10-Jul	0.20	0.14	0.51	0.10	0.26	0.44	0.46
11-Jul	0.20	0.14	0.51	0.10	0.26	0.44	0.45
12-Jul	0.21	0.15	0.52	0.10	0.26	0.44	0.45
13-Jul	0.22	0.15	0.52	0.11	0.26	0.45	0.44
14-Jul	0.23	0.16	0.52	0.11	0.26	0.45	0.44
15-Jul	0.23	0.16	0.52	0.12	0.26	0.46	0.43
16-Jul	0.24	0.17	0.52	0.12	0.25	0.46	0.43
17-Jul	0.25	0.17	0.52	0.12	0.25	0.46	0.42
18-Jul	0.25	0.18	0.51	0.13	0.25	0.47	0.42
19-Jul	0.26	0.18	0.51	0.13	0.25	0.47	0.42
20-Jul	0.26	0.19	0.51	0.14	0.25	0.48	0.41
21-Jul	0.27	0.19	0.51	0.14	0.25	0.48	0.41
22-Jul	0.27	0.19	0.50	0.14	0.25	0.48	0.41
23-Jul	0.28	0.20	0.50	0.15	0.24	0.49	0.41
24-Jul	0.28	0.20	0.49	0.15	0.24	0.49	0.40
25-Jul	0.29	0.20	0.49	0.15	0.24	0.49	0.40
26-Jul	0.29	0.21	0.48	0.16	0.24	0.50	0.40
27-Jul	0.29	0.21	0.48	0.16	0.24	0.50	0.40
28-Jul	0.30	0.21	0.47	0.16	0.24	0.50	0.40
29-Jul	0.30	0.21	0.47	0.16	0.24	0.51	0.40
30-Jul	0.30	0.21	0.46	0.17	0.23	0.51	0.40
31-Jul	0.30	0.21	0.46	0.17	0.23	0.51	0.40
1-Aug	0.30	0.21	0.45	0.17	0.23	0.51	0.40

[illegible]	[illegible]	[illegible]	0.45	0.17	0.23	0.51	0.40
[illegible]	[illegible]	[illegible]	0.44	0.17	0.23	0.52	0.40
[illegible]	[illegible]	[illegible]	0.44	0.17	0.23	0.52	0.40
5-Aug	0.30	0.21	0.43	0.17	0.23	0.52	0.40
6-Aug	0.30	0.21	0.43	0.17	0.23	0.52	0.40
7-Aug	0.30	0.21	0.42	0.17	0.22	0.52	0.40
8-Aug	0.29	0.21	0.42	0.17	0.22	0.52	0.40
9-Aug	0.29	0.20	0.42	0.17	0.22	0.52	0.40
10-Aug	0.29	0.20	0.41	0.17	0.22	0.52	0.41
11-Aug	0.28	0.20	0.41	0.17	0.22	0.52	0.41
12-Aug	0.28	0.19	0.41	0.17	0.22	0.52	0.41
13-Aug	0.27	0.19	0.40	0.16	0.22	0.52	0.41
14-Aug	0.27	0.19	0.40	0.16	0.22	0.52	0.42
15-Aug	0.26	0.18	0.40	0.16	0.22	0.51	0.42
16-Aug	0.26	0.18	0.40	0.16	0.22	0.51	0.42
17-Aug	0.25	0.17	0.40	0.15	0.22	0.51	0.42
18-Aug	0.25	0.17	0.40	0.15	0.22	0.51	0.43
19-Aug	0.24	0.16	0.40	0.15	0.22	0.50	0.43
20-Aug	0.23	0.16	0.40	0.14	0.22	0.50	0.43
21-Aug	0.23	0.15	0.40	0.14	0.22	0.50	0.44
22-Aug	0.22	0.15	0.40	0.14	0.22	0.49	0.44
23-Aug	0.21	0.14	0.40	0.13	0.22	0.49	0.44
24-Aug	0.21	0.14	0.40	0.13	0.22	0.49	0.45
25-Aug	0.20	0.13	0.40	0.12	0.22	0.48	0.45
26-Aug	0.19	0.13	0.40	0.12	0.22	0.48	0.45
27-Aug	0.18	0.12	0.41	0.12	0.22	0.47	0.46
28-Aug	0.18	0.12	0.41	0.11	0.22	0.47	0.46
29-Aug	0.17	0.11	0.41	0.11	0.22	0.46	0.46
30-Aug	0.16	0.11	0.42	0.10	0.22	0.46	0.47
31-Aug	0.15	0.10	0.42	0.10	0.22	0.45	0.47
1-Sep	0.15	0.10	0.42	0.10	0.22	0.45	0.47
2-Sep	0.14	0.09	0.42	0.09	0.22	0.44	0.48
3-Sep	0.13	0.09	0.43	0.09	0.22	0.43	0.48
4-Sep	0.13	0.08	0.43	0.08	0.22	0.43	0.48
5-Sep	0.12	0.08	0.43	0.08	0.22	0.42	0.48
6-Sep	0.12	0.08	0.44	0.08	0.22	0.41	0.48
7-Sep	0.11	0.07	0.44	0.07	0.22	0.41	0.49
8-Sep	0.10	0.07	0.44	0.07	0.22	0.40	0.49
9-Sep	0.10	0.06	0.44	0.06	0.22	0.39	0.49
10-Sep	0.09	0.06	0.44	0.06	0.22	0.39	0.49
11-Sep	0.09	0.06	0.45	0.06	0.22	0.38	0.49
12-Sep	0.08	0.05	0.45	0.06	0.22	0.37	0.49
13-Sep	0.08	0.05	0.45	0.05	0.22	0.37	0.49
14-Sep	0.08	0.05	0.45	0.05	0.22	0.36	0.49
15-Sep	0.07	0.05	0.45	0.05	0.22	0.35	0.48
16-Sep	0.07	0.04	0.44	0.04	0.21	0.35	0.48
17-Sep	0.06	0.04	0.44	0.04	0.21	0.34	0.48
18-Sep	0.06	0.04	0.44	0.04	0.21	0.34	0.48
19-Sep	0.06	0.04	0.44	0.04	0.21	0.33	0.47
20-Sep	0.05	0.03	0.43	0.03	0.21	0.32	0.47
21-Sep	0.05	0.03	0.43	0.03	0.21	0.32	0.46
22-Sep	0.05	0.03	0.42	0.03	0.21	0.31	0.46
23-Sep	0.05	0.03	0.41	0.03	0.21	0.31	0.45
24-Sep	0.04	0.03	0.41	0.03	0.21	0.30	0.45
25-Sep	0.04	0.03	0.40	0.03	0.20	0.30	0.44
26-Sep	0.04	0.03	0.39	0.02	0.20	0.29	0.43

[illegible]	[illegible]	[illegible]	0.38	0.02	0.20	0.29	0.42
[illegible]	[illegible]	[illegible]	0.37	0.02	0.20	0.28	0.41
[illegible]	[illegible]	[illegible]	0.36	0.02	0.20	0.28	0.40
30-Sep	0.03	0.02	0.34	0.02	0.19	0.28	0.39
1-Oct	0.03	0.02	0.33	0.02	0.19	0.27	0.38
2-Oct	0.03	0.02	0.32	0.02	0.19	0.27	0.37
3-Oct	0.03	0.02	0.30	0.02	0.18	0.27	0.36
4-Oct	0.03	0.02	0.29	0.01	0.18	0.26	0.35
5-Oct	0.02	0.02	0.27	0.01	0.18	0.26	0.34
6-Oct	0.02	0.02	0.26	0.01	0.17	0.26	0.32
7-Oct	0.02	0.02	0.24	0.01	0.17	0.26	0.31
8-Oct	0.02	0.01	0.23	0.01	0.17	0.26	0.29
9-Oct	0.02	0.01	0.22	0.01	0.16	0.26	0.28
10-Oct	0.02	0.01	0.20	0.01	0.16	0.26	0.27
11-Oct	0.02	0.01	0.19	0.01	0.15	0.26	0.25
12-Oct	0.02	0.01	0.17	0.01	0.15	0.26	0.24
13-Oct	0.02	0.01	0.16	0.01	0.14	0.26	0.22
14-Oct	0.02	0.01	0.15	0.01	0.14	0.26	0.21

From the Table 6.183, one can say that the highest probability of a day being wet is 30%, which was 36% with 2.5 mm threshold value, from to 28th July to 7th August (210 to 220). The highest probability of a day being wet given the previous day is wet was 62% with 2.5 mm threshold value, which is now 52% from 12th July to 17th July (164 to 169). The highest probability of a day being wet given the previous two days are wet was 63 % with 2.5 mm threshold value, which is now 59 % from 15th June to 17th June (167 to 169).

Figs. 6.154 present the dry spell length of 7 to 14 days using 8 mm of threshold value. From the Fig. 6.154 one can say that the overall probabilities obtained are less compared to the one observed for the 2.5 mm threshold value. The spell lengths of 7 to 14 days over period of 30 days are calculated as shown in Fig. 6.152. The results show that the lowest probability of a dry spell of 7 days, within the 30 days following sowing, has dropped to 0.59 by 29th July (day 211). A dry spell of 10 days over the 30 days period has dropped to 0.21 by 17th July (day 199). A dry spell of 14 days over the 30 days has dropped to 0.04 by 18th July (day 200).

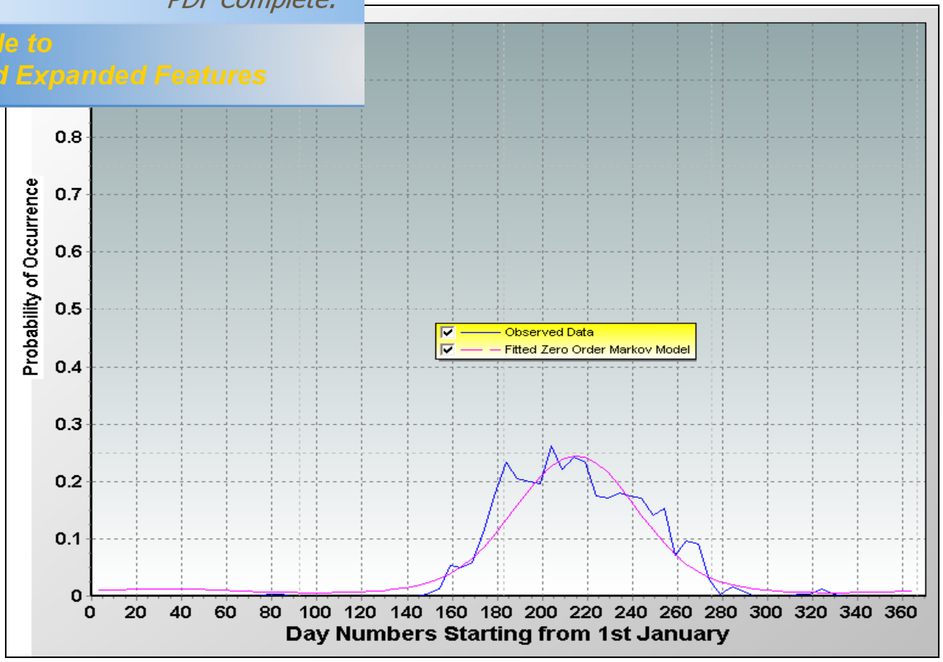

Fig. 6.154 Zero order Markov model fitted to rain event with 8 mm threshold rainfall

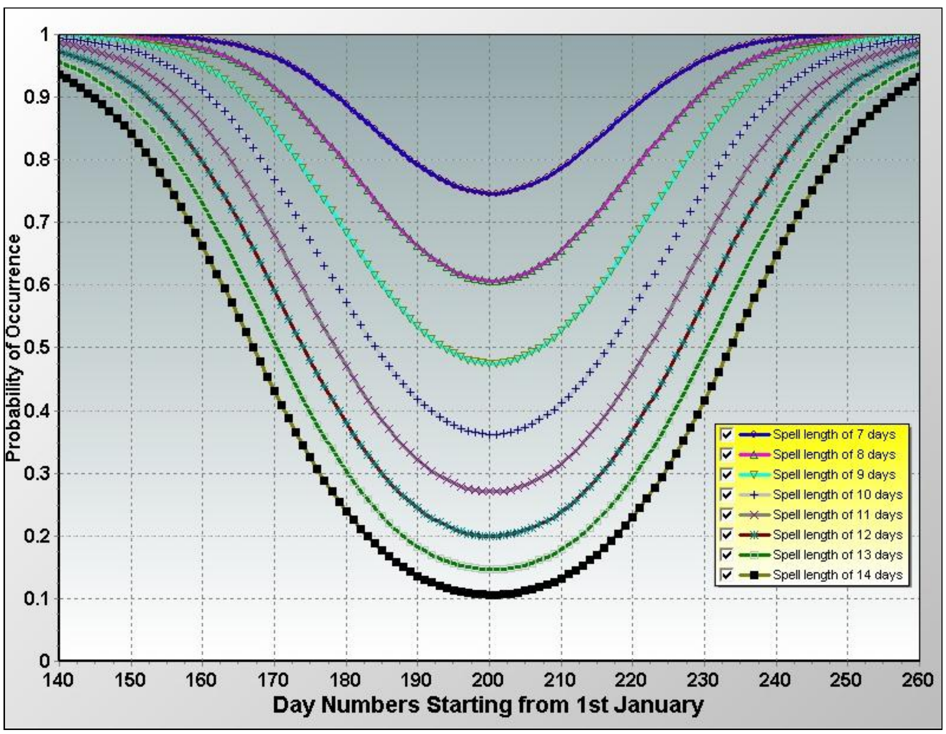

Fig. 6.155 Probability of dry spell length of 7 to 14 days using zero order Markov model with 8 mm threshold rainfall

e probability increases as the order of the Markov to second. When one compares the probability of occurrence for 2.5 mm and 8 mm threshold value, it is found that the probability for later one is less than the former threshold value.

Thus by changing and increasing the threshold value of rainfall, the probabilities of wet spell are reduced. Also for both the cases one can observe that as the dry spell length increases from 7 to 14 days the probability of occurrence decreases. Thus more the length of dry spell more is the probability of getting wet spell for a choosen period. Therefore the onset dates must be planned such that the critical growth stages requiring water coincides with the maximum probability values of wet spell obtained for the respective stations. This will be correlated once the onset dates are obtained. Similar observations can be made based on the probability plots of dry spell length of 7 to 14 days for 2.5 mm and 8 mm threshold values for remaining 72 raingauge stations.

6.9.3 Climatic Indices

The climatic indices (CI) are worked out for planning of the crops to be grown in the area. The indices determined can be used to select the crop based on crop coefficient (Kci) value which is below the CI value. The indices are initially calculated on monthly basis which are presented in Table 6.184. It is observed that as the area is receiving rainfall during the monsoon months (June to September) only, the CI values for rest of the months are zero. So it is very much evident that during these four months the rainfed agriculture is possible. But this information is too rough and detailed rainfed period needs to be analyzed. Therefore the indices are calculated on weekly basis too. Table 6.185 presents the weekly CI values. Fig. 6.156 depicts the monthly and weekly CI and Kci for Aslali raingauge station.

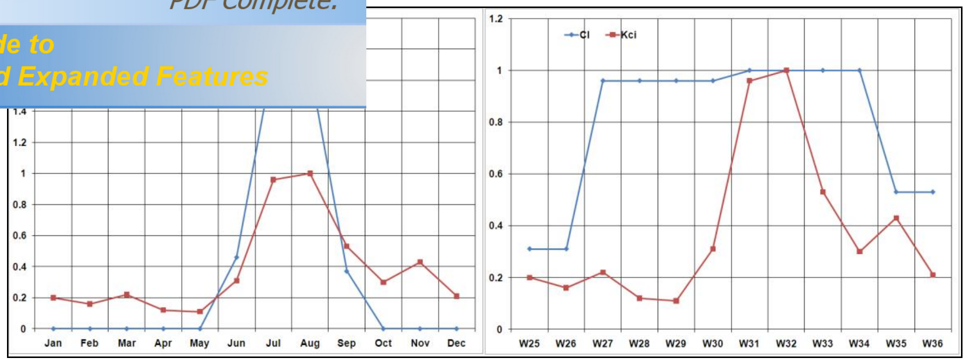

Fig. 6.156 Monthly and weekly CI and Kci for Aslali raingauge station.

