

**MODELLING OF DROUGHT UNDER DIFFERENT
AGRO-CLIMATIC ZONES OF GUJARAT**

गुजरात के विभिन्न कृषि-जलवायुवीय क्षेत्रों में सूखे का प्रतिरूपण

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the Degree of

DOCTOR OF PHILOSOPHY

in

Agricultural Engineering

(SOIL AND WATER CONSERVATION ENGINEERING)



By

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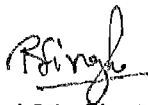
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CERTIFICATE - I

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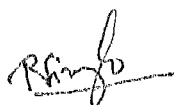
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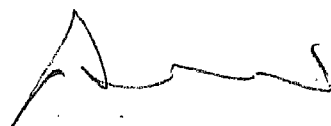
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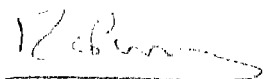
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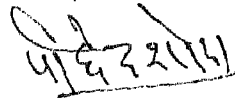
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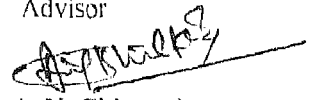

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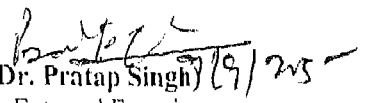

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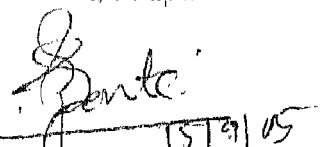

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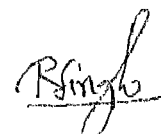

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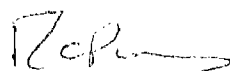
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This is to certify that **Mr. Bhom Singh Deora** student of **Doctor of Philosophy**, Department of Soil and Water Engineering, College of Technology and Engineering has made all the corrections/modifications in the thesis entitled "**Modelling of Drought Under Different Agro-climatic Zones of Gujarat**" which were suggested by the external examiner and the advisory committee in the oral examination held on 09/09/2005. The final copies of the thesis duly bound and corrected were submitted on 15/09/2005.



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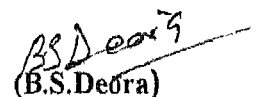
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LIST OF SYMBOLS AND ABBREVIATIONS

α	Scale parameter
β	Shape parameter
γ	Location parameter
σ	Standard deviation
μ	Mean value of S_t
τ	Standard statistic measure
$\Gamma(\gamma)$	Gamma function of
χ^2	Chi-square values
$^{\circ}\text{C}$	Degree Celsius
α_K, β_K	Fourier coefficient of periodic mean series, harmonic K
$\phi_{p,k}$	K^{th} autoregressive coefficient of model order P
$\phi_{p,p}$	Partial autoregressive coefficient of model order P
<	Less than
>	Greater than
%	Per cent
AAU	Anand Agricultural University
AET	Actual evapotranspiration
Ag	Agriculture
Agril.	Agricultural
A_K, B_K	Fourier coefficient of harmonic K
ANN	Artificial Neural Networks
A_0	Mean of historical series
AR(p)	Autoregressive model of order p
ASAE	American Society of Agricultural Engineers
ASCE	American Society of Civil Engineers
a_t	Independent normally distributed residual variable
AWC	Available water holding capacity of soil
C_l	Auto covariance function at lag l, $l = 0, 1, 2, \dots, p$
cm	Centimeter
Coeff.	Coefficient
Cons.	Conservation
CTAE	College of Technology and Engineering
CV	Coefficient of variation

Deptt.	Department
Div.	Division
Drain.	Drainage
(DEF) _w	Weekly water deficit
E	East
Engg.	Engineering
et al.	et alii, and others
etc.	et cetera
ET ₀	Reference evapotranspiration
FAO	Food and Agriculture Organization
Fig.	Figure
GIS	Geographic information system
i. e.	Id est, that is
I _a	Aridity index
I _h	Humidity index
I _m	Moisture index
I _{ma}	Moisture adequacy index
Inst.	Institution
Int.	International
Irri.	Irrigation
ISAE	Indian Society of Agricultural Engineers
ISE	Integral square error
J	Journal
K	Number of significant harmonics
km	Kilometer
kPa	Kilo Pascal
LGS	Length of growing season
m	Meter
Max	Maximum
Mct.	Meteorological
m ha	Million hectare
MJ	Mega Joule
Min	Minimum
mm	Millimeter
MSD (u)	Mean square deviation

MSD (j)	Mean square deviation of j harmonics
N	North
NAU	Navsari Agricultural University
NBSS & LUP	National Bureau of Soil Survey and Land Use Planning
No.	number
OEM	Onset of effective monsoon
p	Time span of periodicity/ Order of autoregressive model
P (D)	Initial probability of week being dry
P (D/D)	Conditional probability of dry week preceded by a dry week
P (2D)	Probability of 2 consecutive dry weeks
P (W)	Initial probability of week being wet
P (W/W)	Conditional probability of wet week preceded by a wet week
P (2W)	Probability of 2 consecutive wet weeks
pp	Page
P_t	Periodic component at time t, $t = 1, 2, \dots, N$
r	Correlation coefficient
R^2	Coefficient of determination
Reso.	Resource
r_k	Serial correlation coefficient at lag 1
RMSE	Root mean square error
S	Serial
s	Second
SD	Standard deviation
SDAU	Sardar Krushinagar Dantiwada Agricultural University
Soc.	Society
smw	Standard meteorological week
S_t	Stochastic component at time t, $t = 1, 2, \dots, N$
Std	Standard
STOR	Actual storage of soil moisture
T_t	Trend component
Trans.	Transaction
viz.	namely
X_t	Average weekly water deficit series
Y_t	Trend free series

I – INTRODUCTION

Drought has been a matter of serious concern to man since time immemorial and a challenge of nature's large scale and formidable phenomenon. It is a climatic anomaly characterized by deficient supply of moisture, which may result from sub-normal, untimely and uneven distribution of rainfall. Among the various hazards of nature, it is one of the major disaster as it brings innumerable miseries to the mankind. Almost every year some part or the other of the globe suffers from such calamities. Drought is a recurring phenomena and its occurrence cannot be avoided.

The complex system of monsoon winds, orientation of mountains and erratic cyclones lead to the extreme spatial and temporal variation in the rainfall distribution. The aberration is related to the atmospheric air mass circulation due to the extraterrestrial as well as the earth-ocean-atmospheric complex forces. Owing to this the total monsoon precipitation in the Indian sub-continent is subjected to spatial and temporal variations leading to occurrence of droughts. This adversely affects the availability of water for the human consumption, industrial, agricultural and for the multitudes of other purposes where water is essential.

Droughts are usually defined as periods of dryness due to lack of rain. The concept varies from region to region depending upon the normal climatic condition, available water resources, land use, agricultural practices and several other economic activities of the region. The perception of drought is different to different people. To meteorologist, drought is a situation when rainfall deviates appreciably (25 %) below normal for an extended period. To the hydrologist, it suggests below average water level in streams, lakes and reservoirs. To the agriculturist, it means amount of rainfall and its distribution causing moisture stress during crop growth period including maturity stage, leading to decrease in crop production. Thus, drought may be classified as meteorological, hydrological and agricultural.

Agricultural planning in water short countries is based on conservation, utilization and management of rainwater. In India, after independence, due to population explosion and demand for more food production, irrigation development received much attention and ushered in the so-called green revolution. Even then, still 70 percent of the cultivated area of the country is under rainfed agriculture and contributes about 42 percent food grains and 75 percent of the pulses and oilseeds production. Average annual rainfall of the country is about 120 cm and 80 percent of this occurs only in monsoon season. Due to frequent droughts and related socio-economic constraints, per hectare yield in rainfed areas is very low. The populations in these areas are poorer, not much literate and depend on agriculture for their employment and livelihood.

Study of drought characteristics is one of the important aspects in the rainfed farming as well as in water resource planning, management and allocation of irrigation water. Most of the studies refer to the stream flow or meteorological drought analysis for a particular basin or a specific historical event without giving much emphasis to the quantitative and qualitative aspects of the drought. In India some work has been reported on the characterization aspects of agricultural drought.

The prediction aspects of drought duration are developed better than the drought severity aspects. The later need to be improved because information on drought severity is of paramount practical importance and forms an essential part of design process of storage facilities for abatement of droughts (Panu and Sharma, 2000). The estimation and prediction of extreme cases of drought thus becomes essential to optimize the management of water resources under wide range of possible future demands and hydrological conditions.

The success or failure of crops particularly under rainfed conditions is closely linked with the rainfall pattern. Coincidence of dry spells with the sensitive phenological stages of the crop causes damage to the crop development. Hence, simple criteria related to sequential phenomenon like dry and wet spells and prediction of probability of onset and termination of the wet season could be used to obtain specific information needed for crop planning and for carrying out agricultural operations (Khichar et al., 1991).

The task of monitoring and controlling the field water balance is valuable for efficient management of water and soil. Extent of water deficit and surplus for a given region is important in planning for water harvesting structures, artificial ground water recharge and adjusting agricultural operations in such a way so as to bring maximum synchronization between availability of water and critical stages of crop growth.

Water deficit is a complex and non-linear phenomenon because it depends on several interacting climatologic factors such as precipitation, temperature, humidity, wind speed, bright sun shine hours, etc. Information of the period during which deficiency of moisture in soil are likely to occur is essential so that advance action can be taken to avoid severe moisture stress to the crops. Choice of crop varieties withstanding moisture stress, adoption of appropriate conservation measures and life saving irrigation through recycling surplus water may be possible measures by the advance information.

An Artificial Neural Networks (ANN) is an effective tool to model complex non-linear relationship between input and output sets (Kumar et al., 2002; Sudheer et al., 2003). ANN models have been found useful and efficient, particularly in problems for which the characteristics of the process are difficult to describe using physical equations. ANN model can compute complex non-linear problem, which may be too difficult to represent by conventional mathematical equations. These models are well suited to the situations where the relationship between the input variable and output is not explicit. Instead, ANN map the

implicit relationship between inputs and outputs through training by field observations. The model may require significantly less input data than a similar conventional mathematical model, since variables that remain fixed from one simulation to another do not need to be considered as inputs. ANN are useful, requiring fewer input and computational efforts and less real time control. ANN can quickly present sensitive responses to tiny input changes in a dynamic environment. Recently, due to functional advantages over the traditional analytical approaches, ANN have been preferred for modelling of agricultural meteorological phenomenon including water deficit.

Forecasting of water deficit particularly in water resources project planning, design and operation is of paramount importance. It is increasingly recognized that time series analysis is of considerable practical use in dealing with forecasting of hydrological variables (Salas et al., 1980). Employing a mathematical model that represents the stochastic process of water deficit, the likely synthetic sequences of future water deficit values can be obtained. Stochastic processes deal with continuous or discrete state and time parameters. The analysis of time series is done to understand the mechanism that generate the data and to produce likely future sequences, if required. These are attempted by making inferences regarding the underlying laws of the stochastic process from one or more sequences of recorded observations and then to postulate a model that fits the data, which are again used for estimation purposes. At first it is necessary to identify and analyze the different components of time series and then generate the future sequences (Kottegoda, 1980).

Water deficit during drought varies spatially and temporally. Spatially distributed measurements of water deficit are beneficial to predict the drought origin, spread and decay over a region (Rama Krishna and Sastri, 1980). Geostatistical approach makes use of interpolation technique such as kriging to obtain data for unrecorded points or areas. Kriging technique has also been found to give accurate estimates for interpolated values in other fields (Vieria et al., 1981; Hudson and Wackernagel, 1994; Panigrahy and Singh, 2000). Therefore, geostatistical approach can be used to interpolate water deficit data and to produce isodeficit line maps for studying spatial and temporal variability over a region. This type of analysis could be a useful tool to pinpoint pattern of drought origin and gradual spread into various regions and would provide advance information to crop planners and administrators so that ameliorative measures can be taken up well in time.

Agricultural operations in rainfed area start with onset of southwest monsoon. It is essential to forecast the calendar of onset of effective monsoon since a slight delay in sowing of rainfed crops may lead to drastic reduction in grain yield and adversely affects the next crop too. The duration of the kharif crops depends on the withdrawal of monsoon rainfall. It has been experienced that quite often the crops suffer from terminal drought due to the early

cessation of rainfall. Therefore, it is necessary to investigate rainfall related crop planning parameters in the context of drought.

Rainfed and drought prone areas predominates the agricultural sector in Gujarat. In the state, out of the net cropped area (96 m ha) about 67 per cent rainfed area makes the state's agricultural scenario dismal. Studies on the nature of occurrence of drought and other characteristic features provide basic information required for evaluating climatic potential of an area for agricultural development, for evolving suitable cropping pattern and for implementing cultural/ conservation practices tailored to rainfall distribution in the area. Various developmental agencies involved in tackling drought problems in the region lack in the information about the drought characteristics and forecast. As a result, rainfall and water resources are utilized in a very inefficient way leading to crop failure even in normal rainfall year due to shorter or longer drought spells. This calls for the study of the drought characterization and modelling to develop appropriate control measures and consequent management of drought.

Recognizing the above concern and realizing that no such study has been carried out under different agro-climatic zones of Gujarat, this study has been undertaken with the following objectives:

- (i) To analyse the rainfall pattern and estimate dry spells
- (ii) To estimate the moisture status on the basis of water balance
- (iii) To evaluate droughts and estimate frequencies of water deficit
- (iv) To predict water deficit using artificial neural networks
- (v) To develop and validate appropriate stochastic model for water deficit
- (vi) To study spatial and temporal variability of water deficit using geostatistical model, and
- (vii) To plan suitable cropping pattern on the basis of drought analysis.

II - REVIEW OF LITERATURE

Droughts cause misery to both human and livestock populations, accelerate degradation of natural resources and put a heavy burden on government. They affect livelihood and economy of a large population in rainfed, arid and semi-arid regions. Drought problems are complex and multifaceted which require prediction based on soil moisture balance. Severity and duration of drought should be studied to understand and mitigate the suffering of human and reorientation of agricultural cropping system. This leads to use of latest techniques for studying of various aspects of drought. A brief review of work done by many workers on rainfall analysis, water deficit, drought and modelling is presented in subsequent sections of this chapter.

2.1 RAINFALL ANALYSIS

Agricultural production in dry farming track depends mainly on the distribution of adequate amount of rainfall during the various phases of crop growth and development. Attempts made by some researchers to study probable rainfall in a short period and its distribution in space as well as the sequences of dry and wet periods are presented here.

2.1.1 Rainfall Pattern

Singh et al., (1991) investigated the probability of occurrence of one day intense rainfall over 12 stations in the Kutch district of Gujarat state. The study reveals that the highest observed rainfall during the study period is more than 175 mm at all the stations, which has a return period of 10 years.

Parikh et al., (1995) analysed the rainfall data of 64 years (1927-90) at Navsari (Gujarat) for drought prediction and crop planning. The expected rainfall magnitudes at four different probabilities were estimated for each week, month, season and year. The rainfall magnitudes to be normal, abnormal and drought for a given month, season and year were worked out along with their standard deviation and coefficient of variance. The probability analysis of 1 to 7 days maximum rainfall was also carried out.