Table 6.184 Monthly CI Values for North Gujarat Agroclimatic Zone

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Aslali	0.00	0.00	0.00	0.00	0.00	0.46	1.75	1.68	0.37	0.00	0.00	0.00
Bareja	0.00	0.00	0.00	0.00	0.00	0.48	1.87	2.30	0.36	0.00	0.00	0.00
Barejadi	0.00	0.00	0.00	0.00	0.00	0.52	2.08	2.11	0.56	0.00	0.00	0.00
Chandola	0.00	0.00	0.00	0.00	0.00	0.28	2.11	1.88	0.36	0.00	0.00	0.00
Dehgam	0.00	0.00	0.00	0.00	0.00	0.51	1.82	1.73	0.42	0.00	0.00	0.00
Sanand	0.00	0.00	0.00	0.00	0.00	0.48	1.76	1.94	0.50	0.00	0.00	0.00
Nal Lake	0.00	0.00	0.00	0.00	0.00	0.31	1.24	1.23	0.22	0.00	0.00	0.00
Vasai	0.00	0.00	0.00	0.00	0.00	0.33	2.40	2.03	0.53	0.00	0.00	0.00
Ambaji	0.00	0.00	0.00	0.00	0.00	0.40	2.08	1.57	0.55	0.00	0.00	0.00
Amirgadh	0.00	0.00	0.00	0.00	0.00	0.37	2.06	1.85	0.35	0.00	0.00	0.00
Bapla	0.00	0.00	0.00	0.00	0.00	0.12	1.37	1.10	0.24	0.00	0.00	0.00
Chandisar	0.00	0.00	0.00	0.00	0.00	0.17	1.52	1.11	0.34	0.00	0.00	0.00
Chitrasani	0.00	0.00	0.00	0.00	0.00	0.24	1.59	1.41	0.39	0.00	0.00	0.00
Danta	0.00	0.00	0.00	0.00	0.00	0.49	2.37	1.72	0.52	0.00	0.00	0.00
Dantiwada	0.00	0.00	0.00	0.00	0.00	0.24	1.54	1.24	0.40	0.00	0.00	0.00
Deesa	0.00	0.00	0.00	0.00	0.00	0.41	1.23	1.21	0.23	0.00	0.00	0.00
Dhanera	0.00	0.00	0.00	0.00	0.00	0.13	1.21	1.30	0.24	0.00	0.00	0.00
Gadh	0.00	0.00	0.00	0.00	0.00	0.17	1.26	1.08	0.22	0.00	0.00	0.00
Hadad	0.00	0.00	0.00	0.00	0.00	0.36	1.86	1.55	0.35	0.00	0.00	0.00
Junisarotri	0.00	0.00	0.00	0.00	0.00	0.18	1.86	1.81	0.46	0.00	0.00	0.00
Nava	0.00	0.00	0.00	0.00	0.00	0.20	1.13	1.12	0.20	0.00	0.00	0.00
Palanpur	0.00	0.00	0.00	0.00	0.00	0.36	1.71	1.36	0.38	0.00	0.00	0.00
Panthawada	0.00	0.00	0.00	0.00	0.00	0.14	1.19	1.35	0.22	0.00	0.00	0.00
Sanali ashram	0.00	0.00	0.00	0.00	0.00	0.28	1.43	1.52	0.49	0.00	0.00	0.00
Wadgam	0.00	0.00	0.00	0.00	0.00	0.42	2.00	1.35	0.29	0.00	0.00	0.00
Mansa	0.00	0.00	0.00	0.00	0.00	0.39	2.10	1.67	0.27	0.00	0.00	0.00
Raipur weir	0.00	0.00	0.00	0.00	0.00	0.41	1.98	1.69	0.26	0.00	0.00	0.00
Balasinor	0.00	0.00	0.00	0.00	0.00	0.59	2.04	1.55	0.42	0.00	0.00	0.00
Dakor	0.00	0.00	0.00	0.00	0.00	0.52	1.74	1.89	0.29	0.00	0.00	0.00
Kapadwanj	0.00	0.00	0.00	0.00	0.00	0.60	2.42	2.17	0.56	0.00	0.00	0.00
Kathlal	0.00	0.00	0.00	0.00	0.00	0.53	1.65	1.41	0.42	0.00	0.00	0.00
Kheda	0.00	0.00	0.00	0.00	0.00	0.42	2.01	2.30	0.52	0.00	0.00	0.00
Mahemdabad	0.00	0.00	0.00	0.00	0.00	0.58	1.59	1.77	0.78	0.00	0.00	0.00
Mahisa	0.00	0.00	0.00	0.00	0.00	0.60	1.63	1.79	0.47	0.00	0.00	0.00
Nadiad	0.00	0.00	0.00	0.00	0.00	0.60	1.73	1.76	0.47	0.00	0.00	0.00
Pinglaj	0.00	0.00	0.00	0.00	0.00	0.29	1.74	1.93	0.61	0.00	0.00	0.00
Savli tank	0.00	0.00	0.00	0.00	0.00	0.55	1.76	1.61	0.38	0.00	0.00	0.00

[illegible]	[illegible]	[illegible]	[illegible]	0.00	0.00	0.37	1.51	1.71	0.24	0.00	0.00	0.00
[illegible]	[illegible]	[illegible]	[illegible]	0.00	0.00	0.71	2.00	1.83	0.46	0.00	0.00	0.00
[illegible]	[illegible]	[illegible]	[illegible]	0.00	0.00	0.41	1.74	1.72	0.39	0.00	0.00	0.00
Dharoi	0.00	0.00	0.00	0.00	0.00	0.52	1.81	1.77	0.57	0.00	0.00	0.00
Kadi	0.00	0.00	0.00	0.00	0.00	0.55	1.91	1.72	0.37	0.00	0.00	0.00
Kalol	0.00	0.00	0.00	0.00	0.00	0.35	2.10	1.89	0.33	0.00	0.00	0.00
Katosan	0.00	0.00	0.00	0.00	0.00	0.57	1.78	1.14	0.33	0.00	0.00	0.00
Kheralu	0.00	0.00	0.00	0.00	0.00	0.38	1.68	1.61	0.43	0.00	0.00	0.00
Mehsana	0.00	0.00	0.00	0.00	0.00	0.28	1.65	1.35	0.40	0.00	0.00	0.00
Ransipur	0.00	0.00	0.00	0.00	0.00	0.37	1.52	1.59	0.46	0.00	0.00	0.00
Thol	0.00	0.00	0.00	0.00	0.00	0.24	1.29	1.95	0.16	0.00	0.00	0.00
Unjha	0.00	0.00	0.00	0.00	0.00	0.15	1.31	1.06	0.09	0.00	0.00	0.00
Vijapur	0.00	0.00	0.00	0.00	0.00	0.45	1.74	1.62	0.54	0.00	0.00	0.00
Visnagar	0.00	0.00	0.00	0.00	0.00	0.33	1.54	0.95	0.41	0.00	0.00	0.00
Patan	0.00	0.00	0.00	0.00	0.00	0.17	1.26	1.11	0.31	0.00	0.00	0.00
Sidhpur	0.00	0.00	0.00	0.00	0.00	0.27	1.48	1.43	0.28	0.00	0.00	0.00
Wagdod	0.00	0.00	0.00	0.00	0.00	0.23	1.23	1.17	0.07	0.00	0.00	0.00
Badoli	0.00	0.00	0.00	0.00	0.00	0.25	2.26	1.94	0.51	0.00	0.00	0.00
Bayad	0.00	0.00	0.00	0.00	0.00	0.69	1.90	2.15	0.68	0.00	0.00	0.00
Bhiloda	0.00	0.00	0.00	0.00	0.00	0.57	2.23	2.16	0.69	0.00	0.00	0.00
Dantral	0.00	0.00	0.00	0.00	0.00	0.58	2.01	1.74	0.32	0.00	0.00	0.00
Himmatnagar	0.00	0.00	0.00	0.00	0.00	0.60	1.92	1.75	0.52	0.00	0.00	0.00
Idar	0.00	0.00	0.00	0.00	0.00	0.56	1.90	2.05	0.69	0.00	0.00	0.00
Khedbhrama	0.00	0.00	0.00	0.00	0.00	0.35	1.85	2.14	0.79	0.00	0.00	0.00
Kundlacampo	0.00	0.00	0.00	0.00	0.00	0.35	2.48	2.47	0.87	0.00	0.00	0.00
Limla dam	0.00	0.00	0.00	0.00	0.00	0.35	1.97	1.98	0.45	0.00	0.00	0.00
Malpur	0.00	0.00	0.00	0.00	0.00	0.65	1.92	2.83	0.65	0.00	0.00	0.00
Meghraj	0.00	0.00	0.00	0.00	0.00	0.46	2.06	2.07	0.50	0.00	0.00	0.00
Modasa	0.00	0.00	0.00	0.00	0.00	0.58	2.07	2.16	0.53	0.00	0.00	0.00
Pal	0.00	0.00	0.00	0.00	0.00	0.34	1.95	2.04	0.77	0.00	0.00	0.00
Prantij	0.00	0.00	0.00	0.00	0.00	0.65	2.01	2.26	0.48	0.00	0.00	0.00
Sabli	0.00	0.00	0.00	0.00	0.00	0.25	1.62	1.95	0.53	0.00	0.00	0.00
Shamlaji	0.00	0.00	0.00	0.00	0.00	0.50	2.56	2.06	0.61	0.00	0.00	0.00
Vadgam	0.00	0.00	0.00	0.00	0.00	0.44	1.88	1.83	0.55	0.00	0.00	0.00
Vijaynagar	0.00	0.00	0.00	0.00	0.00	0.45	2.18	1.82	0.56	0.00	0.00	0.00
Virpur	0.00	0.00	0.00	0.00	0.00	0.38	1.67	1.83	0.45	0.00	0.00	0.00

Table 6.185 Weekly CI Values for North Gujarat Agroclimatic Zone

Station	W25	W26	W27	W28	W29	W30	W31	W32	W33	W34	W35	W36	W37
Aslali	0.00	0.70	0.40	1.30	1.70	1.70	1.20	0.90	0.70	0.50	0.40	0.00	0.00
Bareja	0.90	0.60	0.60	0.70	1.30	1.40	2.20	1.60	0.70	0.60	0.50	0.00	0.00
Barejadi	0.20	0.80	0.50	1.60	1.70	0.80	2.30	1.20	0.60	0.60	0.50	0.00	0.00
Chandola	0.60	0.90	0.20	1.40	1.20	0.50	1.40	0.70	0.60	0.40	0.40	0.00	0.00
Dehgam	0.00	0.60	0.90	0.60	1.50	0.90	1.20	1.80	0.80	0.50	0.40	0.20	0.00
Sanand	0.20	0.60	1.90	0.60	0.70	0.60	1.30	0.70	0.50	0.40	0.30	0.20	0.20
Nal Lake	0.70	0.40	1.00	0.30	0.50	0.30	1.20	0.60	0.00	0.00	0.30	0.00	0.00
Vasai	0.00	1.00	0.40	0.90	1.10	1.00	2.00	2.00	0.50	0.70	0.50	0.20	0.00
Ambaji	0.00	0.30	0.60	1.80	1.30	2.20	1.90	1.90	0.80	0.80	1.00	0.00	0.00
Amirgadh	0.30	0.20	0.30	0.50	1.40	3.10	2.60	1.60	0.70	0.60	0.20	0.20	0.00
Bapla	0.00	0.40	0.30	0.20	1.40	2.40	2.30	0.80	0.80	0.80	0.20	0.00	0.00
Chandisar	0.00	0.00	0.30	0.20	1.40	2.40	2.30	0.80	0.80	0.80	0.20	0.00	0.00
Chitrasani	0.00	1.00	0.80	0.40	1.60	1.80	1.90	1.30	0.40	0.20	0.20	0.80	0.60
Danta	0.00	0.20	0.70	0.90	1.80	1.70	2.60	1.30	0.90	0.70	0.70	0.10	0.00
Dantiwada	0.00	0.00	0.40	0.40	1.20	1.40	1.80	1.20	0.30	0.20	0.10	0.40	0.00

[illegible]	[illegible]	[illegible]	[illegible]	0.40	1.60	0.80	1.00	0.80	0.30	0.30	0.60	0.00	0.00
[illegible]	[illegible]	[illegible]	[illegible]	0.10	1.10	0.90	1.60	0.80	0.10	0.20	0.30	0.10	0.00
[illegible]	[illegible]	[illegible]	[illegible]	0.60	0.60	0.80	1.30	0.60	0.20	0.80	0.40	0.00	0.00
Hadad	0.00	0.20	0.50	1.30	1.50	1.60	1.90	0.90	0.80	0.60	0.50	0.10	0.00
Junisarotri	0.00	0.50	0.50	0.50	0.70	1.50	1.30	1.60	0.40	0.40	0.60	0.00	0.00
Nava	0.00	0.00	0.20	0.20	0.90	0.70	0.70	0.60	0.00	0.00	0.00	0.00	0.00
Palanpur	0.00	0.20	0.90	0.50	1.20	3.00	2.50	1.20	0.40	0.20	0.50	0.60	0.00
Panthawada	0.00	0.60	0.20	0.30	0.60	0.90	2.40	0.80	0.90	0.10	0.30	0.00	0.00
Sanali ashram	0.00	0.20	0.40	1.50	1.10	1.50	1.50	1.60	0.70	0.60	0.40	0.00	0.00
Wadgam	0.00	0.50	1.20	0.60	1.60	1.70	2.20	0.90	0.40	0.90	0.20	0.00	0.00
Mansa	0.00	0.30	1.50	1.80	1.30	1.00	1.50	1.00	0.50	0.40	0.30	0.10	0.00
Raipur weir	0.00	0.20	0.80	1.30	1.00	0.80	1.10	0.70	0.60	0.30	0.50	0.00	0.00
Balasinor	0.60	0.70	1.00	1.30	1.90	1.40	1.90	1.20	0.50	0.80	0.40	0.10	0.00
Dakor	0.00	0.50	0.10	1.00	1.00	0.50	1.40	0.90	0.90	0.60	0.00	0.00	0.00
Kapadwanj	0.00	0.50	0.80	1.50	1.20	2.40	1.70	1.20	1.00	0.40	0.80	0.00	0.00
Kathlal	0.00	0.50	0.50	1.10	0.80	1.50	1.40	0.90	1.00	0.40	0.60	0.10	0.00
Kheda	0.00	0.60	1.40	1.10	0.90	1.00	1.10	0.70	1.00	0.60	0.50	0.20	0.00
Mahemdabad	0.00	0.40	1.30	0.90	1.40	1.10	1.40	1.20	1.10	0.80	1.00	0.20	0.00
Mahisa	0.00	0.40	0.60	1.00	0.80	1.70	1.40	0.90	0.50	0.70	0.80	0.00	0.00
Nadiad	0.10	0.70	0.90	1.00	1.40	1.60	1.70	1.40	0.80	0.40	0.60	0.30	0.00
Pinglaj	0.00	0.30	0.40	0.90	1.30	0.80	1.60	0.80	0.80	0.60	0.80	0.20	0.00
Savli tank	0.00	0.30	0.80	1.10	0.90	1.40	1.60	0.90	0.80	0.40	0.50	0.00	0.00
Vadol	0.00	0.20	0.20	0.70	0.90	1.60	1.10	1.20	0.50	0.80	0.40	0.00	0.00
Vaghroli tank	0.10	0.80	0.60	1.20	1.10	1.60	2.10	1.20	0.90	0.50	0.20	0.00	0.00
Ambaliyasan	0.00	0.00	0.60	0.60	0.50	0.90	0.70	1.00	0.70	0.60	0.30	0.30	0.00
Dharoi	0.10	0.20	0.90	1.50	1.30	1.40	1.80	1.40	1.00	0.70	0.70	0.10	0.10
Kadi	0.00	0.50	1.00	1.00	1.20	0.70	0.80	0.60	0.50	0.40	0.50	0.00	0.00
Kalol	0.10	0.40	0.70	1.00	1.20	1.10	1.60	1.00	0.70	0.50	0.20	0.00	0.00
Katosan	0.00	0.50	1.00	1.00	1.20	0.70	0.80	0.60	0.50	0.40	0.50	0.00	0.00
Kheralu	0.10	0.20	0.60	1.00	0.50	1.20	1.50	1.10	0.70	0.40	0.70	0.00	0.00
Mehsana	0.00	0.50	1.00	1.00	1.20	0.70	0.80	0.60	0.50	0.40	0.50	0.00	0.00
Ransipur	0.00	0.30	0.90	1.20	1.40	1.10	1.60	1.10	0.40	0.50	0.80	0.00	0.00
Thol	0.00	0.10	0.50	0.40	0.30	0.50	0.80	0.40	0.80	0.10	0.10	0.20	0.00
Unjha	0.00	0.00	0.60	0.10	1.20	1.10	0.80	0.40	0.00	0.10	0.00	0.00	0.00
Vijapur	0.00	0.80	0.80	1.30	1.50	1.10	1.90	0.90	0.40	0.60	1.10	0.00	0.00
Visnagar	0.00	0.30	0.80	0.80	1.20	0.60	0.80	0.80	0.50	0.30	0.20	0.00	0.00
Patan	0.00	0.10	0.40	0.60	0.50	0.50	1.20	0.40	0.30	0.20	0.30	0.00	0.00
Sidhpur	0.00	0.20	1.10	0.50	0.80	1.50	2.10	0.90	0.70	0.30	0.30	0.00	0.00
Wagdod	0.00	0.40	0.30	0.50	0.80	0.70	0.70	0.50	0.20	0.00	0.00	0.00	0.00
Badoli	0.10	0.50	0.10	1.60	1.90	1.80	2.40	1.70	1.50	0.90	0.80	0.50	0.10
Bayad	0.00	0.10	0.80	0.50	1.10	1.40	1.90	1.50	2.10	0.90	0.50	0.80	0.20
Bhiloda	0.10	0.40	1.00	1.80	2.00	2.10	2.20	1.60	1.00	0.80	1.00	0.20	0.00
Dantral	0.40	0.80	1.30	1.40	1.30	1.30	1.20	1.20	1.30	0.50	0.30	0.00	0.00
Himmatnagar	0.10	0.10	0.70	1.30	1.60	1.40	2.10	1.60	0.60	0.60	1.20	0.00	0.10
Idar	0.10	0.80	0.20	1.10	1.60	1.60	2.60	1.50	1.80	0.90	1.40	0.40	0.00
Khedbhrama	0.00	0.40	1.00	1.00	1.40	1.30	2.20	1.50	1.20	0.90	0.70	0.10	0.00
Kundlacampo	0.10	0.40	0.90	1.80	2.00	2.10	2.90	1.90	2.10	1.00	1.00	0.10	0.20
Limla dam	0.00	0.10	1.10	0.50	1.50	1.10	1.20	0.80	0.70	0.50	0.60	0.00	0.00
Malpur	0.40	0.40	0.80	1.20	1.20	1.70	1.40	1.70	1.10	1.00	0.60	0.30	0.30
Meghraj	0.00	0.60	0.70	1.20	1.60	1.30	1.60	1.80	0.80	1.00	0.50	0.30	0.20
Modasa	0.00	0.70	0.40	1.20	2.00	1.50	1.70	1.20	1.40	1.10	1.00	0.20	0.00
Pal	0.10	0.60	0.50	1.30	2.00	1.30	2.20	1.50	1.20	0.80	1.00	0.20	0.20
Prantij	0.10	0.30	1.30	1.10	2.10	1.50	1.30	1.30	0.60	0.50	0.70	0.10	0.00
Sabli	0.00	0.20	0.90	1.40	1.20	1.50	2.00	1.30	1.20	0.60	0.50	0.20	0.00

[illegible]	[illegible]	[illegible]	[illegible]	1.80	1.40	2.00	1.90	1.90	1.70	1.20	0.60	0.40	0.00
[illegible]	[illegible]	[illegible]	[illegible]	1.00	1.50	1.30	1.10	1.30	1.00	0.50	1.20	0.10	0.00
[illegible]	[illegible]	[illegible]	[illegible]	1.40	1.10	1.80	1.40	1.40	1.60	1.30	1.20	0.00	0.00
Virpur	0.50	1.00	1.60	1.20	1.10	1.60	1.50	0.80	0.80	0.70	0.30	0.10	0.00

Once the indices are obtained, the Kci values are determined for the region as explained in section 5.9.3. Table 6.186 depicts the monthly Kci values corresponding to monthly CI. Table 6.187 presents the weekly Kci values corresponding to weekly CI.