Ghadekar and Miskin (1998) analysed 28 years (1962-89) rainfall data of Nagpur and studied the rainfall suitability at various probability levels for sorghum crop. The total rainfall during kharif season was 861.5 mm. The coefficient of variation ranged between 74.3 per cent (25th week) to 144.7 per cent (39th week). The rainfall at 50 per cent probability was well distributed during 12 weeks (25-36th) ranging between 44.5 to 36.3mm being adequate and sufficient for sorghum crop considering its weekly demand (21-35 mm week⁻¹).

Pandey et al., (1999) analysed daily rainfall data for ninety years (1901-1990) of all the districts of Gujarat state to work out the occurrence of drought and floods in the state. The

study reveals that the arid region receives rainfall of 500 mm or less in most of the years while humid regions receive more than 1000 mm. However, the drought and floods are observed in both the regions.

Rao (1999) studied the variability of monsoon rainfall over the Godavari river basin for different time scales. The monsoon rainfall in the Godavari river basin was more variable (17%) than the all India monsoon rainfall (11%) during the period of study (1951-90). Similarly inter-annual variability of monsoon rainfall on smaller time scales was still higher and increased from seasonal to daily scales. The intro-seasonal variability of monsoon rainfall has a significant negative relationship with the total seasonal rainfall in the basin.

Reddy et al., (2001) identified drought-prone areas in Andhra Pradesh using long term weekly rainfall data (1969-93) of 700 raingauge stations. The drought prone areas, based on the length of growing period, rainfall variability, frequency of recurrence of drought and number of dry spells were further refined and categorized as mild, moderate, severe and chronic agricultural drought-prone zone.

Singh (2001) investigated summer-monsoon rainfall during normal, flood and drought years over India. During flood years the monsoon rainfall increases mostly all over parts of the country and large area less than 100 cm isohyets covers Orissa and adjoining Madhya Pradesh. During drought years the rainfall amount decreases over the entire country and isohyets of 100 cm shrinks to almost a point. The coefficient of variation (CV) increases during the drought year but during flood and normal years no significant change in the variability pattern is noticed.

Singh et al., (2002) analysed fifty years (1946-95) rainfall at Jhansi to estimate occurrence of drought. Analysis shows that mean annual rainfall of Jhansi is 913.2 mm with 24.0 per cent variation. It was found that August was wettest months followed by July.

Kumar (2003) studied rainfall data of varying length (15 to 27) at different stations in Shimala district on monthly, seasonal and annual basis. The statistical parameters like mean, standard deviation, coefficient of variation and coefficient of skewness of the rainfall were determined. Mean annual rainfall was found to be maximum at Phancha (2086 mm) and minimum at Kumarsain (556 mm). The coefficient of variation of annual rainfall varied from 17 % to 50 %. The annual rainfall was found to be non-symmetrically distributed at all stations.

Patel et al., (2004) analysed rainfall data of Guajarat (1901-2002) and indicated that the consecutive years of receiving negligible to below normal rainfall never exceeded more than three years, whereas the consecutive years of having been received near normal to above normal ranged from one to seven years in north and middle region, one to five years in Saurashtra and Kutch region and one to seventeen years in South Gujarat region, respectively.

2.1.2 Onset and Withdrawal of Monsoon

Dash and Senapati (1992) estimated onset and withdrawal of wet season by forward and backward accumulation of rainfall. The authors used 75 mm accumulated rainfall as the onset time for growing season for dry seeded crops and 300 mm as the termination of rain to sustain a second rice crop. The results show that 75% probability is expected at least 75 mm rainfall in 22nd week and 200 mm in 26th week.

Pekhale (1995) determined probable dates of onset of effective monsoon (OEM) and probable periods of critical dry spells in scarcity region of Maharashtra. The mean dates of OEM using Ashok Raj's criterion at Solapur, Rahuri and Dhule were found to be July 7, July 18 and July 1, respectively. The months having more probability of occurrence of critical dry spell are August at Solapur, June and July at Rahuri and July at Dhule.

Das and Mukhopadhyay (1996) studied onset of effective monsoon (OEM) in two north Bengal districts by using slightly modified Raman's definition of OEM. The results revealed that although the retreat of monsoon in the study area occurs about at the same time of withdrawal of monsoon rains from the rest of India, the onset of monsoon is much advance (last part of April to early May) in comparison to that of Kerala where the southwest monsoon hits its first spell in the Indian Peninsula.

Rath et al., (1996) determined the safe growing period during kharif season based on the onset and termination of the wet season. The authors used 75 mm forward accumulation of rainfall as the onset time for the growing season for dry seeded crops and 200 mm accumulated rainfall for initiation of puddling of rice fields. The end of the wet season is determined by backward summing of 300 mm rainfall that would be expected to sustain a second rice crop or other short duration field crops.

Babu and Lakshminarayana (1997) determined the crop growing season by estimating beginning and end of the rainy season by fixing the forward accumulation and backward accumulation of rainfall respectively at 75 mm and 20 mm at 75 percent probability. The analysis of 26 years weekly rainfall data at Polkepad in Andhra Pradesh reveals that the rainy season begins in the 27th standard week and ends in the 40th standard week.

Atre and Pekhale (1998) examined the criteria for onset of effective monsoon given by Ashok Raj and suggested some modification by considering agricultural rainy day and reference crop evapotranspiration. It was found that mean dates of onset of effective monsoon by both the criteria are not different and hence, the new criterion is useful in scarcity region of Maharashtra.

Panigrahi and Panda (2002) considered forward accumulation of 75 and 200 mm rainfall and backward accumulation of 200, 300 and 500 mm rainfall to ascertain the start and end of monsoon, respectively, in rainfed belt of Kharagpur area. The probabilities of

occurrence of these values in different weeks are estimated. The analysis revealed that the monsoon starts effectively from 24th week and remains active up to 39th week.

Jat et al., (2003b) estimated onset and withdrawal of rainy season for Bhilwara in Rajasthan by fixing forward accumulation of 75 mm rainfall from 22nd week and backward accumulation of 10 mm rainfall from 52nd week, respectively. Results indicated that rainy season starts in 28th week with 72 per cent probability and terminates in 39th week with 48 per cent probability. The coefficient of variation of onset and withdrawal was observed to be 5.39 and 13.0 per cent, respectively.

2.1.3 Dry and Wet Spell Analysis

Pandharinath (1991) estimated probabilities of dry, wet weeks, conditional probabilities of dry week preceded by dry week, wet week preceded by a wet week and consecutive 2 or 3 dry/wet weeks at nine stations in Andhra Pradesh during monsoon season (June- September) using Markov-Chain model. The study revealed that leaving the first two weeks of June, the probability of occurrence of a dry week is moderate to high (30 to 60%) in North Andhra Pradesh and it is 20 to 50 per cent in south coastal Andhra Pradesh. The conditional probability of occurrence of a dry week given the preceding week dry is also high, but the occurrence of two or three consecutive dry weeks is small.

Dash and Senapati (1992) used the Markov-Chain model to study the probability of dry and wet spells for Bhubaneswar. The study concluded that from 22nd week to 36th week, rainfall is adequate to grow rice crop. The authors also found that sowing rice crop in 25th week has 7.5 percent probability of two consecutive dry weeks. The study concluded that there are 40 per cent chances of recurring dry weeks till the 22nd week, hence a period is not suitable for crop planning.

Sarkar (1994a) investigated the distribution of the length of wet and dry spells and weather cycles at Madras during the north-east monsoon months. The length distribution of each type of spell and weather cycle was found to obey the first order Markov-Chain model. At Madras the most frequent length of weather cycle cannot be less than three days.

Das and Mukhopadhyay (1996) analysed daily rainfall data of Coach Behar (1971-90) and Jalpaiguri (1972- 90) districts of Terai zone of West Bengal to study the nature of critical dry spells during the monsoon season. The study revealed that, there was possibility of occurrence of dry spell of 10 days or more once in every 4 years. Expected length of dry spell (in days) for 2,5,10 and 20 year return periods was estimated with the help of suitably fitted curves for each location.

Sarkar (1997) studied 10 day duration probability of consecutive dry and wet spells of different lengths at Madras during north-east Monsoon. Results revealed that the probability

of a day being wet was highest during 1-10 November. Maximum length of a dry spell can be expected during December while the largest wet spell of 9 days is possible in November.

Singh and Bhandari (1998) analysed 25 Years (1971-1995) weekly rainfall data to establish drought frequency based on Markov-Chain model considering less than 20 mm rainfall as dry week and 20 mm or more as a wet week. The initial (59-83 %) and conditional (72-90 %) wet probability was the highest from 25th to 35th meteorological weeks. The probabilities of getting two and three consecutive weeks during this period indicate the continuous and heavy rainfall, which can be conserved for the deficit period.

Khichar et al., (2000) used Markov-Chain model to analyse weekly rainfall data of Haryana and calculated probabilities of different lengths and expected frequencies of dry spells. The authors found that probability of occurrence of dry spells was more than 0.90 from 23rd to 25th week and afterwards it decreased to 0.50 in 31st week. The study concluded that superimposing crop calendar on dry and wet spells sequences would provide information about water deficiency or water surplus. It was also concluded that initial and conditional probabilities provided the basic information on rainfall distribution needed for agricultural operations.

Sarkar et al., (2001) investigated 10 days period wise simple probability and probability of consecutive dry and wet spells of different lengths, using Markov-Chain model over Vidarbha region during south-west monsoon months considering 30 years daily data (1960-1990). The study reveals that probability of a day being a wet and probability of consecutive wet spell of different lengths are by and large high during the last and first 10 day periods of July and August, respectively when the monsoon is at its peak. During the first two 10 day periods in June and last two 10 day periods in September, the probability of a dry day and that of consecutive dry spell of different length are quite high.

Sharma et al., (2003) tested transformations such as power, SMEMAX, log and log-log on dry days data of the fortnights in Udaipur region. Almost identical estimates of dry days were obtained by power, log and log-log transformations at 80 per cent probability of non-exceedance (5 year return period). On the basis of dry spell analysis it was observed that kharif crops could be sown in 24th week at Udaipur. The supplemental irrigation can be applied in 36th week from the harvested runoff water.

Sharma and Kumar (2003) analysed 20 years rainfall of Nagaur in Rajasthan to determine occurrence of dry spells by Markov-Chain model. The results indicated that the initial (45-60 %) and conditional (46-99.9 %) wet week probability was the highest from 29th to 34th standard week. The high probability of getting two consecutive wet weeks between this period indicates the continuous and good rainfall. The rise in dry week probability in 33rd and 35th standard week was indicative of a dry spell period.

Singh et al., (2004) analysed 26 years (1977-2002) rainfall data to determine occurrence of dry and wet spells for crop planning at Bathinda in Punjab. The results indicated that the probability of occurrence of dry spell was above 92 per cent from 1st standard meteorological week (smw) to 22nd smw except for 4th, 7th and 8th smw during which the probability of dry spell was 77, 73 and 85 per cent, respectively. From 23rd smw onward, the probability of dry spell started decreasing and reached minimum (38 per cent) during 27th smw followed by an increase and approaching 100 per cent from 44 to 50 smw. The chances of wet spell to occur were maximum (62 per cent) during the 27th smw in July.

2.2 REFERENCE EVAPOTRANSPIRATION

Evapotranspiration, which includes evaporation from land and water surfaces and transpiration by vegetation, continues to be foremost importance in prediction of drought. The literature on this topic is extensive. Few important reviews are presented here.

Thornthwaite (1948) determined the water needs of vegetation over large areas in order to carry out broad climatic classification. The author estimated potential evapotranspiration on a monthly basis from readily available climatological data such as mean air temperature and day length. The potential evapotranspiration values obtained were adjusted to the number of days in a month and the maximum duration of sunshine depending on season and latitude of the place.

Blaney and Criddle (1962) developed and proposed a simplified empirical formula to compute evapotranspiration (consumptive use) using a correlation, which utilized mean monthly air temperature, amount of daylight and a crop factor showing seasonal variation.

Hargreaves (1968) conducted several important experiments and developed methods to compute evapotranspiration from pan evaporation data. The method and the procedure presented are applicable to both arid and humid climate and to locations where data are quite complete as well as to those locations for which only temperature and rainfall data are available.

Sarkar and Biswas (1986) developed a theory for agro-climatic classification on the basis of an index called 'Moisture Availability Index (MAI), which is defined as the ratio of assured rainfall to potential evapotranspiration. Three improvements have been made on earlier classification viz. moisture availability index has been taken on weekly basis; minimum assured rainfall has been considered at different probability levels and the different values of MAI and their duration have been taken as appropriate to various crop phases. The classification, however, has been recommended on the basis of moisture availability index at 50% probability level, which is considered to be an optimum value. The main classification has been further subdivided depending upon the length of water stress period. The theory so developed has been applied to the dry farming tract of India.

Hatfield and Allen (1997) studied different forms of the reference evapotranspiration equations that included Priestly-Taylor and Penman-Monteith. To estimate actual

evapotranspiration, the Priestly-Taylor with adjusted coefficient for available soil water and the Penman- Monteith with a variable soil surface resistance were compared to water use for grain sorghum, cotton and grass forage at three locations. Both models gave acceptable results, however, the Penman-Monteith model with daily meteorological data input provided more consistent results over the growing season.

Samani (2000) introduced a procedure to estimate solar radiation and subsequently reference crop evapotranspiration using the minimum climatological data. A modification was made to the original equation that uses minimum and maximum temperature to estimate solar radiation and reference crop evapotranspiration. The proposed modification allowed for the correction of the errors associated with indirect climatological parameters affecting the local temperature range.

Kashyap and Panda (2001) evaluated the crop evapotranspiration estimation methods and developed a crop coefficient for potato in the sub-humid region. The study was carried out at Kharagpur, having a sub-humid climate. Daily reference crop evapotranspiration (ET_0) was measured with an electronic data logger connected to the lysimeter. Grass was used as the reference crop observing actual evapotranspiration. Ten climatological methods, Penman, FAO-Penman, FAO-Corrected Penman, 1982-Kimberley-Penman, Penman-Monteith, Turc-Radiation, Priestly-Taylor, FAO-Radiation, Hargreaves and FAO-Blaney Criddle were used to estimate the reference evapotranspiration. Performance of climatological method in estimating the ET_0 values as compared to the lysimeter-measured values was evaluated on the basis of RMSE. The Penman-Monteith equation gave the best result followed by the 1982-Kimberley-Penman, FAO-Penman, Turc-Radiation and FAO-Blaney Criddle. The RMSE in all the cases varied between 0.08 and 0.756. The crop coefficients were estimated on the basis of lysimeter measured actual ET.

Bhakar and Singh (2003) estimated reference evapotranspiration under sub-humid climatic conditions of Rajasthan. Ten most commonly used reference evapotranspiration models were selected for testing their validity under the climatic conditions of Udaipur region. The important reference evapotranspiration models are: (i) Penman FAO-24 model, (ii) Penman-Monteith FAO-56 model, (iii) Kimberley-Penman model, (iv) Priestly-Taylor model, (v) Jensen-Haise Alfalfa Reference model, (vi) Hargreaves grass related model, (vii) SCS Blaney Criddle model, (viii) FAO-24 Blaney Criddle model, (ix) FAO-24 Pan Evaporation model, and (x) Christiansen Pan Evaporation model. Testing of these models was made on the basis of actual measurements of agricultural crops based reference evapotranspiration (ET_{0A}). Out of 10 models only 3 models viz. Penman-Monteith FAO-56, Jensen-Haise Alfalfa Reference and FAO-24 Blaney Criddle models were found to predict ET_{0A} accurately under the climatic conditions of Udaipur region.