Table 6.186 Monthly Kci Values for North Gujarat Agroclimatic Zone

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Aslali	0.20	0.16	0.22	0.12	0.11	0.31	0.96	1.00	0.53	0.30	0.43	0.21
Bareja	0.20	0.16	0.14	0.12	0.16	0.31	0.96	1.00	0.53	0.23	0.43	0.21
Barejadi	0.20	0.16	0.14	0.12	0.19	0.31	0.96	1.00	0.53	0.23	0.37	0.21
Chandola	0.20	0.16	0.14	0.12	0.19	0.31	0.96	1.00	0.53	0.30	0.39	0.21
Dehgam	0.20	0.16	0.14	0.12	0.16	0.43	0.96	1.00	0.43	0.23	0.39	0.21
Sanand	0.20	0.16	0.14	0.12	0.16	0.37	0.96	1.00	0.43	0.23	0.18	0.21
Nal Lake	0.20	0.16	0.29	0.12	0.16	0.53	0.96	1.00	0.53	0.30	0.43	0.21
Vasai	0.20	0.16	0.14	0.12	0.11	0.37	0.96	1.00	0.53	0.23	0.43	0.21
Ambaji	0.23	0.17	0.14	0.12	0.11	0.43	0.89	0.94	0.56	0.34	0.47	0.23
Amirgadh	0.20	0.16	0.14	0.12	0.16	0.30	0.94	1.00	0.55	0.30	0.38	0.21
Bapla	0.20	0.16	0.14	0.12	0.11	0.22	0.94	1.00	0.37	0.23	0.18	0.21
Chandisar	0.20	0.16	0.14	0.12	0.11	0.22	0.94	1.00	0.37	0.23	0.38	0.21
Chitrasani	0.20	0.16	0.14	0.12	0.11	0.22	0.94	1.00	0.55	0.23	0.38	0.21
Danta	0.23	0.17	0.30	0.12	0.11	0.46	0.89	0.94	0.56	0.34	0.46	0.23
Dantiwada	0.20	0.31	0.22	0.12	0.16	0.30	0.94	1.00	0.45	0.23	0.38	0.51
Deesa	0.51	0.16	0.13	0.22	0.11	0.29	0.88	0.92	0.44	0.31	0.42	0.17
Dhanera	0.20	0.16	0.39	0.12	0.11	0.22	0.94	1.00	0.37	0.23	0.38	0.21
Gadh	0.21	0.31	0.13	0.12	0.19	0.29	0.88	0.92	0.37	0.31	0.42	0.17
Hadad	0.23	0.17	0.14	0.12	0.74	0.46	0.89	0.94	0.56	0.27	0.47	0.23
Junisarotri	0.20	0.37	0.14	0.12	0.19	0.22	0.96	1.00	0.53	0.42	0.18	0.21
Nava	0.21	0.16	0.13	0.12	0.16	0.21	0.88	0.92	0.37	0.31	0.42	0.17
Palanpur	0.20	0.16	0.14	0.12	0.16	0.30	0.94	1.00	0.55	0.30	0.18	0.51
Panthawada	0.20	0.16	0.14	0.12	0.11	0.22	0.94	1.00	0.45	0.30	0.18	0.21
Sanali ashram	0.23	0.17	0.14	0.12	0.11	0.30	0.89	0.94	0.56	0.34	0.20	0.23
Wadgam	0.20	0.16	0.14	0.12	0.11	0.30	0.94	1.00	0.55	0.30	0.18	0.21
Mansa	0.20	0.16	0.40	0.12	0.11	0.31	0.96	1.00	0.53	0.23	0.18	0.21
Raipur weir	0.20	0.16	0.14	0.12	0.19	0.22	0.96	1.00	0.53	0.23	0.18	0.21
Balasinor	0.18	0.15	0.26	0.30	0.20	0.56	0.88	0.92	0.62	0.30	0.17	0.19
Dakor	0.18	0.15	0.13	0.11	0.11	0.30	0.88	0.92	0.54	0.30	0.38	0.19
Kapadwanj	0.20	0.16	0.14	0.12	0.11	0.45	0.96	1.00	0.53	0.23	0.43	0.21
Kathlal	0.18	0.15	0.13	0.11	0.11	0.43	0.88	0.92	0.54	0.23	0.17	0.19
Kheda	0.20	0.16	0.22	0.12	0.19	0.43	0.96	1.00	0.53	0.30	0.43	0.51
Mahemdabad	0.18	0.27	0.20	0.11	0.20	0.56	0.88	0.92	0.54	0.23	0.38	0.19
Mahisa	0.18	0.15	0.13	0.11	0.11	0.30	0.88	0.92	0.45	0.14	0.34	0.19
Nadiad	0.18	0.15	0.13	0.11	0.11	0.53	0.88	0.92	0.54	0.30	0.38	0.19
Pinglaj	0.20	0.16	0.29	0.12	0.19	0.45	0.96	1.00	0.53	0.23	0.43	0.21
Savli tank	0.18	0.15	0.13	0.11	0.16	0.21	0.88	0.92	0.54	0.23	0.38	0.19
Vadol	0.18	0.15	0.13	0.11	0.16	0.30	0.88	0.92	0.45	0.23	0.17	0.19
Vaghroli tank	0.18	0.15	0.13	0.11	0.38	0.45	0.88	0.92	0.54	0.23	0.17	0.19
Ambaliyasan	0.20	0.16	0.14	0.12	0.11	0.31	0.96	1.00	0.43	0.23	0.43	0.21

[illegible]	[illegible]	[illegible]	[illegible]	0.12	0.17	0.55	0.89	0.94	0.56	0.34	0.47	0.23
[illegible]	[illegible]	[illegible]	[illegible]	0.12	0.16	0.45	0.96	1.00	0.43	0.23	0.43	0.51
[illegible]	[illegible]	[illegible]	[illegible]	0.12	0.16	0.31	0.96	1.00	0.53	0.30	0.43	0.21
Katosan	0.20	0.16	0.14	0.12	0.11	0.45	0.96	1.00	0.37	0.30	0.18	0.21
Kheralu	0.23	0.17	0.30	0.12	0.17	0.43	0.89	0.94	0.56	0.34	0.46	0.23
Mehsana	0.20	0.16	0.29	0.12	0.16	0.31	0.96	1.00	0.53	0.30	0.39	0.21
Ransipur	0.23	0.17	0.14	0.12	0.11	0.30	0.89	0.94	0.46	0.27	0.20	0.23
Thol	0.20	0.16	0.14	0.12	0.19	0.31	0.96	1.00	0.43	0.23	0.39	0.21
Unjha	0.48	0.16	0.14	0.12	0.20	0.30	0.94	1.00	0.37	0.14	0.18	0.21
Vijapur	0.23	0.17	0.30	0.12	0.11	0.30	0.89	0.94	0.56	0.27	0.47	0.59
Visnagar	0.57	0.17	0.23	0.12	0.17	0.30	0.89	0.94	0.56	0.34	0.53	0.59
Patan	0.51	0.16	0.27	0.12	0.11	0.29	0.88	0.92	0.44	0.43	0.42	0.40
Sidhpur	0.20	0.31	0.39	0.12	0.20	0.30	0.94	1.00	0.45	0.30	0.42	0.21
Wagdod	0.21	0.16	0.13	0.12	0.11	0.21	0.88	0.92	0.37	0.24	0.42	0.17
Badoli	0.23	0.17	0.14	0.12	0.11	0.30	0.89	0.94	0.64	0.27	0.39	0.23
Bayad	0.23	0.17	0.30	0.12	0.21	0.30	0.89	0.94	0.56	0.34	0.20	0.23
Bhiloda	0.23	0.17	0.39	0.12	0.21	0.54	0.89	0.94	0.64	0.34	0.46	0.23
Dantral	0.23	0.17	0.14	0.12	0.21	0.54	0.89	0.94	0.56	0.34	0.20	0.23
Himmatnagar	0.23	0.17	0.30	0.12	0.17	0.30	0.89	0.94	0.56	0.34	0.46	0.23
Idar	0.23	0.17	0.43	0.12	0.11	0.30	0.89	0.94	0.56	0.34	0.47	0.23
Khedbhrama	0.23	0.17	0.39	0.12	0.11	0.46	0.89	0.94	0.56	0.34	0.46	0.59
Kundlacampo	0.23	0.17	0.14	0.12	0.21	0.46	0.89	0.94	0.64	0.34	0.20	0.23
Limla dam	0.23	0.17	0.14	0.12	0.17	0.30	0.89	0.94	0.56	0.34	0.20	0.23
Malpur	0.23	0.17	0.30	0.12	0.21	0.46	0.89	0.94	0.56	0.34	0.47	0.23
Meghraj	0.23	0.17	0.14	0.12	0.17	0.46	0.89	0.94	0.64	0.34	0.47	0.23
Modasa	0.23	0.17	0.14	0.12	0.17	0.56	0.89	0.94	0.64	0.34	0.46	0.23
Pal	0.23	0.17	0.14	0.12	0.11	0.30	0.89	0.94	0.56	0.34	0.20	0.23
Prantij	0.23	0.17	0.30	0.12	0.17	0.55	0.89	0.94	0.64	0.34	0.46	0.23
Sabli	0.23	0.17	0.14	0.12	0.11	0.30	0.89	0.94	0.56	0.34	0.20	0.23
Shamlaji	0.23	0.17	0.14	0.12	0.11	0.56	0.89	0.94	0.64	0.34	0.46	0.23
Vadgam	0.23	0.17	0.30	0.12	0.17	0.46	0.89	0.94	0.56	0.27	0.47	0.59
Vijaynagar	0.23	0.17	0.39	0.12	0.17	0.55	0.89	0.94	0.64	0.34	0.47	0.23
Virpur	0.23	0.17	0.14	0.12	0.11	0.30	0.89	0.94	0.64	0.27	0.20	0.23

Table 6.187 Weekly Kci Values for North Gujarat Agroclimatic Zone

Station	W25	W26	W27	W28	W29	W30	W31	W32	W33	W34	W35	W36	W37
Aslali	0.31	0.31	0.96	0.96	0.96	0.96	1.00	1.00	1.00	1.00	0.53	0.53	0.53
Bareja	0.31	0.31	0.96	0.96	0.96	0.96	1.00	1.00	1.00	1.00	0.53	0.53	0.53
Barejadi	0.31	0.31	0.96	0.96	0.96	0.96	1.00	1.00	1.00	1.00	0.53	0.53	0.53
Chandola	0.31	0.31	0.96	0.96	0.96	0.96	1.00	1.00	1.00	1.00	0.53	0.53	0.53
Dehgam	0.43	0.43	0.96	0.96	0.96	0.96	1.00	1.00	1.00	1.00	0.43	0.43	0.43
Sanand	0.37	0.37	0.96	0.96	0.96	0.96	1.00	1.00	1.00	1.00	0.43	0.43	0.43
Nal Lake	0.53	0.53	0.96	0.96	0.96	0.96	1.00	1.00	1.00	1.00	0.53	0.53	0.53
Vasai	0.37	0.37	0.96	0.96	0.96	0.96	1.00	1.00	1.00	1.00	0.53	0.53	0.53
Ambaji	0.43	0.43	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.56	0.56	0.56
Amirgadh	0.30	0.30	0.94	0.94	0.94	0.94	1.00	1.00	1.00	1.00	0.55	0.55	0.55
Bapla	0.22	0.22	0.94	0.94	0.94	0.94	1.00	1.00	1.00	1.00	0.37	0.37	0.37
Chandisar	0.22	0.22	0.94	0.94	0.94	0.94	1.00	1.00	1.00	1.00	0.37	0.37	0.37
Chitrasani	0.22	0.22	0.94	0.94	0.94	0.94	1.00	1.00	1.00	1.00	0.55	0.55	0.55
Danta	0.46	0.46	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.56	0.56	0.56
Dantiwada	0.30	0.30	0.94	0.94	0.94	0.94	1.00	1.00	1.00	1.00	0.45	0.45	0.45
Deesa	0.29	0.29	0.88	0.88	0.88	0.88	0.92	0.92	0.92	0.92	0.44	0.44	0.44
Dhanera	0.22	0.22	0.94	0.94	0.94	0.94	1.00	1.00	1.00	1.00	0.37	0.37	0.37
Gadh	0.29	0.29	0.88	0.88	0.88	0.88	0.92	0.92	0.92	0.92	0.37	0.37	0.37

[illegible]	[illegible]	[illegible]	[illegible]	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.56	0.56	0.56
[illegible]	[illegible]	[illegible]	[illegible]	0.96	0.96	0.96	1.00	1.00	1.00	1.00	0.53	0.53	0.53
[illegible]	[illegible]	[illegible]	[illegible]	0.88	0.88	0.88	0.92	0.92	0.92	0.92	0.37	0.37	0.37
Palanpur	0.30	0.30	0.94	0.94	0.94	0.94	1.00	1.00	1.00	1.00	0.55	0.55	0.55
Panthawada	0.22	0.22	0.94	0.94	0.94	0.94	1.00	1.00	1.00	1.00	0.45	0.45	0.45
Sanali ashram	0.30	0.30	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.56	0.56	0.56
Wadgam	0.30	0.30	0.94	0.94	0.94	0.94	1.00	1.00	1.00	1.00	0.55	0.55	0.55
Mansa	0.31	0.31	0.96	0.96	0.96	0.96	1.00	1.00	1.00	1.00	0.53	0.53	0.53
Raipur weir	0.22	0.22	0.96	0.96	0.96	0.96	1.00	1.00	1.00	1.00	0.53	0.53	0.53
Balasinor	0.56	0.56	0.88	0.88	0.88	0.88	0.92	0.92	0.92	0.92	0.62	0.62	0.62
Dakor	0.30	0.30	0.88	0.88	0.88	0.88	0.92	0.92	0.92	0.92	0.54	0.54	0.54
Kapadwanj	0.45	0.45	0.96	0.96	0.96	0.96	1.00	1.00	1.00	1.00	0.53	0.53	0.53
Kathlal	0.43	0.43	0.88	0.88	0.88	0.88	0.92	0.92	0.92	0.92	0.54	0.54	0.54
Kheda	0.43	0.43	0.96	0.96	0.96	0.96	1.00	1.00	1.00	1.00	0.53	0.53	0.53
Mahemdabad	0.56	0.56	0.88	0.88	0.88	0.88	0.92	0.92	0.92	0.92	0.54	0.54	0.54
Mahisa	0.30	0.30	0.88	0.88	0.88	0.88	0.92	0.92	0.92	0.92	0.45	0.45	0.45
Nadiad	0.53	0.53	0.88	0.88	0.88	0.88	0.92	0.92	0.92	0.92	0.54	0.54	0.54
Pinglaj	0.45	0.45	0.96	0.96	0.96	0.96	1.00	1.00	1.00	1.00	0.53	0.53	0.53
Savli tank	0.21	0.21	0.88	0.88	0.88	0.88	0.92	0.92	0.92	0.92	0.54	0.54	0.54
Vadol	0.30	0.30	0.88	0.88	0.88	0.88	0.92	0.92	0.92	0.92	0.45	0.45	0.45
Vaghroli tank	0.45	0.45	0.88	0.88	0.88	0.88	0.92	0.92	0.92	0.92	0.54	0.54	0.54
Ambaliyasan	0.31	0.31	0.96	0.96	0.96	0.96	1.00	1.00	1.00	1.00	0.43	0.43	0.43
Dharoi	0.55	0.55	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.56	0.56	0.56
Kadi	0.45	0.45	0.96	0.96	0.96	0.96	1.00	1.00	1.00	1.00	0.43	0.43	0.43
Kalol	0.31	0.31	0.96	0.96	0.96	0.96	1.00	1.00	1.00	1.00	0.53	0.53	0.53
Katosan	0.45	0.45	0.96	0.96	0.96	0.96	1.00	1.00	1.00	1.00	0.37	0.37	0.37
Kheralu	0.43	0.43	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.56	0.56	0.56
Mehsana	0.31	0.31	0.96	0.96	0.96	0.96	1.00	1.00	1.00	1.00	0.53	0.53	0.53
Ransipur	0.30	0.30	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.46	0.46	0.46
Thol	0.31	0.31	0.96	0.96	0.96	0.96	1.00	1.00	1.00	1.00	0.43	0.43	0.43
Unjha	0.30	0.30	0.94	0.94	0.94	0.94	1.00	1.00	1.00	1.00	0.37	0.37	0.37
Vijapur	0.30	0.30	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.56	0.56	0.56
Visnagar	0.30	0.30	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.56	0.56	0.56
Patan	0.29	0.29	0.88	0.88	0.88	0.88	0.92	0.92	0.92	0.92	0.44	0.44	0.44
Sidhpur	0.30	0.30	0.94	0.94	0.94	0.94	1.00	1.00	1.00	1.00	0.45	0.45	0.45
Wagdod	0.21	0.21	0.88	0.88	0.88	0.88	0.92	0.92	0.92	0.92	0.37	0.37	0.37
Badoli	0.30	0.30	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.64	0.64	0.64
Bayad	0.30	0.30	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.56	0.56	0.56
Bhiloda	0.54	0.54	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.64	0.64	0.64
Dantral	0.54	0.54	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.56	0.56	0.56
Himmatnagar	0.30	0.30	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.56	0.56	0.56
Idar	0.30	0.30	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.56	0.56	0.56
Khedbhrama	0.46	0.46	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.56	0.56	0.56
Kundlacampo	0.46	0.46	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.64	0.64	0.64
Limla dam	0.30	0.30	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.56	0.56	0.56
Malpur	0.46	0.46	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.56	0.56	0.56
Meghraj	0.46	0.46	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.64	0.64	0.64
Modasa	0.56	0.56	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.64	0.64	0.64
Pal	0.30	0.30	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.56	0.56	0.56
Prantij	0.55	0.55	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.64	0.64	0.64
Sabli	0.30	0.30	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.56	0.56	0.56
Shamlaji	0.56	0.56	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.64	0.64	0.64
Vadgam	0.46	0.46	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.56	0.56	0.56
Vijaynagar	0.55	0.55	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.64	0.64	0.64
Virpur	0.30	0.30	0.89	0.89	0.89	0.89	0.94	0.94	0.94	0.94	0.64	0.64	0.64

ly CI and Kci values indicates that, crops can be h standard meteorological week (18th June) till the end of 37th standard meteorological week (16th September). Based on the initial information obtained from the above results related to dry spell and climatic indices the further analysis for onset, cessation and growth lengths are carried out for aid in planning rainfed irrigation in the region.