2.3 WATER BALANCE

Drought is evaluated in a more meaningful manner by water balance approach taking into account the rainfall pattern, evapotranspiration and moisture characteristics of soil. Some review pertinent to this aspect is presented here.

Ram Mohan et al., (1984) evaluated the index of moisture adequacy (I_{ma}) derived from water balance procedures to categorize droughts from agricultural and ecological point of view. Selected drought spells were analysed critically by plotting the ratio of the departure of monthly indices of I_{ma} from the climatic normal, to the standard deviation of I_{ma} for that month. This technique was found to be of great value in agricultural and ecological investigations as due weightage is given to drought resistance and tolerance of crops which are adapted to the region.

Subramaniam and Narasinha Raju (1986) worked out the water availability periods of nine stations in north coastal Andhra Pradesh by computing water balance. The region experienced more number of moist days in high land area than in coastal belt. The onset and cessation of water availability periods were also presented.

Victor et al., (1991) carried out weekly water balance for the years 1911-85 considering different available water holding capacities ranging from 25-200 mm to examine the extent to which the moisture regime and aridity are dependent on water holding capacity of soil. The analysis revealed that the aridity is accentuated by the shallowness of the soil coupled with low rainfall. The number of years with drought was found to vary from 3 to 6 per decade. The annual average water balance of the entire state during climatically extreme years have also been illustrated and discussed.

Kerkides et al., (1996) calculated water balance for 31 locations in Greece on the basis of long-term average monthly precipitation, evapotranspiration, and combined soil and vegetation characteristics using the method of Thornthwaite and Mather (1955).

Dange (1998) studied moisture availability index (MAI) in plain zone of Maharashtra as per Thornthwaite water balance technique considering different soil types viz., shallow, medium and deep.

Das et al., (2002) studied variability in spatial distribution of various water balance parameters and developed moisture deficit index for dry farming regions. The results indicated that during most parts of crop season water transpired from the plant by and large lies between 30-40 mm per week.

Singh et al., (2004) studied weekly water balance for Ranichauri in Uttaranchal. The study revealed that water surplus was observed during monsoon season and water deficit was restricted to October, November and April to June. Though the moisture adequacy index indicated that the region has sufficient moisture throughout the year, the region suffers from moisture stress during rabi season due to slope and high seepage losses.

2.4 DROUGHT CHARACTERISATION

Drought is experienced with greater or less frequency in all climatic regimes. During past two decades numbers of studies have been reported on the identification of drought and its characterisation. Some specific reviews related to this topic are listed below:

Pawade (1981) analysed daily rainfall data of 5 stations in Akola district of Maharashtra state to get the mean date of commencement of critical dry spells (CDS) along with their mean duration using Ashok Raj's Criteria. The dates of commencement of first, second and third CDS were from July 11 to July 26, August 4 to August 25 and August 31 to September 19, respectively.

Rao and Subramaniam (1986) identified the commencement and cessation of different intensities of meteorological drought during 1934-77 at 23 locations of the Maharashtra State by using Palmer's approach. While adopting Palmer's approach the definition of potential runoff and the weighting factors originally given by him are suitably modified for the climatic conditions of Maharashtra. The modified drought indices performed well for identification of various classes of drought in the region. The analysis showed that the spatial distribution of drought prone areas during kharif was similar to that of rabi season in the region. During kharif season alone severe/extreme drought conditions prevailed for 28 out of 44 years in the state. But there are few stations like Kolhapur and Sironcha (sub-humid) where the drought situation never touched the extreme conditions.

Chowdhury et al., (1989) made an attempt to quantify drought for the country as a whole and identified drought years by developing drought index based on rainfall for 113 years (1875-1987). The difference between area affected by drought in any year and the 113 years mean drought area divided by the standard deviation was defined as drought index. The study revealed that the year 1918 was the worst drought year since the rainfall observation has started to be recorded in India. The occurrence of drought appeared to be random phenomenon. However, the time interval between successive years of drought appears to follow a Poission distribution. From the return period analysis, it appears that drought can cover $1/5^{\text{th}}$ of the area of the country once in 5 years, nearly a third of the area once in 10 years and affect half of India once in 50 years. Occurrence of drought affecting more than 65% of the total area of the country is an extremely rare event.

Dalvi et al., (1992) studied daily rainfall data of 22 years (1965-86) for nine stations in Vidarbha region of Maharashtra state for critical dry spell analysis. Study revealed that on an average 2 critical dry spells occur in this region except at Gondia where average 3 critical dry spells occur. The authors have stated the period of occurrence of critical dry spells, which is valuable in selecting crop and their varieties to obtain the required level of drought tolerance.

Taksale (1992) carried out drought analysis for Marathwada region in Maharashtra. Cumulative probability nomograms for developmental stages of various crops were prepared. Also isohyetal maps for Marathwada region representing onset of effective monsoon dates, average number of rainy days and dates and duration of three critical dry spells were drawn.

Paul (1993) proposed a methodology to characterize meteorological drought based on the normality of seasonal and deficit years rainfall (mean and standard deviation). The years were classified as incipient, large, severe, disastrous and extreme droughts and corresponding drought index was developed. The author also studied agricultural drought with respect to its characteristic parameters such as duration and severity, considering upland rice as the reference crop at Hazaribag. Frequency analysis was carried out for drought durations of 2 to 6 weeks and their exceedence probability curves were plotted. The author noted that initial drought severity is higher than the intermediate and the terminal stage except for 6 weeks duration. Occurrences of drought of 5 to 6 weeks are very less with very less probability. Maximum dry spell duration follows extreme value distribution.

Sajjan (1998) studied meteorological characterization of 1994-95 drought and water deficit in north western region of Bangladesh and determined longest wet and dry periods by Markov model and largest rain-sum at different probability are drawn to identify the regional variation characteristics. Water availability and 10-day water deficit is calculated for the period of 1976-96 and fitted extreme value type distribution to 10-day maximum for each station. Result shows that extreme value type-I distribution seems to fit the deficit well.

Chaube (1999) studied consistency of 10 different drought indices (like variability of rainfall, criterion of Indian Meteorological Department, irrigation facilities, crop loss, frequency of occurrence of rain, inadequacy of rainfall, erratic distribution of rainfall, deficiency of runoff, soil moisture stress and aridity index) in identification of drought in 99 districts, identified as drought prone in India by Central Water Commission. The study showed that on an all India basis aridity index, erratic distribution of rainfall and deficiency of rainfall are more consistent and therefore may appear to be superior criteria for identification of drought proneness with the assumption that agro-climatic variation does not influence choice of drought indices. The degree of consistency among these ten indices considering the variation in agro-climatic conditions in the 99 drought prone districts indicate that only some specific indices are preferable for each of the nine identified agro-climatic zones of India. Based on this regional analysis some indices are recommended for identification of drought.

Sarkar (2000) studied agricultural drought of 1987 monsoon season in India using Thornthwaite's technique of weekly water balance utilizing potential evapotranspiration values obtained by Penman's method. Above normal value of weekly aridity index has been taken as the agricultural drought index to demarcate the drought affected areas. Results showed that a major portion of the Gujarat state had continuously been under the grip of moderate to severe

drought conditions since 18-24 June till September end. Other areas substantially affected were Rajasthan, Punjab, Haryana, Coastal Andhra Pradesh, Madhya Pradesh, Uttar Pradesh and Vidarbha in Maharashtra where prolonged drought spell abating only for short periods prevailed in the season.

Sumathi et al., (2000) assessed the severity of the recurrence of drought in Perambatur, Tamilnadu and suggested strategies to combat the effect of drought using rainfall data for 40 years (1960-99). Study revealed that Perambatur has a chance of drought occurrence once every three year. Water harvesting technique and soil conservation structures are suggested as drought mitigation strategies.

Sarkar (2001) investigated the incidence, spread, intensification and cessation of drought in a fortnightly time scale during monsoon 1999 in India using aridity index. Results revealed that in the first fortnight of June a major proportion of Orissa and adjoining east Madhya Pradesh suffered from severe drought conditions which had been wiped out in the next fortnight during which however, severe drought conditions over central and south-eastern India decreased. Subdued rainfall activity in the first fortnight of July brought a large portion of northwest and central India under severe drought condition. Good rainfall activities in the second fortnight of July over traditionally drought prone northwest and central India favoured a good kharif. From mid-August to about third week of September, subdued rainfall activity over northwest and peninsular India had worsened the drought situation over these areas. Crop reports revealed that due to this long and dry period crops in Gujarat, Rajasthan, Andhra Pradesh and Karnataka suffered a setback. Good rainfall activity over the country till the complete withdrawal of monsoon largely compensated for whatever the setbacks crop suffered in August and early September.

Sinha Ray and Shewale (2001) determined the probability of occurrence of meteorological drought in various sub divisions of India and the probability of sub division facing two or more consecutive droughts with the help of 124 years data (1875-1998). The results clearly showed that probability of occurrence of drought was maximum in West Rajasthan (25 %) followed by Saurashtra and Kutch (23 %), Jammu and Kashmir (21 %) and Gujarat region (21 %). Maximum probability of occurrence of two consecutive years of drought was in Jammu and Kashmir and West Rajasthan. During the complete 124 years period there were three occasions i.e. in 1877, 1899 and 1918, when the percentage area of the country affected by drought was more than 60 per cent. It was also stated that during last 80 years there was no occasion when the percentage area of the country affected by drought was more than 50 per cent.

Pandey et al., (2002) studied the magnitude and frequency of meteorological drought with rainfall deficiency of Hawalbagh in Uttranchal. Study revealed that during the period of 35 years (1964-98) there were about 17.1 per cent drought, 17.1 per cent excessive flood and

65.8 per cent normal years. Rainfall of drought years was departed negatively (20.4 to 37.5%) from the mean. Although the maximum weeks and maximum months were observed dry in 1964, however, this year did not fall in the drought category. It indicates the limitation of definition laid down for drought classification. The probability analysis revealed that there is 97 percent probability to get 23 droughts, 3 abnormal and 9 normal weeks in a year.

Gore and Sinha Ray (2002) identified large scale droughts over Gujarat by considering rainfall for the period 1901-1999. The study revealed that 43 large scale droughts and significant increasing trend in the area affected by drought over Gujarat. The probability of large scale drought occurrence over Gujarat in all India drought year was 82 percent.

Satpute (2004) investigated drought pattern over Maharashtra by using rainfall of different stations for the period 1976-2002. The study revealed that total drought years vary from 12 to 15 during the study period in different zones, indicating frequency of one drought year in every two years. Analysis of drought years indicated that drought does not occur simultaneously in all the agro-climatic zones but usually occur sporadically all over the state. The results also indicated that droughts are common not only in arid and semi arid climate but equally occur even with higher frequency in dry sub humid climate.

2.5 FREQUENCY ANALYSIS

Frequency analysis is the most common statistical method of analysing hydrologic data. Frequency analysis is used to predict how often certain values of a variable may occur and to assess the reliability of the prediction. Forecasts of drought events can generally reduce the damage caused by droughts. Firstly, and most obviously, warning of an event enables people to adopt drought management strategies. If sufficient lead time is provided, vulnerable possessions may be removed from the drought region and remedial measures can be made in advance to minimize the damage caused by drought.

Chowdhury et al., (1989) analysed 113 years (1875-1987) rainfall data to quantify drought for the country as a whole and studied the frequency distribution of time interval between the occurrences of successive droughts. The occurrence of drought appeared to be a random phenomenon and the time interval between successive years of drought appears to follow a Poisson distribution.

Singh et al., (1991) analysed rainfall characteristics of Kutch district based on rainfall data of 12 stations for the period of 1901 to 1989. The probability of weekly rainfall distribution was worked out by ranking order methods. The results indicated that rainfall has decreasing trend from SW region to NE region. From probability analysis, the study revealed that interior part of the district is more prone to drought conditions as compared to coastal plains. The authors observed that most of the stations had recorded highest observed rainfall values nearer to the estimated rainfall of 100 years return period except at Bhuj, Anjar and Radhanpur.

Gupta (1992) made comparison of commonly used nine procedures for frequency analysis of the rainfall data for their capability of predicting rainfall amount at various probabilities. The study showed that at least seven distributions out of the nine are capable of predicting reasonably good values in the probability range of 0.1- 0.5, which are commonly, used probabilities for planning agricultural operations. The study concluded that power transformation is the most powerful tool for frequency analysis followed by log-Pearson type-III and Pearson-III distributions.

Paul (1993) analysed annual, seasonal and weekly rainfall data for a period of 80 years from deficit point of view at Hazaribag and found that annual and seasonal rainfalls follow log normal and normal distribution. Date of onset of monsoon is normally distributed with 18th June as mean date and the standard deviation of 8 days. The date of termination of effective monsoon as well as maximum dry spell duration follows extreme value distribution.

Bhatt et al., (1996) attempted frequency analysis of one day maximum rainfall data by analysing 24 years (1968-1991) daily rainfall data of Datia. The expected values estimated by extreme value type-I, log normal and log Pearson type-III distributions were compared with the observed values estimated by Weibull formula. The analysis indicated that log Pearson type-III distribution gives the closest fit to the observed data.

Kaledhonkar et al., (1996) computed frequency distribution of longest duration and largest deficit of drought using annual rainfall series of four stations in southwest Orissa. The validity of the method was established by comparing the distribution of longest negative run length of drought with the theoretical distribution obtained from independent normal process. Log normal distribution was successfully fitted to describe the distribution of longest duration and largest deficit of drought.

Sharma (1997) found that the important elements of a drought phenomenon are longest duration and the largest severity of a desired return period. These elements form a basis for designing water storage systems to cope with droughts. At times, a third element, drought intensity, is also used and is defined as the ratio of severity to duration. The commonly available statistics for the drought variables such as annual rainfall, runoff sequences are the mean, coefficient of variation and the lag one serial correlation coefficient and occasionally some indication of probability density functions of the sequences. The external values of the duration and severity modelled using information of aforesaid parameters. The drought severity was modelled as the product of the duration and intensity with the assumption of independence between them. An estimate of drought intensity was realized from the concept of the truncated normal distribution of the standardized form of the drought sequences in the normalized domain. A formula in terms of the extremity, severity and return period was also suggested.

Rana and Thakur (1998) analysed annual, seasonal, monthly and weekly total rainfall data of Kullu valley in Himachal Pradesh to obtain rainfall distribution pattern using three different theoretical frequency distributions like Gumbel, log normal, and log Pearson type-III. The Gumbel distribution fitted well to the observed rainfall data and expected and observed frequencies were found to be in fair agreement with each other. The authors suggested that Gumbel distribution can be used to obtain rainfall distribution pattern in Kullu valley.

Kumar et. al., (1998) analysed rainfall data for a period of 12 years from 1979 to 1990 for Aonla in Uttar Pradesh. The authors used normal distribution, log normal distribution, square root transformation and mixed distribution for their ability to fit monthly rainfall values. Kolmogorov-Smirnov test for goodness of fit was used. It was found that mixed probability distribution gave best at all probability levels.

Kumar et al., (2000) compared commonly used distributions and transformations for probability analysis of monthly dry days data using Kolmogorov-Smirnov test and percentage deviation. The normal distribution with Smemax transformation was found to be best fit for the selected data series at Pantnagar.