6.9.4 Onset, Cessation and Length of Growing Period

Probabilities of exceedance of the onset dates (specified as julian day numbers) are calculated using the Inverse Gaussian distribution. The 80, 50 and 20% probabilities of exceedance are determined and used as indicators of early, normal and late onset respectively.

Onset

According to the data available, the soil analysis involved 2 test samples one from 0 to 15 cm and the other from 15 to 30 cm. The depth of water in each case is determined. The sum of 0 to 15 and 15 to 30 cm gives the total depth of water available for 30 cm of depth. This depth of water obtained is then used to determine the total available water (TAW) for 25 cm of depth and considered as the threshold limit for analysis. For evaluation of onset criteria, a threshold value obtained as given in Table 4.5 for 4 consecutive days is appropriate for the study area (Raes et al 2004). Based on the above threshold value the actual onset and cessation dates for each year are determined. To eliminate the problems of early showers, which are followed by long dry spells, an appropriate initial search date and the corresponding onset are selected starting from June.

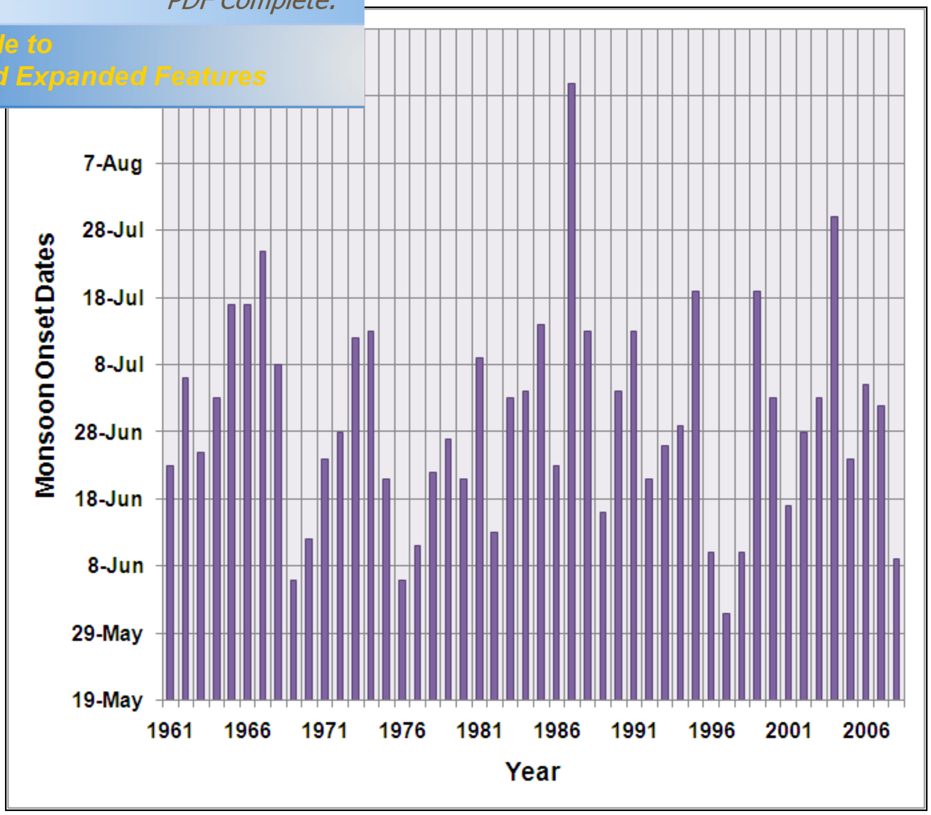

Fig. 6.157 Onset dates observed for Aslali, Ahmedabad district

The date having a probability of at least 20% or more that the root zone has adequate soil moisture was regarded as the date after which the onset criteria apply. The 20% probability level is commonly considered as acceptable while evaluating rainfed agriculture (Mugalavai et al. 2008). Starting from the initial search date the onset was taken to be the date on which the criteria was first satisfied or exceeded. Fig. 6.157 depicts the onset dates obtained for Aslali raingauge station. Similar results are obtained for remaining 72 raingauge stations. This different onset dates further analyzed for determining early, normal and late onset dates corresponding to 80, 50 and 20 percentages. A threshold value of rainfall is obtained for all the 73 raingauge stations and presented in Table 6.188. The onset dates obtained are suggested as the sowing date for the region.

For each of the 73 stations and for each of the 35-48 years of period that daily rainfall data is available the soil water content in the root zone is simulated with help of the soil water balance module in the Instat software. The Pearl millet crop is selected since it is the major crop grown in the region. The maximum rooting depth for Pearl millet is 0.30 m. Water stress is assessed by means of the water stress coefficient Ks (Allen et al., 1998). When water stress occurs, Ks decreases linearly with the soil water content and becomes zero when wilting point is reached. The cessation of the rainy season is assumed when Ks drops below 0.40 (Mugalavai et al. 2008). At that moment the crop experiences severe water stress and early canopy senescence is likely to be triggered. This simple approach eliminates the unrealistic long back-ends to the growing season. The cessation is taken to be the date on which the criterion was first satisfied or exceeded. The date having a probability of at least 20% that the root zone has adequate soil moisture (i.e., Ks is 1) is regarded as the date before which the cessation criteria apply corresponding to the early, normal and late onset dates.

Length of growing season

The length of the growing season (days) for a particular year is taken as the difference between the Julian day numbers of the determined for onset and the cessation dates.

The onset dates are obtained for 73 raingaguge stations. The calculated early, normal and late onset and cessation dates and length of growing season for the rainy season are presented in Table 6.188.

sted Sowing Dates), Cessation and Length of
Gujarat Agroclimatic Zone

Raingauge Station	Depth	Onset (suggested sowing dates)			Cessation			Length		
		Early	Normal	Late	Early	Normal	Late	Early	Normal	Late
Aslali	37	17-Jun	29-Jun	13-Jul	16-Sep	13-Sep	13-Sep	91	76	62
Bareja	31	18-Jun	26-Jun	12-Jul	5-Sep	9-Sep	12-Sep	79	75	62
Barejadi	40	18-Jun	27-Jun	5-Jul	17-Sep	13-Sep	13-Sep	91	78	70
Chandola	40	20-Jun	29-Jun	13-Jul	13-Sep	11-Sep	12-Sep	85	74	61
Dehgam	37	19-Jun	27-Jun	14-Jul	6-Sep	6-Sep	13-Sep	79	71	61
Sanand	40	17-Jun	25-Jun	14-Jul	7-Sep	6-Sep	19-Sep	82	73	67
Nal Lake	40	22-Jun	29-Jun	17-Jul	2-Sep	4-Sep	12-Sep	72	67	57
Wasai	40	20-Jun	3-Jul	12-Jul	14-Sep	12-Sep	14-Sep	86	71	64
Ambaji	40	19-Jun	30-Jun	14-Jul	9-Sep	12-Sep	1-Sep	82	74	49
amirgadh	25	16-Jun	27-Jun	13-Jul	20-Sep	23-Sep	23-Sep	96	88	72
Bapla	30	25-Jun	2-Jul	14-Jul	7-Sep	8-Sep	13-Sep	74	68	61
Chandisar	25	22-Jun	3-Jul	23-Jul	16-Sep	15-Sep	20-Sep	86	74	59
Chitrasani	25	16-Jun	30-Jun	13-Jul	19-Sep	18-Sep	21-Sep	95	80	70
Danta	40	16-Jun	28-Jun	14-Jul	16-Sep	15-Sep	12-Sep	92	79	60
Dantiwada	30	22-Jun	5-Jul	14-Jul	6-Sep	10-Sep	18-Sep	76	67	66
Deesa	30	14-Jun	30-Jun	16-Jul	27-Aug	4-Sep	10-Sep	74	66	56
Dhanera	30	13-Jun	6-Jul	18-Jul	12-Sep	13-Sep	19-Sep	91	69	63
Gadh	25	14-Jun	29-Jun	16-Jul	9-Sep	1-Sep	10-Sep	87	64	56
Hadad	40	25-Jun	4-Jul	15-Jul	17-Sep	5-Sep	1-Sep	84	63	48
Junisarotri	25	19-Jun	2-Jul	16-Jul	18-Sep	13-Sep	13-Sep	91	73	59
Nava	30	17-Jun	3-Jul	18-Jul	23-Aug	7-Sep	12-Sep	67	66	56
Palanpur	25	13-Jun	29-Jun	6-Jul	15-Sep	17-Sep	17-Sep	94	80	73
Panthawada	30	22-Jun	3-Jul	16-Jul	5-Sep	9-Sep	16-Sep	75	68	62
Sanali Ashram	40	21-Jun	1-Jul	14-Jul	10-Sep	10-Sep	10-Sep	81	71	58
Wadgam	30	19-Jun	30-Jun	16-Jul	11-Sep	9-Sep	23-Sep	84	71	69
mansa	40	19-Jun	29-Jun	12-Jul	10-Sep	8-Sep	13-Sep	83	71	63
Raipur weir	37	18-Jun	2-Jul	13-Jul	22-Sep	12-Sep	13-Sep	96	72	62
Balasinor	37	13-Jun	26-Jun	15-Jul	15-Sep	9-Sep	25-Sep	94	75	72
Dakor	37	17-Jun	25-Jun	7-Jul	22-Sep	17-Sep	16-Sep	97	84	71
Kapadwanj	37	16-Jun	26-Jun	12-Jul	16-Sep	14-Sep	14-Sep	92	80	64
Kathlal	37	17-Jun	30-Jun	12-Jul	12-Sep	23-Sep	18-Sep	87	85	68
Kheda	37	18-Jun	26-Jun	6-Jul	20-Sep	14-Sep	15-Sep	94	80	71
Mahemdabad	37	10-Jun	20-Jun	6-Jul	24-Sep	24-Sep	24-Sep	106	96	80
Mahisa	37	19-Jun	27-Jun	15-Jul	17-Sep	22-Sep	20-Sep	90	87	67
Nadiad	37	18-Jun	27-Jun	13-Jul	18-Sep	19-Sep	19-Sep	92	84	68
Pinglaj	37	17-Jun	3-Jul	18-Jul	15-Sep	13-Sep	17-Sep	90	72	61
Savli tank	37	16-Jun	27-Jun	15-Jul	11-Sep	22-Sep	21-Sep	87	87	68
Vadol	37	21-Jun	27-Jun	13-Jul	19-Sep	25-Sep	22-Sep	90	90	71
Vaghroli Tank	37	13-Jun	26-Jun	13-Jul	17-Sep	20-Sep	19-Sep	96	86	68
Ambaliyasan	40	23-Jun	2-Jul	18-Jul	8-Sep	8-Sep	14-Sep	77	68	58
Dharoi	40	15-Jun	25-Jun	13-Jul	20-Sep	17-Sep	5-Sep	97	84	54
Kadi	40	15-Jun	27-Jun	15-Jul	11-Sep	10-Sep	14-Sep	88	75	61
Kalol	40	17-Jun	1-Jul	15-Jul	17-Sep	8-Sep	13-Sep	92	69	60
Katosan	40	20-Jun	29-Jun	13-Jul	8-Sep	9-Sep	10-Sep	80	72	59
Kheralu	40	22-Jun	3-Jul	13-Jul	18-Sep	18-Sep	19-Sep	88	77	68
Mehsana	40	15-Jun	4-Jul	18-Jul	4-Sep	10-Sep	15-Sep	81	68	59
Ransipur	40	22-Jun	12-Jul	13-Jul	13-Sep	18-Sep	17-Sep	83	68	66
Thol	40	18-Jun	3-Jul	25-Jul	6-Sep	7-Sep	16-Sep	80	66	53
Unjha	30	17-Jun	1-Jul	17-Jul	9-Sep	14-Sep	17-Sep	84	75	62

[illegible]	[illegible]	[illegible]	Jun	7-Jul	17-Sep	13-Sep	20-Sep	93	77	75
[illegible]	[illegible]	[illegible]	-Jul	16-Jul	2-Sep	9-Sep	17-Sep	71	70	63
[illegible]	[illegible]	[illegible]	-Jul	21-Jul	30-Aug	6-Sep	13-Sep	68	62	54
Sidhpur	25	13-Jun	27-Jun	7-Jul	8-Sep	12-Sep	15-Sep	87	77	70
Wagdod	40	16-Jun	29-Jun	21-Jul	23-Aug	25-Aug	13-Sep	68	57	54
Badoli	31	22-Jun	1-Jul	14-Jul	21-Sep	19-Sep	19-Sep	91	80	67
Bayad	37	15-Jun	26-Jun	6-Jul	21-Sep	2-Oct	25-Sep	98	98	81
Bhiloda	32	12-Jun	20-Jun	5-Jul	15-Sep	25-Sep	23-Sep	95	97	80
Dantral	30	18-Jun	28-Jun	9-Jul	11-Sep	8-Sep	13-Sep	85	72	66
Himmatnagar	30	10-Jun	27-Jun	14-Jul	13-Sep	17-Sep	20-Sep	95	82	68
Idar	31	16-Jun	25-Jun	2-Jul	17-Sep	30-Sep	17-Sep	93	97	77
Khedbhrama	37	20-Jun	2-Jul	14-Jul	19-Sep	19-Sep	19-Sep	91	79	67
Kundlacampo	37	17-Jun	28-Jun	12-Jul	22-Sep	25-Sep	22-Sep	97	89	72
Limla dam	27	21-Jun	29-Jun	8-Jul	20-Sep	15-Sep	17-Sep	91	78	71
Malpur	32	16-Jun	25-Jun	14-Jul	21-Sep	25-Sep	20-Sep	97	92	68
Meghraj	32	17-Jun	27-Jun	9-Jul	17-Sep	25-Sep	20-Sep	92	90	73
Modasa	32	12-Jun	24-Jun	8-Jul	17-Sep	24-Sep	18-Sep	97	92	72
Pal	37	22-Jun	3-Jul	12-Jul	21-Sep	4-Oct	22-Sep	91	93	72
Prantij	27	13-Jun	25-Jun	4-Jul	10-Sep	23-Sep	19-Sep	89	90	77
Sabli	31	24-Jun	3-Jul	18-Jul	26-Sep	16-Sep	26-Sep	94	75	70
Shamlaji	32	17-Jun	26-Jun	11-Jul	21-Sep	24-Sep	19-Sep	96	90	70
Vadgam	32	19-Jun	29-Jun	12-Jul	16-Sep	22-Sep	15-Sep	89	85	65
Vijaynagar	37	16-Jun	23-Jun	8-Jul	17-Sep	14-Sep	15-Sep	93	83	69
Virpur	31	16-Jun	30-Jun	13-Jul	17-Sep	14-Sep	18-Sep	93	76	67

At Aslali raingauge station, the earliest onset obtained on 17th of June, normal onset obtained on 29th June and latest onset obtained on 13th July. The probability of dry spell length during the onset dates, 30 days and 50 days following onset are presented in Tables 6.189 and 6.190 for Aslali raingauge stations.

From Table 6.189 one can see that for early onset the spell length of 7 days gives maximum probability of 89 %. As the spell length increases the probability decreases. For spell length of 14 days the maximum probability is 24 %. This means that for a crop sown on 17th June the probability of dry spell of 7 days over a period of 30 days is 89% and it decreases as the spell length increases to 14 days upto 24%. Therefore for a crop which can withstand 7 days dryspell during initial sowing period, irrigation has to be provided as the probability of wet spell is only 11 %. But for a crop which is able to withstand 14 days of dry spell during initial sowing period, no supplemental irrigation is required as the probability of wet spell is 76 %. The 30th and 50th days following sowing are having maximum probability of 41 % and 62 % respectively. The first critical growth period of 30th day following sowing date is appropriate as the probabilities are more than 41 %. While for second th day following sowing date is appropriate for spell e than 8 days with maximum probability of 46 %. Thus initial irrigation if provided the crop grown on 17th June can survive during the critical growth stages for spell length of more than 8 days where the probability is greater than 50%.

For the normal onset date of 29th of June, the probability of crop having spell length of 7 days is 65 % and for 14 days it is 7 %. Initial irrigation may be required in case for dry spell length of 7 days, the probability for dry spell length of 8 or more days is greater than 50 % so it may not require inital irrigation. The 1st critical growth stage is falling in the range of 2 to 47 % for 14 to 7 days respectively. While for the 2nd critical growth stage the range is from 21 to 86 % for 14 to 7 days respectively. For dry spell of 11 or more days the 50th day following sowing has probability of less than 42 %. But for 7 to 10 days dry spell the probability is more than 50 %. Therefore irrigation has to be provided for the second critical growth period for the crop which cannot to withstand a dry spell length of 7 to 10 days over a period of 30 days.

For late onset date of 13th July, the probability of sowing date having 7 days dry spell over a period of 30 days period is 43 % and is the maximum. The first critical growth stage is having 75 % probability for 7 days dry spell over a period of 30 days. While for second critical growth stage the probability increases to 99% and is greater than 50 % for all the dry spell length from 7 to 14 days. Therefore irrigation has to be provided. There is no need during initial sowing period but irrigation is must when the second critical growth stage is arrived after 50 days following sowing. For the first critical growth stage irrigation is required for dry spell length of 7 and 8 days and for more than 8 days the wet spell probability is more than 50 %, hence indicating no irrigation requirement.

Dry Spell for Aslali Raingauge Station Using 2.5

Date		Dry Spell Length							
		7	8	9	10	11	12	13	14
Early onset	17th Jun	0.82	0.70	0.57	0.46	0.36	0.28	0.21	0.16
30th day following onset	17th Jul	0.41	0.27	0.17	0.11	0.07	0.04	0.03	0.02
50th day following onset	6th Aug	0.62	0.46	0.34	0.24	0.17	0.12	0.08	0.06
Normal onset	29th Jun	0.65	0.50	0.38	0.27	0.20	0.14	0.10	0.07
30th day following onset	29th Jul	0.47	0.33	0.22	0.15	0.09	0.06	0.04	0.02
50th day following onset	18th Aug	0.86	0.75	0.64	0.53	0.42	0.34	0.26	0.21
Late onset	13th Jul	0.43	0.29	0.19	0.12	0.08	0.05	0.03	0.02
30th day following onset	12th Aug	0.75	0.61	0.48	0.37	0.28	0.20	0.15	0.11
50th day following onset	1st Sep	0.99	0.96	0.92	0.86	0.80	0.72	0.65	0.57

Table 6.190 Probability of Dry Spell for Aslali Raingauge Station Using 8 mm Threshold Value

Date		Dry Spell Length							
		7	8	9	10	11	12	13	14
Early onset	17th Jun	0.89	0.79	0.68	0.57	0.47	0.38	0.30	0.24
30th day following onset	17th Jul	0.59	0.43	0.31	0.21	0.15	0.10	0.07	0.05
50th day following onset	6th Aug	0.80	0.67	0.55	0.43	0.34	0.26	0.19	0.14
Normal onset	29th Jun	0.82	0.70	0.57	0.46	0.36	0.28	0.21	0.16
30th day following onset	29th Jul	0.67	0.52	0.39	0.28	0.20	0.14	0.10	0.07
50th day following onset	18th Aug	0.58	0.43	0.31	0.21	0.15	0.10	0.07	0.04
Late onset	13th Jul	0.61	0.45	0.33	0.23	0.16	0.11	0.08	0.05
30th day following onset	12th Aug	0.89	0.80	0.70	0.59	0.49	0.39	0.32	0.25
50th day following onset	1st Sep	1.00	0.99	0.97	0.95	0.91	0.87	0.82	0.76

Overall the three onset dates can be considered for a crop which can withstand a dry spell length of more than 11 days. But a dry spell length of 7 to 10 days is critical for a crop then in case for early onset and 50th day following the latest onset irrigation needs to be provided.

When one considers 8 mm threshold value the situation becomes more critical as can be seen from Table 6.190. Crops withstanding a long dry spell of 11 to 14 days are only advisible except for the 50th day following latest onset date, where the probabilities are more than 76%. Hence requires irrigation facilities similar to the 2.5 mm threshold value results. For other spell length of 7 to 10 days supplemental irrigation is must as the maximum probabilities are more than 50 %.

Similar results are obtained for the other stations. Tables 6.191 to Table 6.334 represents the probability of dry spell for remaining 72 raingauge stations threshold value. These Tables 6.191 to 6.334 are the onset and probability of dry spell length can be used for planning the crops within the area into consideration.

To confirm that the selected onset and cessation dates for each station are representative of the current climatic conditions, a homogeneity test based on cumulative deviation from the mean is carried out. The results for the homogeneity test reveals that the generated onset and cessation dates are homogeneous over the past 35ï 48 years for each of the 73 stations. This indicates that there is no shift in onset and cessation in the past 35-48 years; however, continuous monitoring should be carried out to detect any shift if it arises in the future. The Mann Kendall trend analysis is also performed to determine any trend if present in the onset dates obtained. Table 6.335 presents the results obtained.

Table 6.335 Trend Values for Onset Dates

Sr. no.	Name of raingauge station	Trend value day / year	Sr. no.	Name of raingauge station	Trend value day / year	Sr. no.	Name of raingauge station	Trend value day / year
1	Aslali	-0.06	26	Mansa	-0.06	51	Visnagar	0.03
2	Bareja	0.14	27	Raipurweir	0.36	52	Patan	0.16
3	Barejadi	0.00	28	Balasinor	-0.24	53	Sidhpur	-0.20
4	Chandola	0.27	29	Dakor	0.16	54	Wagdod *	0.73
5	Dehgam	0.13	30	Kapadwanj	-0.09	55	Badoli	0.16
6	Nal Lake	-0.11	31	Kathlal	0.20	56	Bayad	-0.04
7	Sanand	0.00	32	Kheda	0.00	57	Bhiloda	0.00
8	Vasai	0.27	33	Mahemdabad *	0.43	58	Dantral	0.00
9	Ambaji	0.07	34	Mahisa +	0.35	59	Himatnagar	0.00
10	Amirgadh	-0.25	35	Nadiad	0.30	60	Idar +	0.31
11	Bapla	-0.16	36	Pinglaj	0.31	61	Khedbrahma +	-0.35
12	Chandisar	-0.06	37	Savli tank	0.20	62	Kundlacampo	0.00
13	Chitrasani	-0.20	38	Vadol	-0.20	63	Limla dam	0.00
14	Danta	-0.26	39	Vaghroli Tank	-0.22	64	Malpur	-0.07
15	Dantiwada +	-0.31	40	Ambaliyasan	0.00	65	Meghraj	0.00
16	Deesa	-0.19	41	Dharoi *	-0.29	66	Modasa	-0.03
17	Dhanera	-0.06	42	Kadi	0.00	67	Pal	-0.23
18	Gadh	-0.12	43	Kalol +	-0.36	68	Prantij	-0.09
19	Hadad	-0.18	44	Katosan	-0.09	69	Sabli	-0.05
20	Junisarotri	0.25	45	Kheralu	-0.21	70	Shamlaji	-0.21
21	Nava ***	-0.73	46	Mehsana	0.00	71	Vadgam	0.00
22	Palanpur	-0.10	47	Ransipur	0.00	72	Vijaynagar	0.04
23	Panthawada	-0.19	48	Thol	-0.24	73	Virpur	0.18
24	Sanali Ashram	-0.33	49	Unjha	-0.11			
25	Wadgam	-0.10	50	Vijapur	-0.03			

Note: + Significance at 10 % level; * Significance at 5 % level; *** Significance at 1 % level n be observed that Barejadi, Sanand, Kheda, Ransipur, Bhiloda, Dantral, Himmatnagar, Kundalcampo, Limla dam, Meghraj and Vadgam stations have uniform onset dates indicated by zero trend value. All other raingauge stations have either increasing or decreasing trend with no significance level except Dantiwada, Nava, Mahemadabad, Mahisa, Dharoi, Kalol, Wagdod, Idar and Khedbrahma stations. The maximum increasing trend of 0.73 day per year is observed at Wagdod while maximum decreasing trend is observed at Nava of 0.73 day per year. Fig. 6.158 presents the plot of trend values for the region. The onset and cessation dates and the length of growing season are plotted as isochrones in Figs. 6.159 to 6.167.

From Fig. 6.158 one can say that the trend of onset of monsoon observed in the south is increasing and it decreases as one moves from south to north. Most of the area experiences decreasing trend indicating green colour.

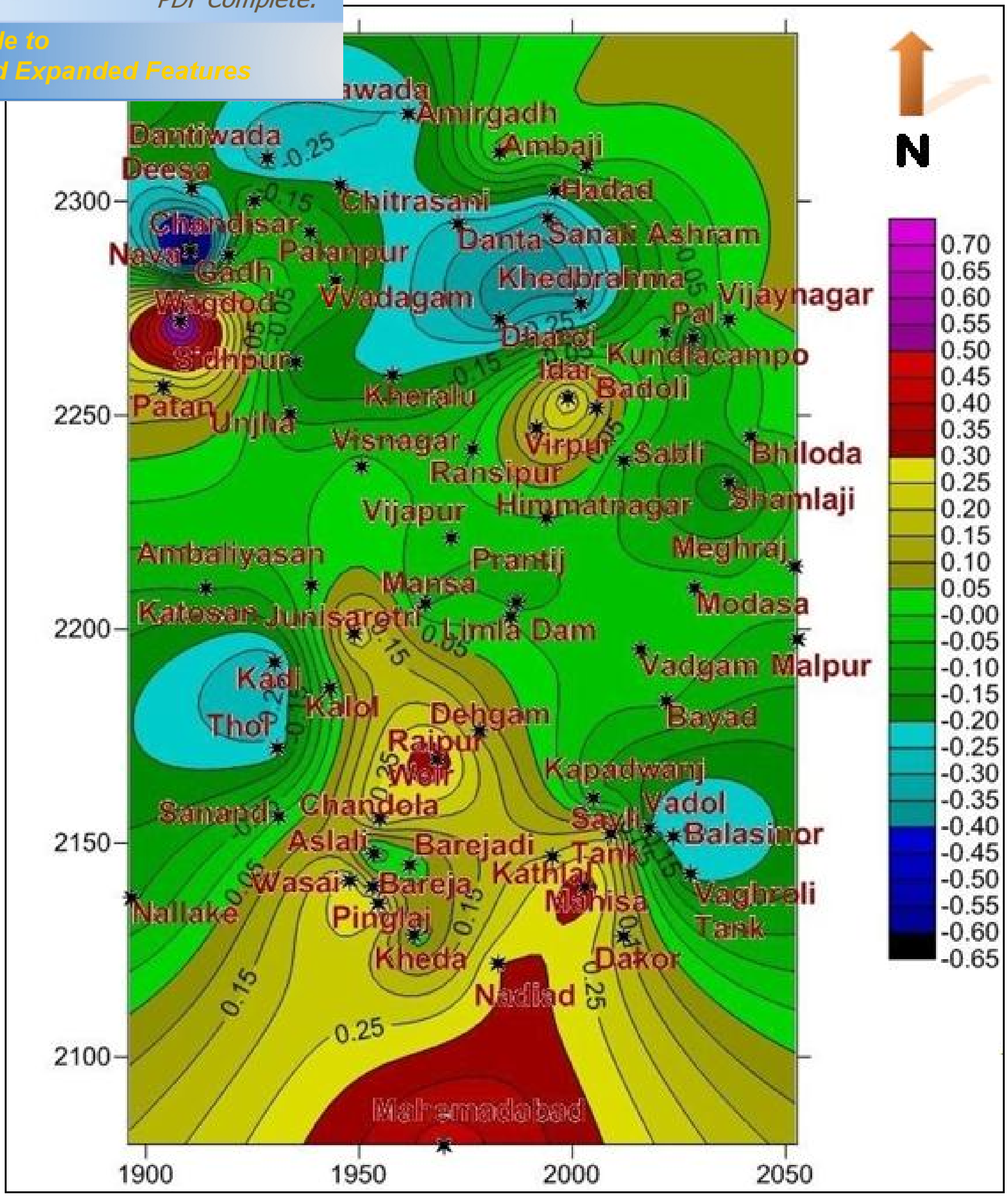

Fig. 6.158 Trend of onset of monsoon for north Gujarat agroclimatic zone.

The amount of supplemental irrigation water required based on the information of probability of dry spell and the onset dates in case for early and late dates for one of the major crops (i.e Pearl millet) are determined for 36 years (1969ï 2005). The maximum values observed during 36 years in each case are given in Tables 6.336 and 6.337 respectively for the raingauge stations in Ahmedabad district. Overall for north Gujarat agroclimatic zone if one considers the early onset date to be the sowing date, the total water

31.62 mm to 501.81mm with an average value of nsiders the late onset date to be the sowing date, the total water requirement ranges from 314.16 mm to 472.25 mm with an average value of 368.40 mm.

Table 6.336 Maximum Amount of Supplemental Irrigation Water Required for Pearl Millet Crop Considering Sowing Date to be Early Onset Date for Ahmedabad District

Station	Total water requirement	Using 2.5 mm threshold value and dry spell length				Using 8 mm threshold value and dry spell length			
		7	8	9	10	7	8	9	10
Aslali	436.67	108.28	56.46	43.56	24.28	225.94	86.26	60.93	55.27
Bareja	501.81	127.19	59.92	32.08	0.00	254.70	254.70	164.17	74.50
Barejadi	431.83	79.53	53.27	37.75	15.77	212.21	212.21	105.47	53.27
Chandola	418.32	93.51	53.41	36.29	12.08	209.27	209.27	209.27	100.62
Dehgam	422.80	72.33	47.79	41.24	23.41	187.77	187.77	187.77	90.98
Nal Lake	402.15	181.57	170.72	81.65	35.50	181.57	181.57	181.57	170.72
Sanand	419.19	131.08	64.30	41.40	15.72	213.11	213.11	213.11	100.12
Wasai	425.94	84.33	53.97	28.81	12.08	216.21	216.21	158.58	79.48

From Table 6.336 for 2.5 mm threshold value it can be observed that as the number of dry spell length increases the amount of water required in excess of rainfall decreases. Overall it can be said that the maximum amount of water required in case for 7 days dry spell length is about 45.15 % (i.e. 181.57 / 402.15) of the total water requirement and decreases to 2.8 % (12.08 / 418.32) of the total water requirement for 10 days dry spell length.

From Table 6.337 for 8 mm threshold value it can be observed that as the number of dry spell length increases the amount of water required excess of rainfall decreases. Overall it can be said that the maximum amount of water required in case for 7 days dry spell length is about 51.74 % (= 225.94 / 436.67) of the total water requirement and decreases to 12.33 % (=53.27 / 431.83) of the total water requirement for 10 days dry spell length.

When one considers the late onset date to be the sowing date, then the total maximum water requirement for Pearl millet varies over the raingauges in the district and ranges from 407.21 mm at Aslali to 472.25 mm at Bareja.

mm threshold value it can be observed that as the increases the amount of water required excess of rainfall decreases. Overall it can be said that the maximum amount of water required in case for 7 days dry spell length is about 45.80 % (= 186.62 / 407.21) of the total water requirement and decreases to 9.75 % (= 41.66 / 427.06) of the total water requirement for 10 days dry spell length.

Table 6.337 Maximum Amount of Supplemental Irrigation Water Required for Pearl Millet Crop Considering Sowing Date to be Late Onset Date in Ahmedabad District

Station	Total water requirement	Using 2.5 mm threshold value and dry spell length				using 8 mm threshold value and dry spell length			
		7	8	9	10	7	8	9	10
Aslali	407.21	186.52	135.37	117.68	109.28	132.08	111.73	94.68	80.27
Bareja	472.25	133.58	105.20	78.66	64.44	221.19	221.19	155.27	124.60
Barejadi	427.06	140.76	93.18	69.82	41.66	174.62	174.62	132.00	93.18
Chandola	420.77	135.60	116.79	98.74	76.83	173.60	173.60	173.60	132.62
Dehgam	409.36	136.55	115.90	102.67	86.06	172.81	172.81	172.81	125.56
Nal Lake	417.67	157.34	144.11	125.98	114.73	157.34	157.34	157.34	144.11
Sanand	411.70	139.99	116.51	104.21	89.09	161.57	161.57	161.57	137.87
Wasai	418.48	133.95	114.43	94.35	74.78	171.12	171.12	141.26	123.77

From Table 6.337 for 8 mm threshold value it can be observed that as the number of dry spell length increases the amount of water required excess of rainfall decreases. Overall it can be said that the maximum amount of water required in case for 7 days dry spell length is about 46.83 % (= 221.19 / 472.25) of the total water requirement and decreases to 19.70 % (= 80.27 / 407.21) of the total water requirement for 10 days dry spell length. Table 6.338 to 6.349 represents the amount of supplemental irrigation water required for Pearl Millet crop for Banaskantha, Gandhinagar, Kheda, Mehsana, Patan and Sabarkantha districts and are given in CD.

From Fig. 6.159 one can say that monsoon hits the southern part first and travels from south to north in the region. Late showers are observed in the western portion consisting Patan district and some parts of Mehsana district. Even the northern part of Banaskantha consisting of Bapla, Panthawada and Dantiwada regions receives rainfall later compared to other regions. For the ranges from 10th June to 25th June with an average ar with an early onset, the onset over the region generally shows a gradual progression from the southern part of the region towards the north, however, it shows a general southwesterly progression. Since this is the period when the south-east (SE) monsoon sets in, the monsoon onset approaches from two ends one progressing from south east and the other with stronger south easterly progression. The two arms then gradually move northwards.

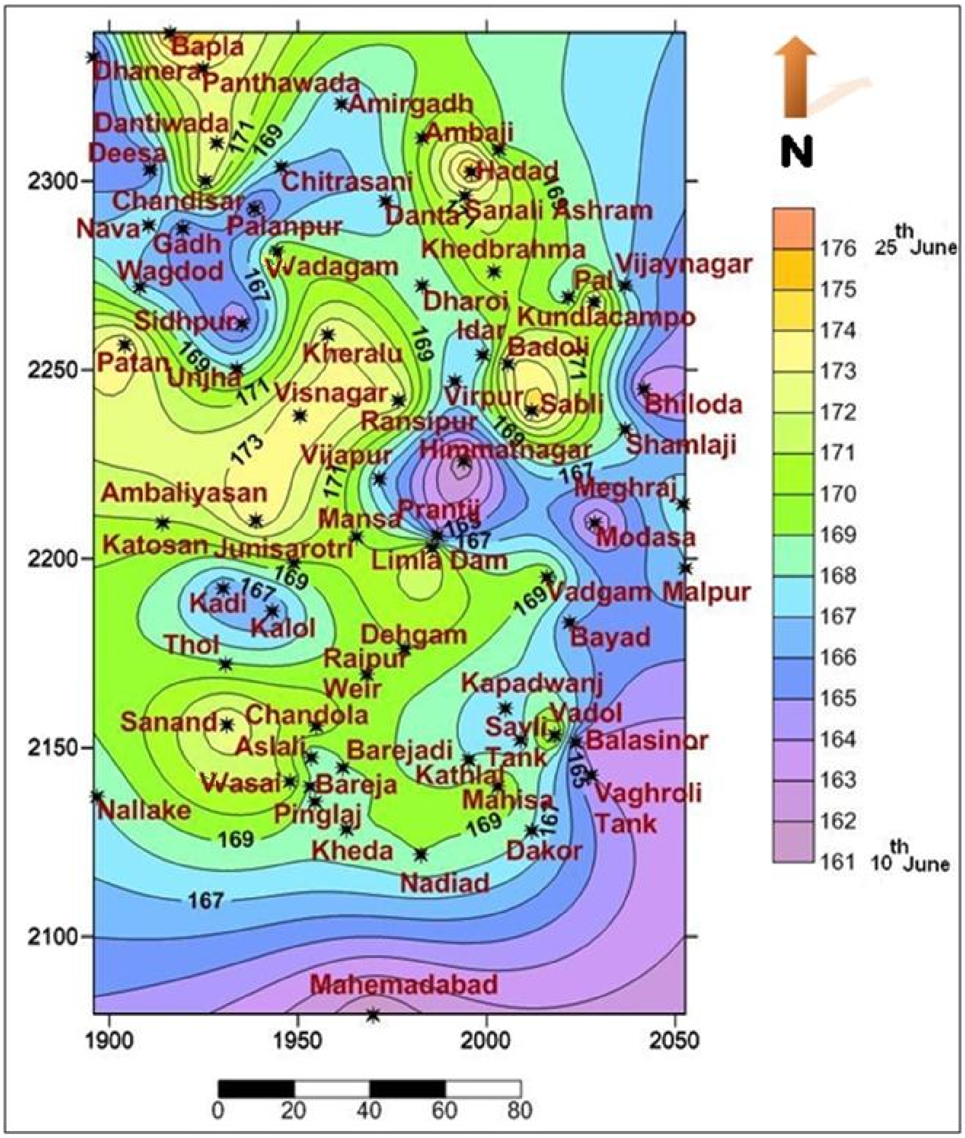

Fig. 6. 159 Early onset dates in Julian days starting from 1st January for north Gujarat Agroclimatic zone

wn for normal and late onset dates, depticts the for the early onset date. The normal and late onset ranges are larger compared to the early onset one. The normal onset dates ranges from 20th June at Bhiloda to 12th July at Ransipur with an average value of 29th June. For late onset the range is between 2nd July and 25th July observed at Idar and Thol respectively with an average value of 13th July.