Kar and Singh (2002) predicted southwest and post monsoon rainfall at different probability levels using different probability models and were compared with observed values given by Weibull's formula. Chi-square test was done to obtain best probability distribution function. Result indicated that for predicting June rainfall log normal and for September rainfall, the log Pearson type-III and for July and August extreme value type-I were the best fit probability distribution functions.

Suresh (2003) evaluated a most suitable probability model for predicting annual maximum daily rainfall for Pusa farm (Bihar) based on rainfall data for 38 years (1964-2001). The Weibull's method was used for computation of observed event at the return periods of 1, 1.25, 2, 5, 25, 50 and 100 years while theoretical events were computed by log normal, Gumbel and Pearson type-III distribution techniques for same return periods. The statistical comparison by Chi-square test for goodness of fit clearly indicated the Pearson type-III distribution as the best probability model.

2.6 ARTIFICIAL NEURAL NETWORKS

An Artificial Neural Network (ANN) is a flexible mathematical structure which is capable of identifying complex nonlinear relationships between input and output data sets. ANN models have been found useful and efficient, particularly in problems for which the characteristics of the processes are difficult to describe using physical equations.

Hsu Kuo-lin et al., (1993) presented a new procedure (entitled LLSSIM) for identifying the structure and parameters of three-layer feed-forward ANN models and

demonstrated the potential of such models for simulating the nonlinear hydrologic behavior of watersheds. The nonlinear ANN model approach was shown to provide better representation of the rainfall-runoff relationship of the medium size Leaf River basin near Collins, Mississippi than the linear ARMAX (Auto Regression Moving Average with exogenous inputs) time series approach or the conceptual SAC-SMA (Sacramento Soil Moisture Accounting) model. Because the ANN approach presented here did not provide models that had physically realistic components and parameters, it is by no means a substitute for conceptual watershed modeling. However, the ANN approach provided a viable and effective alternative to the ARMAX time-series approach for developing input-output simulation and forecasting models in situations that do not require modelling of the internal structure of the watershed.

Yang et. al., (1996) developed and trained an artificial neural network by using the simulated midspan water table depths from DRAINMOD, a conventional water table management model. Compared to DRAINMOD, the model was very simple to run and required only a small amount of data, such as precipitation, ET, and initial midspan water table depth. The results indicated that the artificial neural network model could make predictions similar to DRAINMOD, with the least root mean square error of 0.1193 and doing this significantly faster and with fewer input data. Generally, the artificial neural network structure with six processing elements and one hidden layer was sufficient for the study. It was found that the network should be trained with at least 145000 cycles but more than 200000 cycles are unnecessary. A lag procedure was suggested which improved the performance of artificial neural networks under irregular situations, such as sudden and large rainstorms. A 3-day lag of all input parameters was the best choice when the weather conditions were irregular.

Altendorf et. al., (1999) studied a set of neural networks, each of which predicted soil water content at a given depth as a function of soil temperature. Networks were developed to predict at depths of 0.15m, 0.3m, 0.6m and 1.2 m. Input data consisted of a coefficient describing soil type and soil temperature measured at two depths above and two depths below the desired depth. The networks were generally able to predict the variations in water content over time. Network performance generally improved as deeper depths were considered. For comparison purposes, multiple linear regression models were also used. They did not perform well, particularly in following the trends in the data over time.

Kumar et al., (2002) investigated the utility of artificial neural networks (ANNs) for estimation of daily grass reference crop Evapotranspiration (ET_0) and compared the performance of ANNs with the conventional method (Penman-Monteith) used to estimate ET_0 . Several issues associated with the use of ANNs, including different learning methods, number of processing elements in the hidden layer(s) and the numbers of hidden layers were

examined. Three learning methods, namely; the standard, back-propagation with learning rates of 0.2 and 0.8 and back propagation with momentum were considered. The networks were trained with climatic data (solar radiation, maximum and minimum temperature, maximum and minimum relative humidity and wind speed) as input and the Penman-Monteith estimated ET_0 as output. The best ANN architecture was selected on the basis of weighed standard error of estimate (WSEE) and minimal ANN architecture. The ANN architecture of 6-7-1 (six, seven and one neuron(s) in the input, hidden and output layers, respectively) gives the minimum WSEE (less than 0.3 mm/day) for all learning methods. That value was lower than the WSEE (0.74 mm/day) between the Penman-Monteith and lysimeter measured ET_0 as reported by Jensen et al in 1990. Similarly, ANNs were trained, validated and tested using the lysimeter measured ET_0 and corresponding climatic data. Again, all learning methods gave less WSEE (less than 0.6 mm/day) as compared to the Penman-Monteith method (0.97 mm/day). Based on these results, it can be concluded that the ANN can predict ET_0 better than the conventional method.

Sudheer et. al., (2003) examined the potential of artificial neural networks (ANN) in estimating the actual crop evapotranspiration (ET_c) from limited climatic data. The study employed radial-basis function (RBF) type ANN for computing the daily values of evapotranspiration for rice crop. Six RBF networks, each using varied input combinations of climatic variables, had been trained and tested. The model estimates were compared with measured lysimeter evapotranspiration. The results of the study clearly demonstrated the proficiency of the ANN method in estimating the evapotranspiration. The analyses suggest that the crop ET could be computed from air temperature using the ANN approach. However, the present study used a single crop data for a limited period, therefore further studies using more crops as well as weather conditions may be required to strengthen these conclusions.

Trajkovic et al., (2003) applied a sequentially adaptive radial basis function network to the forecasting of reference evapotranspiration (ET_0). The sequential adaptation of parameters and structure was achieved using an extended Kalman filter. The criterion for network growing was obtained from the Kalman filter's consistency test, while the criteria for neuron/connection pruning were based on the statistical parameter significance test. The weather parameter data (air temperature, relative humidity, wind speed, and sunshine) were available at Nis, Serbia and Montenegro, from January 1977 to December 1996. The monthly reference evapotranspiration data were obtained by the Penman-Monteith method, which was proposed as the sole standard method for the computation of reference evapotranspiration. The network learned to forecast $ET_{0,t+1}$ based on $ET_{0,t-1}$ and $ET_{0,t-23}$. The results showed that ANNs can be used for forecasting reference evapotranspiration with high reliability.

Rajurkar et al., (2004) presented artificial neural network for modelling daily flows during flood events. The rainfall-runoff process was modeled by coupling a simple linear (black box) model with the ANN. The study used data from two large size catchments in India and five other catchments used earlier by the World Meteorological Organization (WMO) for inter-comparison of the operational hydrological models. The study demonstrated that the approach adopted herein for modelling produced reasonably satisfactory results for data of catchments from different geographical locations, which thus proves its versatility. Most importantly, the substitution of the previous days runoff (being used as one of the input to the ANN by most of the previous researchers), by a term that represents the runoff estimated from a linear model and coupling the simple linear model with the ANN may prove to be very much useful in modelling the rainfall-runoff relationship in the non-updating mode.

2.7 STOCHASTIC MODELLING OF DROUGHT

A mathematical model representing a stochastic process is called stochastic model or time series model. The water deficit from an area is stochastic in nature since it is affected by climatological parameters. The stochastic nature of water deficit can be represented by the simulation or mathematical modelling. This modelling is a basic tool to generate desired parameter with greater accuracy. The stochastic modelling of water deficit as time series is important for selection of suitable crop variety, scheduling of irrigation and drought management planning.

Davis and Rappoport (1974) calculated forecasts for the monthly Palmer Drought Severity Index using an exponential smoothing procedure and an autoregressive moving average process using monthly data for 1929-1969. Results demonstrated the usefulness of the autoregressive moving average time series analysis procedure.