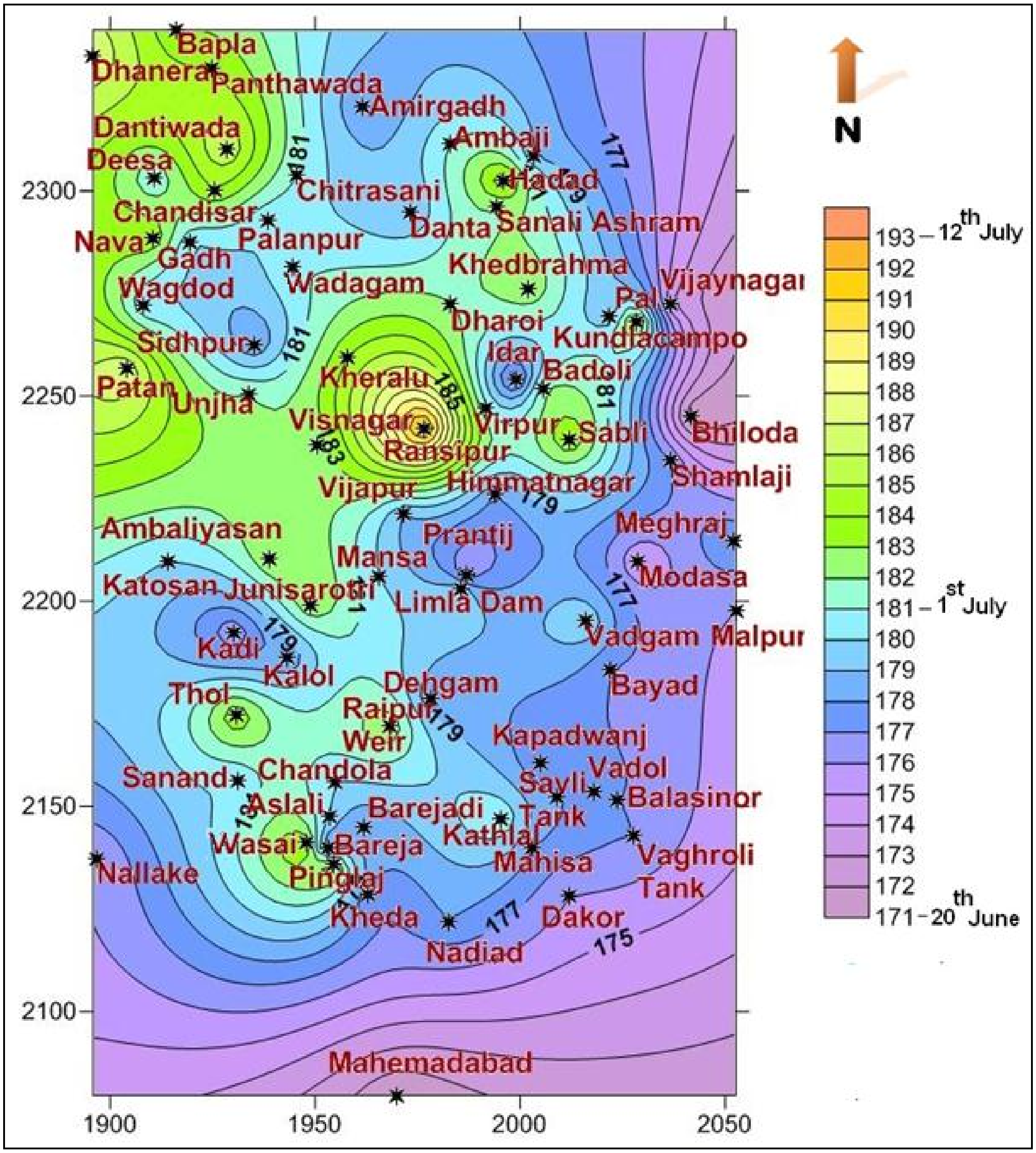

Fig. 6.160 Normal onset dates in Julian days starting from 1st January for north Gujarat agroclimatic zone

rve that in all the three cases of early, normal and arts in the Kheda region and travels simultaneously from two ends one travelling from Ahmedabad to Gandhinagar and other travelling from eastern part of Sabarkantha. Both the arms then meet and the rains then progress from Mehsana to Banaskantha and Patan regions.

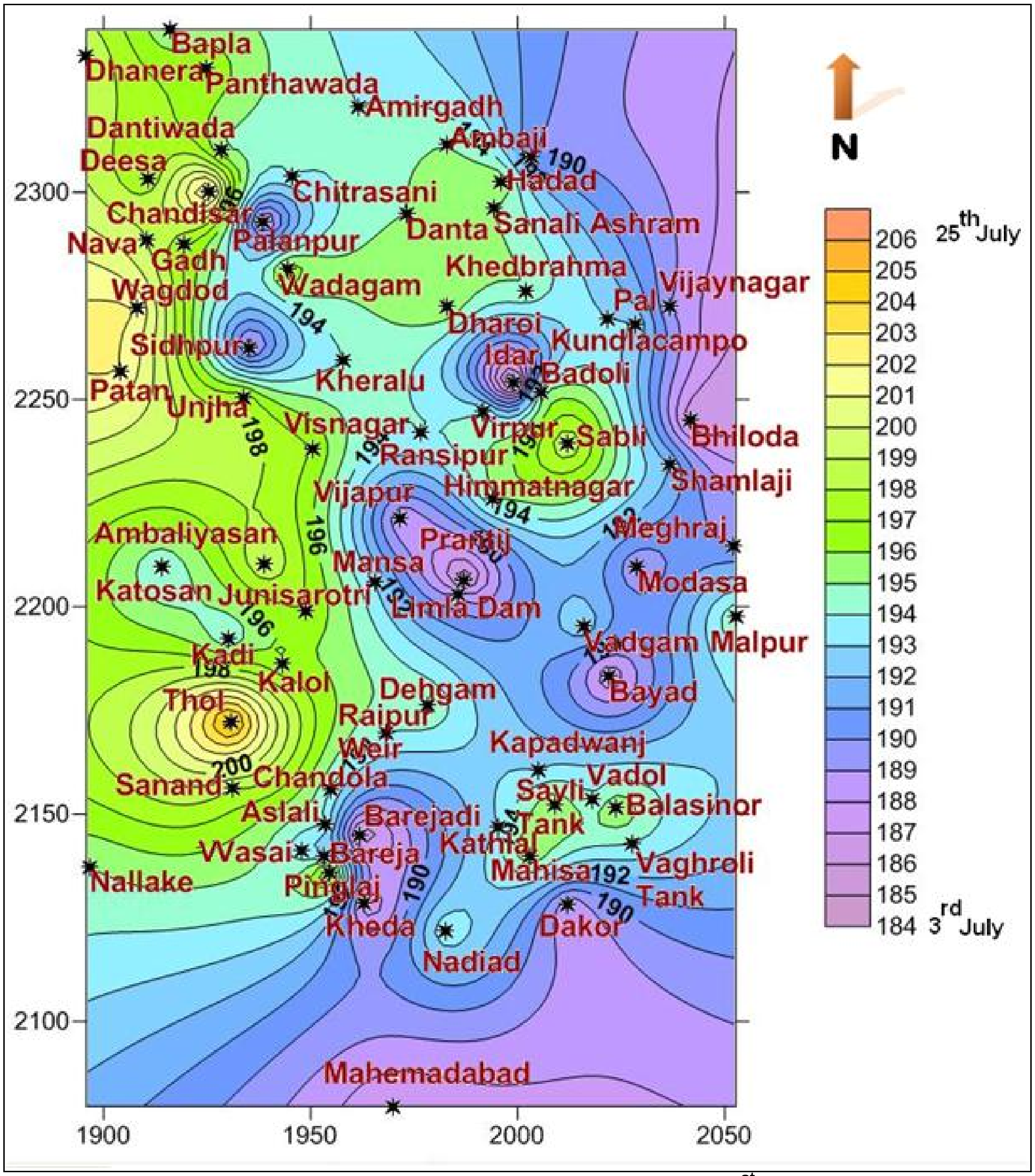

Fig. 6.161 Late onset dates in Julian days starting from 1st January for north Gujarat agroclimatic zone

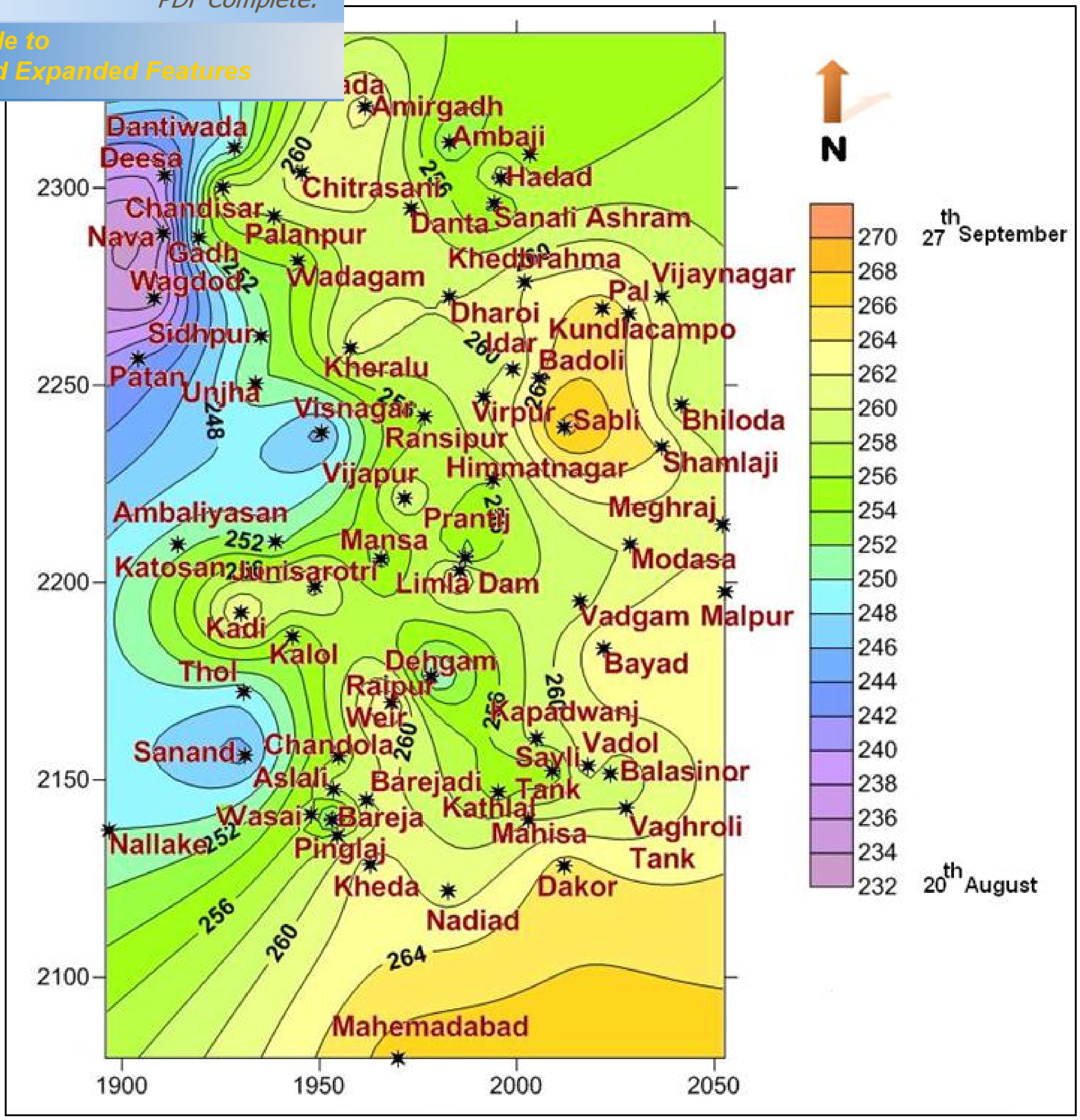

Fig. 6.162 Early cessation dates in Julian days starting from 1st January for north Gujarat agroclimatic zone

Results indicate that the recession pattern is opposite to that observed for the onset one. From Fig. 6.162, the rain first receeds from Patan and north western part consisting areas in Banaskantha district and then receeds from Mehsana, then Sabarkantha then Gandhinagar, then Ahmedabad and then lastly from Kheda and some parts of Sabarkantha district. Thus the length of growing period will be more as one travels from south to north in the region

.165. The cessation ranges from 23rd August at at Sabli with an average value of 13th September.

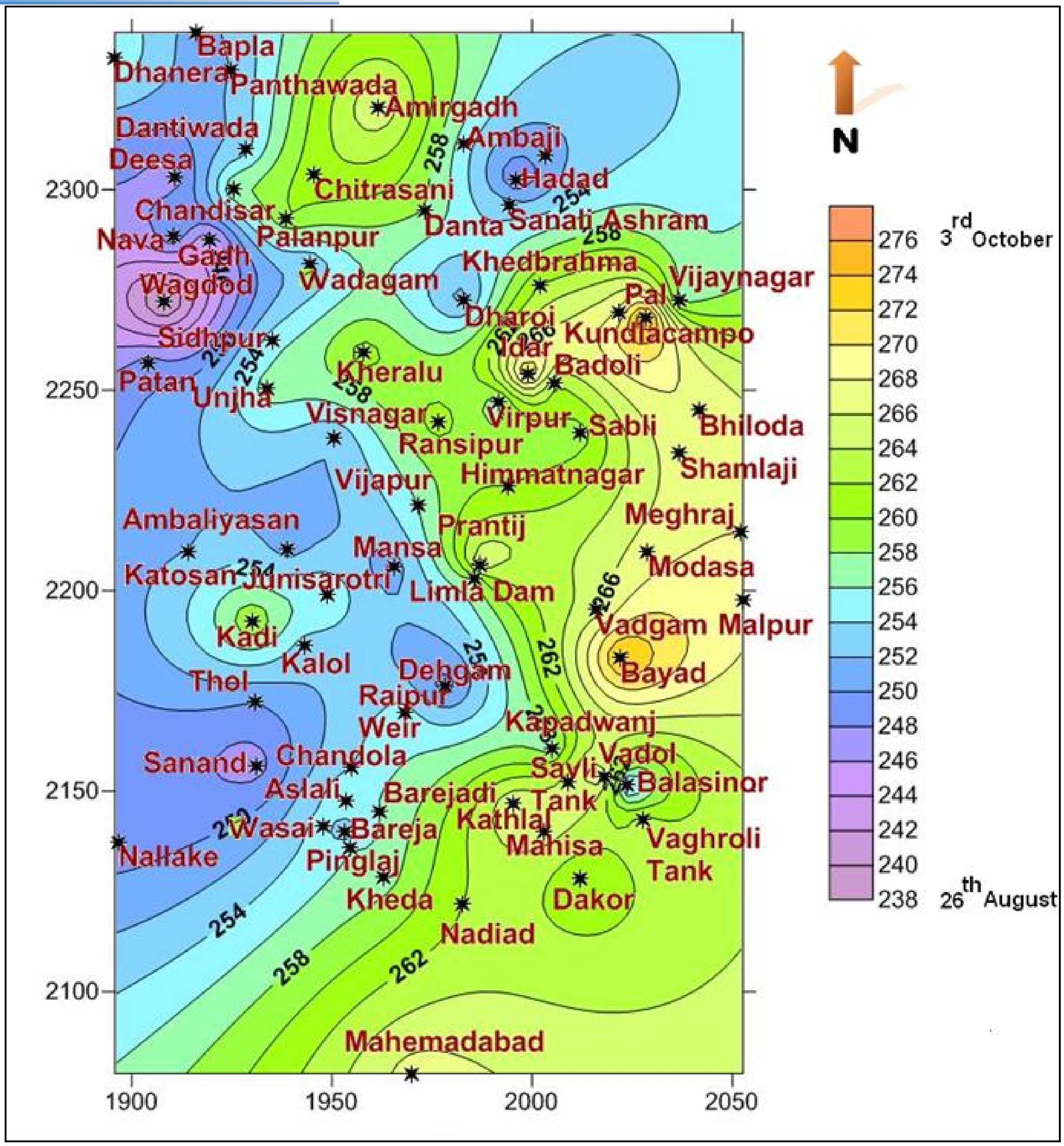

Fig. 6.163 Normal cessation dates in Julian days starting from 1st January for north Gujarat agroclimatic zone

Fig. 6.163 shows normal cessation dates which follows similar pattern as the early cessation ones. The data range is more compared to the early cessation. Monsoon starts receeding from north western part and lastly recedes from the south eastern part as can be seen from Fig. 6.163 in the ges from 25th August to 4th October observed at

ely. The average cessation date is 14th September.

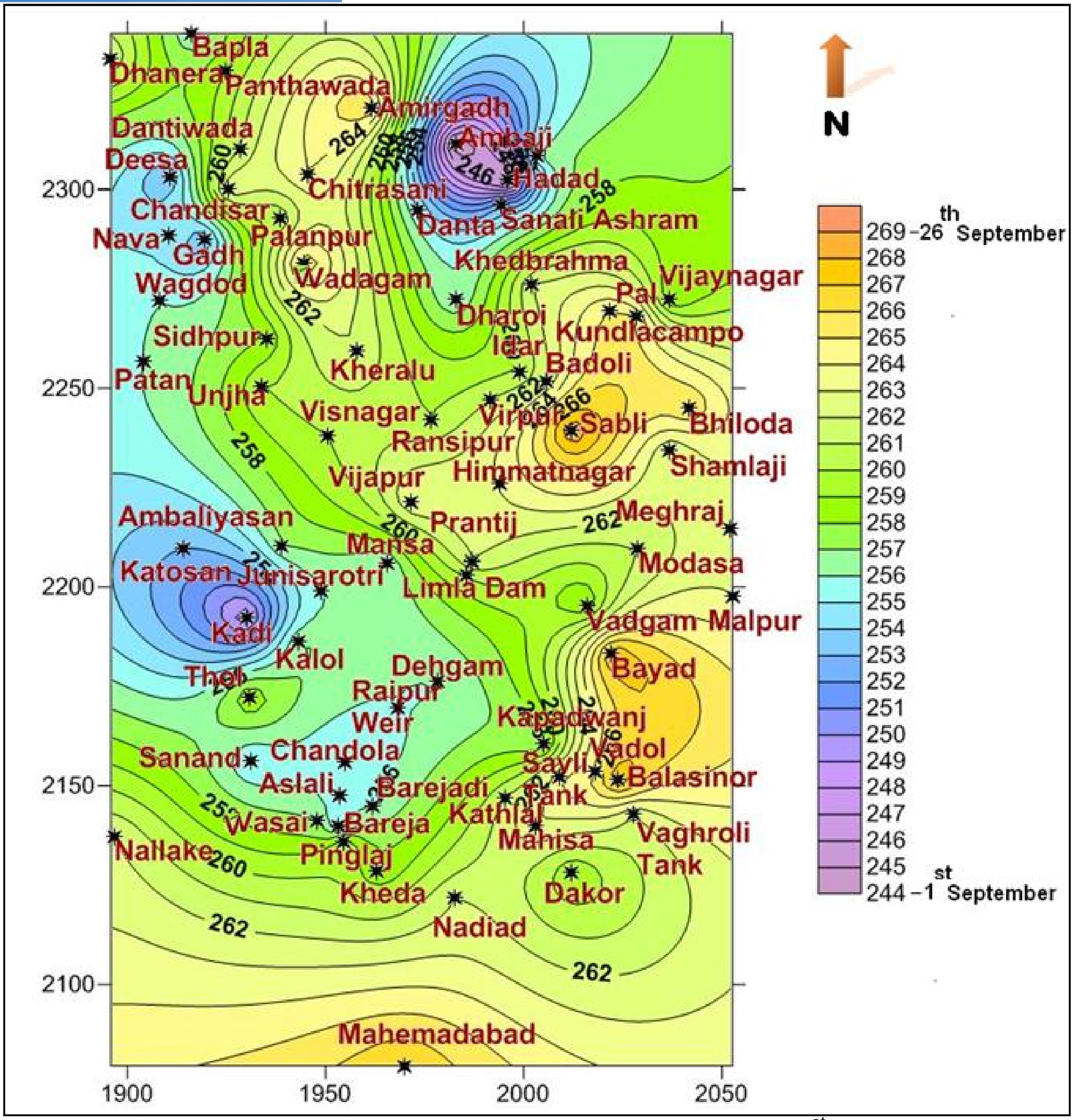

Fig. 6.164 Late cessation dates in Julian days starting from 1st January for north Gujarat agroclimatic zone

From Fig. 6.164 the late cessation dates are denser compared to earliest and latest. The pattern of recession slightly differs from the earlier two isochrones. The rain starts receeding from north central parts consisting of some parts of Banaskantha district and also it starts receeding from western part consisting ate cessation ranges from 1st September at Hadad with an average value of 16th September.

Figs. 6.165 to 6.166 show the isochrones for length of growing period. The three plots show similarity with its respective cessation plots. The early length of growing period ranges from 67 to 106 days with an average period of 88 days. The lowest value corresponds to Deesa raingauge station and the highest is observed at Mahemadabad raingauge station. The normal length of growing period ranges from 57 to 98 days with an average period of 78 days. The lowest value corresponds to Wagdod raingauge station and the highest is observed at Bayad raingauge station. The late length of growing period ranges from 48 to 81 days with an average period of 65 days. The lowest value corresponds to Hadad raingauge station and the highest is observed at Bayad raingauge station.

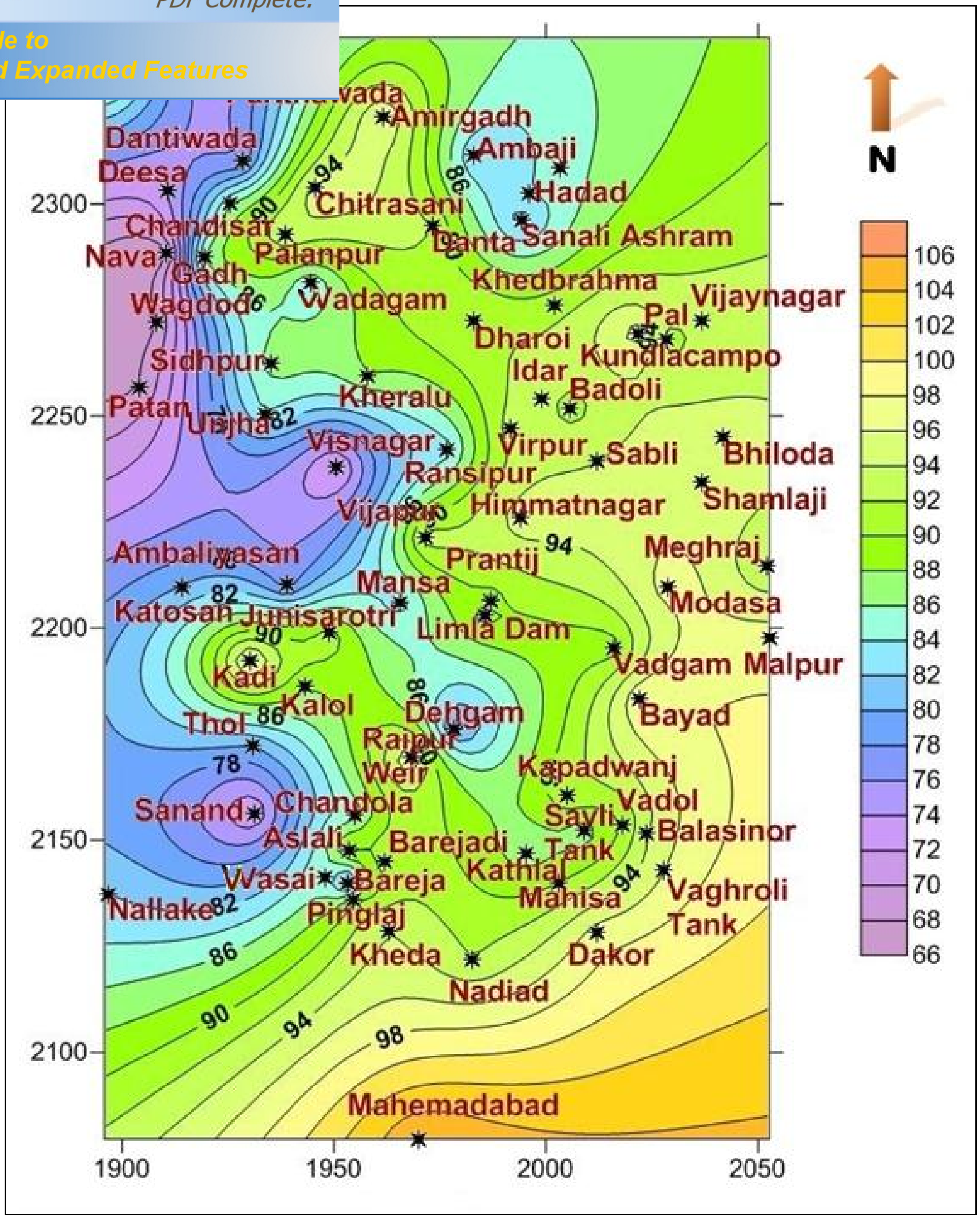

Fig. 6.165 Early length of growing period for north Gujarat agroclimatic zone

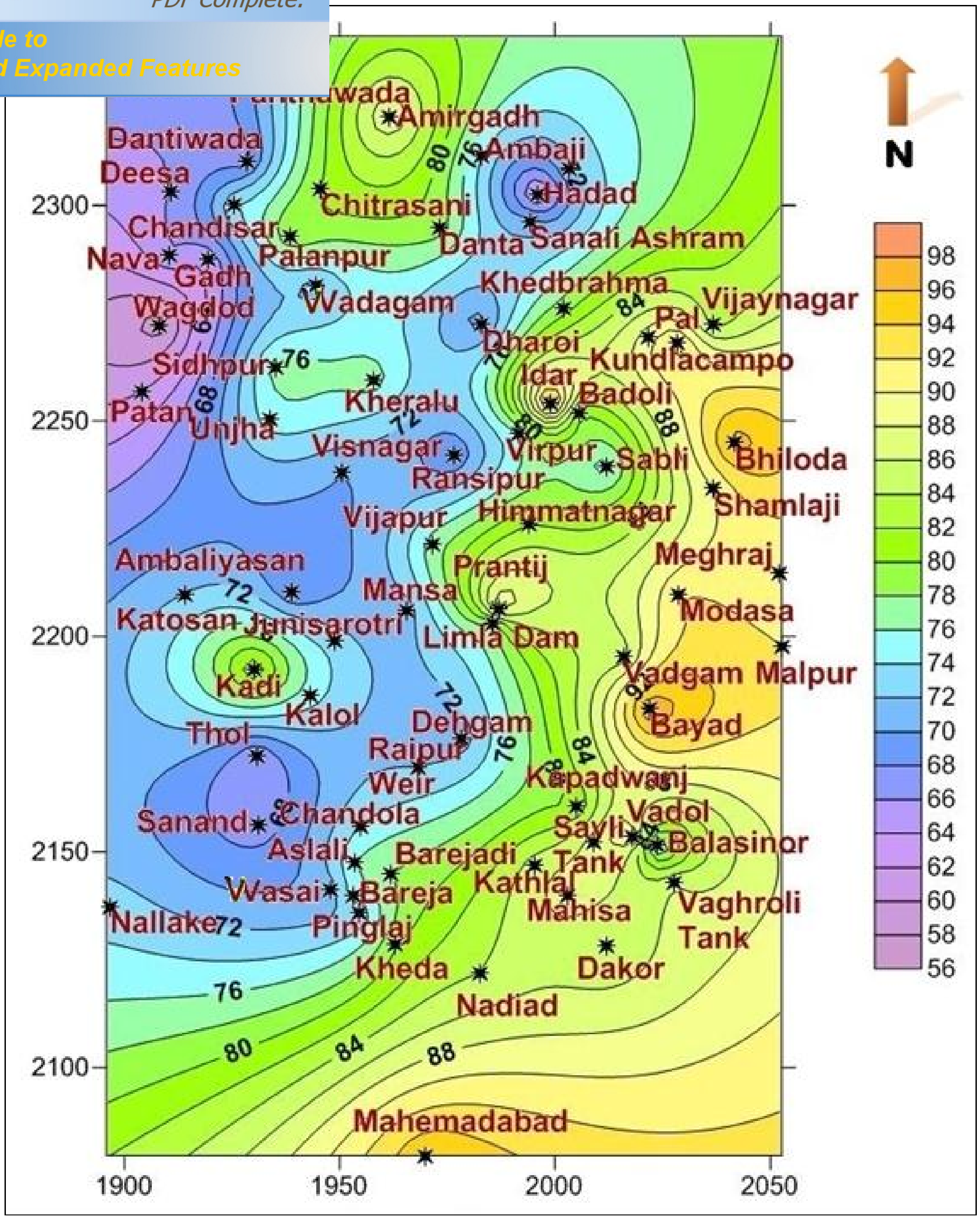

Fig. 6.166 Normal length of growing period for north Gujarat agroclimatic zone

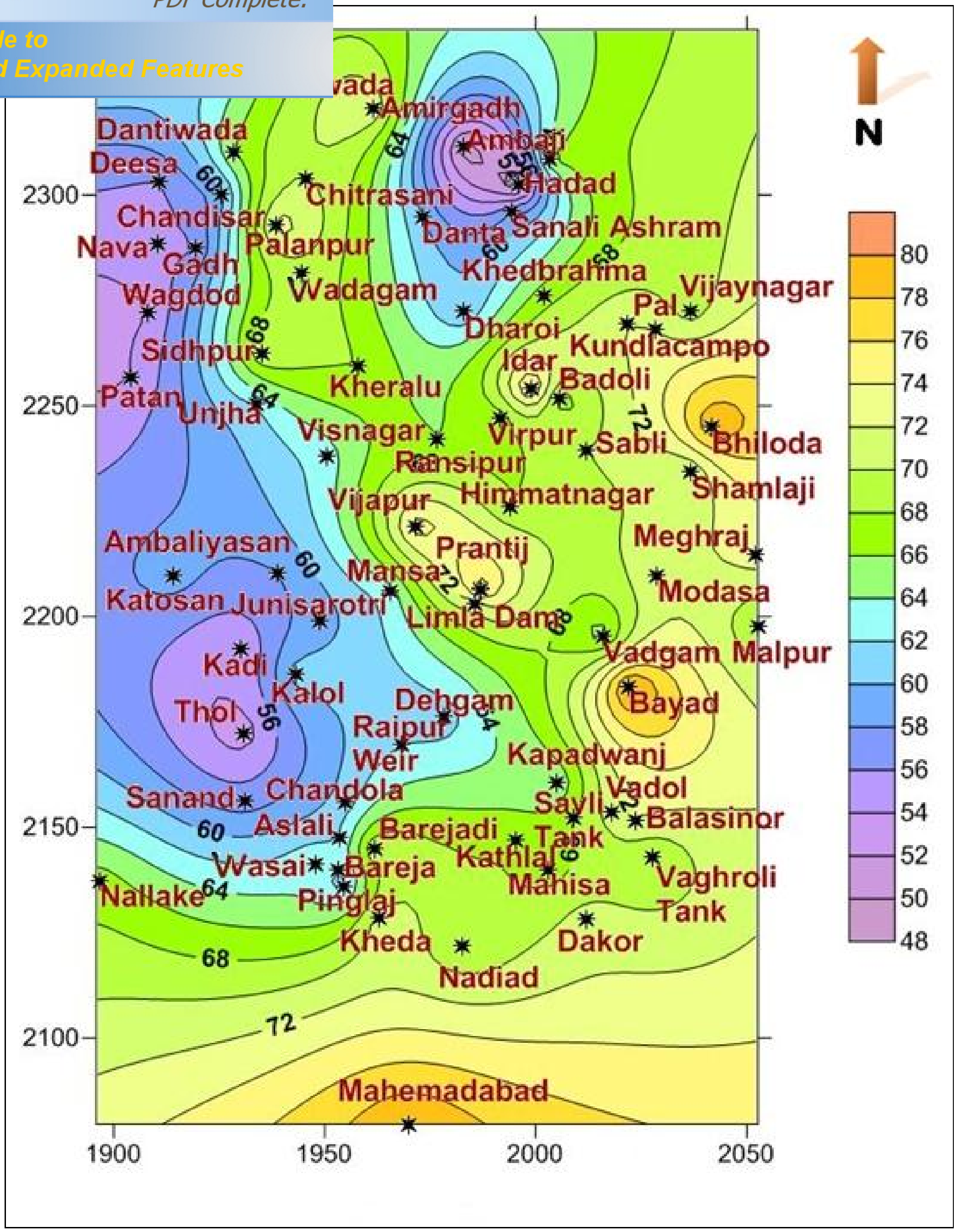

Fig. 6.167 Late length of growing period for north Gujarat agroclimatic zone

hat the dry spell length, the climatic indices, the ength of growing period, are helpful in planning the agriculture activities in the region. Crops like pearl millet, sesame, groundnut, maize, mung bean, cotton and gaur are major crops grown in the area. Observing their critical stages which in most of the cases are at the 30^{th} and 50^{th} day following sowing date, the rainfed agriculture is possible if one considers normal onset date as the sowing dates. When one considers the earliest or latest onset dates as sowing dates, supplemental irrigation, will be required for the crops which cannot to withstand the long dry spell of 7 to 10 days respectively. This value observed for the Ahmedabad district comes to maximum around 52 % to 20 % of total water requirement for 7 to 10 days dry spell respectively. The area is suitable for the crops which are able to withstand a long dry spell of more than 10 days for all the three onset dates. Thus the above information can be utilized judiciously for crop planning in the region.

CHAPTER 7
AND RECOMMENDATIONS

7.1 GENERAL

Based on the results obtained and the analysis performed, following conclusions can be summarized on the overall research work carried out.

7.2 CONCLUSIONS

7.2.1 Missing Climate Data

Cluster analysis was used for forming groups of nearby raingauge stations. The square Euclidean distance measure using averageï linkage rule was found to be the best for forming the clusters based on highest Cophen coefficient value of 0.671. The farthest distance within the clusters formed was 30 km and the nearest was around 4 km.

To determine the best method for filling in the daily missing rainfall data the performance of three methods viz, artificial neural network (ANN), closest station method (CS) and non linear regression (NLR), were evaluated based on various forecast verification (i.e. Bias, Probability of Detection, False Alarm Ratio, Equitable Threat Score and Hanssen and Kuipers score) and model verification (i.e. RMSE, MAE, AIC and BIC) parameters.

Total 68 models were developed and validated. The frequency distribution and box plots presented for Bias, Probability of Detection, False Alarm Ratio, Equitable Threat Score, Hanssen & Kuipers score, RMSE and MAE parameters indicated the superiority of ANN method over CS and NLR methods. For models validated using ANN method, it is concluded that forecast verification parameters were improved over model formulation values.

odels formulated using ANN method was observed as within 5 mm. The model developed using NLR method gave the highest RMSE value ranging from 81 to 85 mm and MAE value upto 30 mm.

Based on AIC and BIC, 66 models out of 68 had ANN method as the best. 2 models out of 68 had closest station method as the best while no model showed non linear regression method as the best during model formulation. The model validation showed 39, 26 and 3 models as the best using ANN, CS and NLR methods based on AIC and BIC values.

The ANN model developed in this study was the most efficient. It was able to generate daily climate data from the nearest available input station. Both the forecast verification and model verification parameters depict the superiority of the ANN method over the CS and NLR methods.

7.2.2 Probability Distributions

The highest observed one day, consecutive 2 to 7 & 10 days maximum rainfall for the period from 1961 to 2008 was 834 mm, 1042 mm, 1166 mm, 1180 mm, 1193 mm, 1193 mm and 1193 mm respectively at Visnagar raingauge station in Mehsana district in the year 1997. The lowest value of one day, consecutive 2 to 7 & 10 days maximum rainfall was observed to be 7 mm in the year 1987 at Dhanera raingauge station in Banaskantha district.

The storms affecting the total rainfall value are observed for one to consecutive 2 to 3 days. For consecutive 4 to 7 days the accumulated rainfall value increased but with less impact on the total amount. For consecutive 10 days the accumulated rainfall showed considerable increase in the value obtained.

tive 2 to 7 and 10 days maximum rainfall showed

In the present study 16 different probability distributions were analyzed for 584 rainfall series. The computed AIC and BIC values for 16 different probability distributions revealed that inverse Gaussian is the best for one day and consecutive 2 to 7 and 10 days maximum rainfall series of 73 raingauge stations. Birnbaum-Saunders, Rayleigh, Log Logistic, Lognormal, Generalized Pareto & Gamma distributions were the second best distributions among the various 16 distributions analyzed. The commonly used extreme value and exponential distributions were the least ranked amongst the various 16 distributions.

The parameters of the inverse Gaussain distribution, μ and λ were obtained for all the 584 dataset of rainfall series. The value of μ ranged from 92.88 to 358.09 and that for λ ranged from 108.50 to 1647.06.

Considering the rainfall depthï durationï return period for a recurrence interval of 2 years the lowest value of maximum rainfall of 69 mm, 91 mm, 105 mm, 111 mm, 116 mm, 121 mm, 125 mm and 136 mm is expected to occur every two years for one day and consecutive 2 to 7 & 10 days respectively. The highest value of maximum rainfall of 144 mm, 193 mm, 217 mm, 238 mm, 253 mm, 266 mm, 280 mm and 328 mm is expected to occur every 2 years for one day & consecutive 2 to 7 & 10 days.

For a recurrence interval of 100 years the lowest value of maximum rainfall of 270 mm, 361 mm, 395 mm, 441 mm, 476 mm, 482 mm, 512 mm and 606 mm is expected to occur every 100 years for one day maximum and consecutive 2 to 7 & 10 days respectively. The highest maximum rainfall of 580 mm, 768 mm, 851 mm, 894 mm and 951 mm, 964 mm, 998 mm and 1,220 mm is expected to occur at interval of 100 years for one day and consecutive 2 to 7 and 10 days respectively.

r north Gujarat agroclimatic zone of 58.65 mm/day, day, 23.60 mm/day, 19.72 mm/day, 17.14 mm/day, 15.17 mm/day and 11.56 mm/day is expected to occur every two years for the crop grown and having tolerance of one day and consecutive 2 to 7 & 10 days respectively. It is observed that the drainage coefficients are the lowest amongst the 73 raingauge stations in the north Gujarat agroclimatic zone. Similarly the highest drainage coefficient obtained for the region are of 122.40 mm/day, 82.02 mm/day, 61.48 mm/day, 50.57 mm/day, 43.01 mm/day, 37.68 mm/day, 34.00 mm/day and 27.88 mm/day is expected to occur every two years for one day & consecutive 2 to 7 & 10 days respectively at Mahemadabad raingauge station of Kheda district.

For a recurrence interval of 100 years, the lowest drainage coefficient of 229.50 mm/day, 153.43 mm/day, 111.92 mm/day, 93.71 mm/day, 80.92 mm/day, 68.28 mm/day, 62.17 mm/day and 51.51 mm/day for the crop grown and having tolerance of one day and consecutive 2 to 7 & 10 days respectively is determined. The highest drainage coefficient of 493 mm/day, 326.40 mm/day, 241.12 mm/day, 189.98 mm/day, 161.67 mm/day, 136.57 mm/day, 121.19 mm/day and 103.70 mm/day is expected to occur at interval of 100 years for the crop grown and having tolerance of one day and consecutive 2 to 7 and 10 days respectively for north Gujarat agroclimatic zone.

7.2.3 Development of Regression Relationships

From Table 6.155, it is seen that for all the 73 raingauge stations the correlation between the return period and one day and consecutive 2 to 7 & 10 days maximum rainfall obtained by the regression analysis is excellent and i.e. r is greater than 0.9976. The relationship developed is logarithmic of the type

(7.1)

where

R_x = one day maximum rainfall; consecutive 2 to 7 & 10 days maximum rainfall; mm

x = 1 to 7 & 10

T = return period, years

C_1, C_2 = constants

With reference to Table 6.156 it is proved that for all the 73 raingauge stations the correlation between one day and consecutive 2 to 7 and 10 days maximum rainfall is excellent i.e r is greater than 0.9979. The relationship developed is linear of the type

$$R_x = C_3 + C_4 (R_1) \quad (7.2)$$

where,

R_x = consecutive 2 to 7 &10 days maximum rainfall, mm;

x = 2 to 7 & 10

R_1 = one day maximum rainfall in mm;

C_3, C_4 = constants

The regression relationship developed are formulated and validated using various goodness of fit parameters such as correlation coefficient, r, coefficient of determination, R^2, coefficient of efficiency, E1, index of agreement, d1, inequality coefficient, U, root mean square error, RMSE and maximum absolute error, MAE. The r, R^2, E1 and d1 for the models developed were nearly perfect with the values greater than 0.96 for model formulation. The r, R^2, E1 and d1 are nearly perfect and greater than 0.98 for model validation. The RMSE is less than 9.8171 mm and MAE is less than 5.5600 mm for model formulation. In case for model validation, RMSE is less than 5.03 mm and MAE is less than 3.07 mm. The inequality coefficient is nearly zero indicating perfect models.

...ed are accurate upto 95 % for return period from 2 ...nships developed can be used for design or review of various hydraulic structures for planning and managing the resources in the region.

7.2.4 Characteristics of Climate Data

An attempt was made to modify the Mockus equation using the fitted probability distribution value. The modified form of Mockus equation is given as

$$N = (4.3 t_{10} \log R_{mod})^2 + 6 \qquad (7.3)$$

where,

N = minimum acceptable length of records,

t_{10} = Student ñtò value at 90% significance level and (N ï 6) degrees of freedom,

R_{mod} = Ratio of 100 years maximum event to 2 years maximum event for the fitted distribution

The length of record obtained by the above equation is more than that obtained by the original equation.

From Table 6.157, the length of record available is adequate for statistical analysis. It is concluded that the modified form of Mockus equation is to be used for determining the length of records.

The mean annual rainfall for the region ranges from 457.08 mm to 863.00 mm. It is proved that the annual rainfall series are positively skewed indicating an asymmetric tail extending towards more positive values. 25 stations are significantly positively skewed. It is seen that the kurtosis ranges from -1.218 to 7.936 indicating the relative flat or peaked distribution. Both the skewness and kurtosis obtained concluded that the annual rainfall series violates the assumptions of normality that underlies many of the statistics like correlation erefore the criterion based tests are used for model

The coefficient of variation is greater than 25 % and ranges from 40 % to 67 % and hence not dependable. According to Foster (1949), the raingauge stations receive scanty rainfall.

It is concluded from Fig. 6.47 that the normal rainfall pattern is varied for all the raingauge stations. From Figs. 6.48 to 6.54 it can be seen that the annual rainfall pattern varies with the altitude of the raingauge stations for Ahmedabad, Banaskantha, Gandhinagar, Kheda and Patan districts. Mehsana and Sabarkantha districts show no specific observations with respect to altitude of the raingauge stations.

It is concluded that 38 out of 73 raingauge stations observed increasing trend ranging from 0.17 mm / year to 9.74 mm / year. Rest 35 raingauges observed decreasing trend ranging from 0.03 mm / year to 10.25 mm / year.

Similar descriptive statistics for the climate stations are also determined and overall it can be concluded that the maximum and minimum temperature, average relative humidity and sunshine hours showed increasing trends except for Dantiwada climate station, which consists of different time period dataset from 1982 to 2008. Decreasing trend for wind speed was observed for all the climate stations

Based on precipitation concentration index it can be concluded that there is substantial variability in the monthly rainfall series. The average precipitation concentration index is around 40 % as can be seen from Figs. 6.65 to 6.70.

Therefore it can be concluded that different statistical parameters computed indicate erratic behaviour of climate parameters with respect to time and space in the region.

Spatial and Temporal Rainfall Patterns

The normalized rainfall curves can be represented by the exponential curves giving the concentration indices (COIN) value. The COIN value obtained for 73 raingauge stations show 12 % variation which is significant one at 0.01.

The COIN values are ranging from 0.54 to 0.66 with an average value of 0.60. It is concluded that this average value divides the entire region into higher and lower concentration of rainfall.

It is observed that the raingauge stations with higher values of COIN observe higher amounts of daily rainfall, increasing the variability of daily concentration of rainfall.

It is concluded that as one move from north towards south the variability of rainfall decreases. The upper part of north Gujarat agroclimatic zone consisting of Banaskantha, Patan and some parts of Mehsana districts the concentration of rainfall is higher compared to the lower part of the zone consisting of Kheda, Ahmedabad and some parts of Sabarkantha districts.

Therefore a COIN, defined on the basis of the exponential curves, enables the contrast or concentration of the different daily amounts to be evaluated for the region.

It is observed that the region receives most of the rainfall with fewer rainy days indicating the need for water storing structures for high intensity of rainfall.

7.2.6 Design Storm for Hathmati Catchment Area

From the design storm analysis of the Hathmati Water Resources Project following conclusions have been emerged:

all in the catchment was about 740 mm with a mm. The coefficient of variability of annual rainfall was about 39%. July month has the lowest variability of 51% among the four months while June has about 100%, August has about 61% and September has about 105%, variability.

10 severe rainstorms had occurred over the catchment during the 48 year period. Out of these 10 rainstorms, 5 were observed in July, 4 in August and 1 in June. This very heavy intensity of rainfall depths were observed in the years 1968, 1973, 1982, 1984, 1990, 1991, 1993, 1997, 2005 and 2006.

The highest rain depths obtained by DD method for 1-day duration was close to 23 years, 2-day duration was close to 14 years, 3-day duration was close to 60 years, 4-day duration was close to 54 years and 5-day duration was close to 60 year return period estimated by statistical method.

The estimates of PMP for 1,2,3,4 and 5 day durations for the Hathmati catchment have been found to be 285 mm, 370 mm, 555 mm, 647 mm and 700 mm respectively.

It was found that probable maximum precipitation estimates by statistical method were well comparable with values obtained by the hydro meteorological method for different durations. As the hydrometeorological method involves additional data for dew point temperatures and lengthy calculation, PMP by statistical method can be easily used with appropriate return period for planning purposes.

7.2.7 Drought Analysis

The modified SPI classification presented by Agnew (2000) was used for categorizing moderate, severe and extreme drought events. Further the SPI equation is modified using newer approach of fitting the dataset to the best probability distribution i.e. Inverse Gaussian and given as

(7.4)

where

X_{ip} = fitted probability of rainfall at i[th] observation

$\bar{x}_p$ = mean of probability

σ_p = standard deviation of probability

The results were compared with the conventional approach of using unfitted (i.e. in its original form) and gamma fitted dataset. Different time scales of 4, 12 and 24 months were adopted. Instead of 3 month time scale a 4 month time scale was adopted for predicting seasonal variation of drought. For average and long term drought, duration of 12 and 24 months were studied respectively.

The area is drought prone as in more than 20% years the drought is experienced for the period from 1961 to 2008.

From Figs. 6.78 to 6.150 one can conclude that the drought category changes as the time scale changes from 4 to 24 months. At longer time scale such as 24 months the drought becomes less frequent.

The original data give less number of drought events compared to the gamma and inverse Gaussian distributions. The total drought events are nearly same for gamma and inverse Gaussian distribution. But the numbers of individual drought intensity events differ. The extreme events observed are more for the inverse Gaussian distribution compared to original and gamma fitted distribution. It can be concluded that the best fitted inverse Gaussian distribution used for classifying the drought intensities for the region give more realistic results.

d Agriculture

The climate of the region is classified using the moisture availability index (MAI). One or two months observed MAI values equal to or greater than 1.33. Arid climate has limited suitability for rainfed agriculture, which has to be therefore planned for optimum utilization of rainfall. Somewhat wet climate requires natural or artificial drainage for good production. It is concluded that the region experiences arid climate for most of the raingauges analysed. It is proved that though the north Gujarat is in one agroclimatic zone, two different types of climate are observed in the region.

An improved technique for analyzing wet and dry spells using three orders of Markov Chain was presented. Two threshold values for categorizing rain and dry day were used. The one used was according to the IMD classification of adopting 2.5 mm from meterological point of view and the second one was introducted based on the consideration of initial abstraction value of 8 mm as per Doorenbos and Pruitt (1977) from agriculture point of view. The performance of zero, first and second order Markov chain models were studied based on AIC and BIC. It was found that the zero order model is the best model for representing the probabilities of dry spell length of 7 to 14 days.

Climatic indices were determined on monthly and weekly basis. It was found that the July and August are most reliable for rainfed agriculture. The detailed analysis for the weekly CI and Kci values indicated that, crops can be taken up starting from 25th standard meteorological week (18th June) till the end of 37th standard meteorological week (16th September). Crops like pearl millet, sesame, groundnut, maize, mung bean, cotton and gaur are major crops grown in the area. Observing their critical stages, which in most of the case for all the crops are nearer to the 30th and 50th day following sowing dates, the rainfed agriculture is possible if one considers normal onset date as the sowing date.

ation obtained from the results related to dry spell further analysis for onset, cessation and growth lengths was carried out for detailed planning of rainfed agriculture in the region.

The onset was identified by using water balance technique for the raingauge station. The identified onset was presented in the form of dependable probability of exceedance levels which are quite valuable for planning of rainfed agricultural activities. This approach was further modified by introducing the condition of rainy days for obtaining more realistic onset value. Thus a search for onset date with atleast 2 out of 4 days must be rainy was applied.

The suggested average onset dates are 17th June, 29th June and 13th July which are earliest, normal and latest respectively. The average cessation dates obtained are 13th September, 14th September and 16th September for the respective earliest, normal and latest onset dates. The average length of growing season is 88 days, 78 days and 65 days for early, normal and late onset respectively.

This information is very important to the farmers in the region for crop selection and planning sowing dates based on suggested onset dates.

In the present study the sowing dates are suggested for the 73 raingauge and presented in Table 6.188. Further evaluation of successful rainfed irrigation is carried out and discussed based on the results obtained by analyzing dry spell length, the climatic indices, the onset, the cessation and length of growing period.

When one considers the earliest or latest onset dates, supplemental irrigation will be required for the crops which cannot withstand the long dry spell of 7 to 10 days. In general one can conclude for Pearl millet, one of the major crop grown in the region, that the additional amount of water required may be

% of total water requirement, for dry spell length of

For crops which can withstand long dry spell of more than 10 days, sowing can be considered using any of the three onset dates suggested in Table 6.188 for respective stations.

7.3 RECOMMENDATIONS

AIC and BIC are recommended over the goodness of fit test (Kolmogrov Smirnov, Chiï square and Anderson Darling) for model selection.

In addition of correlation coefficient r, coefficient of determination R^2 and RMSE, it is recommended to report the performance of other goodness of fit parameters such as coefficient of efficiency, index of agreement, inequality coefficient and maximum absolute ratio for model validation.

Overall, the best models identified for filling in daily missing rainfall series offer a new framework for meteorological data reconstruction. These models can be extended to other context in which the objective is to fill gaps in recorded meteorological data.

The inverse Gaussian probability distribution identified is recommended to obtain the probability of rainfall series for north Gujarat agroclimatic zone.

For soil and water conservation measures, construction of dams, irrigation and drainage works the rainfall depthï durationï return period and regression relationships are recommended, to determine the design rainfall depth.

To determine the design storm for a catchement, statistical frequency method with appropriate return period is recommended over the hydrometorological studies involving lengthy and numerous input parameters.

tor the climate data using the statistical techniques ate change scenarios for combating the future extreme events which are observed now a days.

Modified standardized precipitation index proposed in the study and the Agnew (2000) classification for drought magnitude are recommended for drought studies.

It is observed that the classification of drought varies according to the dataset considered. Therefore it is recommended to transform the rainfall series to its best distribution and use modified SPI equation for drought studies.

It is recommended to use zero order Markov type models to describe the occurrence of wet and dry spells for crop planning and water resources management.

Based on the purpose of study it is recommended to use appropriate threshold value for wet and dry days classification as it affects the overall results obtained.

It is recommended to use the modified water balance approach considering rainy days condition presented, for determining the onset and cessation dates.

The Kci values developed on weekly basis and presented in Table 6.187 are recommended for selection of crops in the area.

The normal onset dates suggested in Table 6.188 for sowing of rainfed crops in the region are recommended.

If one adopts early or late onset dates, suggested in Table 6.188, to be the sowing dates, supplemental irrigation maximum upto 52 % of total water early or later growth stages, are recommened for nd a long dry spell of 7 to 10 days.

Crops which can withstand a dryspell of more than 10 days are suitable for rainfed irrigation in the region and hence, it is recommended to develop more varities for the same.

7.4 FUTURE SCOPE OF WORK

One can predict the incomplete rainfall series using the time series models (i.e. autoregressive, integrated and moving models) and compare it with the approach presented in the study.

One can utilize the complete rainfall series for other climate studies for the north Gujarat agroclimatic zone.

One can re-examine the design storm for the remaining major irrigation projects in the region using the similar methodology.

Both modified fourier index and precipitation concentration index calculated from monthly rainfall data over a number of successive years can be used in the same north Gujarat agroclimatic region and compared with the concentration indices (COIN) to characterize rainfall zones.

The present methodology can be suggested for planning water resources and irrigation activities for the remaining seven agroclimatic zones and compare the climate scenarios observed.

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