Box and Jenkins (1976) have systematically discussed the time series models. Most of the recent advances in time series analysis are based on the basic work of Box and Jenkins.

Katz and Skaggs (1981) described statistical problems that may be encountered in fitting autoregressive-moving average (ARMA) process to meteorological time series. Techniques that lead to an increased likelihood of choosing the most appropriate ARMA process to model the data at hand are emphasized. Modelling of Palmer Drought Index time series for climatic division of the United States is considered in detail by ARMA processes and shown that low order purely autoregressive processes adequately fit these data.

Jolliffe (1983) illustrated how second order autoregressive model can substantially account for observed quasi-periodic behaviour in meteorological or climatological series by using data on sunspots, Baltic ice and zonal circulation as index.

Kamte and Dahale (1984) evaluated first order autoregressive AR(1) model to generate n-day minimum rainfall of different durations. The model satisfactorily explains the observed

minimum rainfall of different durations. Further, the probabilities of minimum rainfall of different durations are estimated to understand how best one can delineate the area of droughts.

Srinivasan and Ramesh (1993) examined the efficiency of the periodic models in presenting the basic periodic statistics as well as the over year drought characteristics of highly variable monsoon based river flow through stochastic modelling of the monthly flows measured at Krishnarajasagar reservoir. The over year drought characteristics obtained from the synthesis sequences generated using the low order periodic models are compared with those obtained from Thomas-Fiering log normal three parameter model. The authors found that periodic autoregressive model of order two [PAR (2)] with Wilson Hilferty transformation performs the best of verification stage but this model was found to overestimate the deficit sum.

Gorantiwar et al., (1995) applied autoregressive models (AR) up to fourth order to the historical annual stream flows and logarithmic transformation of the historical annual streamflows of Barker river to generate synthetic annual streamflows. Mean standard deviation and lag one serial correlation coefficient were preserved in generated streamflows of all applied AR models as statistical properties of historic sequence fell within 95 percent confidence limit. Diagnostic checking of residuals series showed that AR model of fourth order applied to logarithmically transformed streamflows fit the annual streamflows data well in preservation of all the statistical characteristics.

Mutua (1998) used a recursive transfer function hydrologic model for the Sagana Catchment of Tana river in Kenya, based on the daily stream flow data. The generalized partial auto correlation technique was used to identify the stochastic characteristics of the data. The identified model appeared to forecast the low flow very well, but it showed significant deviation in the forecast of high flows mainly on day to day basis although the general trend was well duplicated.

Singh (1998) attempted stochastic modelling of monsoon rainfall data at 50 different stations across India to study the persistence structure causing interannual variability in monsoon rainfall. The study of stochastic behaviour of annual summer monsoon rainfall of the Indian sub continent revealed that the annual monsoon rainfall values do not have any persistence between them and they can be reliably estimated for a desired recurrence interval using a normal distribution and transformation of data using a Box-Cox transformation.

Reddy and Kumar (1999) developed a time series model for average monthly rainfall and used it for Bino watershed of Ramganga river. The rainfall series was assumed to be composed of deterministic and stochastic component. Fourier series analysis was used to identify periodic component. The stochastic component was modelled by fitting autoregressive model. The mean and standard deviation of generated series were found close to

the historical series. The absolute, relative and integral square errors indicated a high degree of model fitness to the observed data series.

Subbaiah and Sahu (2002) presented a model for the weekly monsoon season rainfall based on average weekly rainfall data of 49 years (1958-97) at Junagadh. Model is based on the assumption that weekly rainfall in season is a first order Markovian process. Comparison between the historical and synthetic series showed that the two are statistically comparable with respect to measures of central tendency dispersion and distribution.

Jat et al., (2003a) developed a stochastic model for weekly water deficit series under climatic conditions of Kota in Rajasthan. The statistical properties of the generated series have been verified with those of historical series, which were almost the same. Validation of developed stochastic model made by comparison of generated and observed series showed a linear correlation with correlation coefficient of 0.88 and stated that the developed autoregressive model can be used for prediction of weekly water deficit series.

2.8 GEOSTATISTICAL MODELLING

Geostatistics is a mathematical interpolation and extrapolation tool, which uses the spatial statistics of the data set to estimate the property at a location where samples are not available. It consists of variogram and kriging method for model development. Fitting of standard model by geostatistical technique gives accurate estimate for interpolated values. This technique was originally developed for spatial analysis in mining resources. Although not much literature is available with regard to geostatistical modelling of drought, the following reviews reveal the importance and its application technique to various fields of study.

Brooker et al., (1995) investigated soils of irrigated vineyard using geostatistical approach. Effective supply of water for irrigation requires that the capacity of the soil to hold water be measured. Field measurement of the depth and texture of each soil layer in a profile allows calculation of the readily available water for the site. The spatial variation of readily available water is characterized by its semivariogram, calculated over the property under study. This function is used in a geostatistical analysis to determine the average value of the variable over areas watered by opening irrigation valves. The accuracy of such estimates is also provided in the geostatistical procedure of kriging. A case study applied to a vineyard in South Australia deals with root zone readily available water and depth of topsoil. The property was sampled with a grid 75 m X 75 m. Irrigation valve areas are typically 1.3 ha. A 50 % reduction in confidence intervals for the estimates occurred when the valve areas are estimated by kriging compared with those obtained using a simple average of the samples contained within the area. Of interest is the anisotropy seen in the semivariograms. Variation in the N-S direction is much more rapid than in the E-W. This factor is currently incorporated into the rectangular design of the irrigation valve areas. It is suggested that it should also influence sampling design.

Martinez-Cob (1996) evaluated ordinary kriging, co-kriging and modified residual kriging to interpolate long-term mean total annual reference evapotranspiration (AETO) and long-term mean total annual precipitation (APRE) in a mountainous region, where the stationarity hypothesis does not hold for the whole region, but holds locally. AETO and APRE estimates and estimation errors were evaluated at validation stations. Estimates and computed estimation error variances (used as indicators of estimation uncertainty) were also obtained at 19135 km grid points. Estimates at validation stations generally agreed with observed values for all interpolation methods, although modified residual kriging estimates of APRE were slightly worse than those obtained by the other two methods. Based on mean absolute error (MAE) and mean squared error (MSE) at validation stations, no method ranked clearly above another for interpolation of AETO. At grid points, AETO estimation uncertainty was improved by co-kriging by 11.5 % and 8.4 % compared with ordinary kriging and modified residual kriging, respectively. Likewise, co-kriging was superior for interpolation of APRE in terms of MAE and MSE obtained at validation stations. At grid points, co-kriging reduced estimation uncertainty by 18.7 % and 24.3 % compared with ordinary kriging and modified residual kriging, respectively, whereas modified residual kriging in general did not improve ordinary kriging results. Computed estimation error variance values indicated that modified residual kriging would reduce estimation uncertainty in areas where very few weather stations are available for interpolation.

Papamichail and Metaxa (1996) applied kriging to describe the spatial variability of rainfall data over a geographical region in northern Greece. Monthly rainfall data of January and June 1987 were taken from 20 measurement stations throughout the area. The rainfall data were used to compute semivariograms for each month. The resulting semivariograms were anisotropic and fitted by linear and spherical models. Kriging estimates of rainfall and standard deviation were made at 90 locations covering the study area in a rectangular grid and the results used to plot contour maps of rainfall and contour maps of kriging standard deviation. Verification of the kriging estimates of rainfall were made by removing known data points and kriging an estimate at the same location. This verification is known as the jackknifing technique. Kriging errors, a by-product of the calculations, were used to give confidence intervals of the resulting estimates. The acceptable results of the verification procedure showed that geostatistics can be used to describe the spatial variability of rainfall. It was shown how the property of kriging variance depends on the structure and the geometric configuration of the data points and the point to be estimated can be used for the optimal design of the rain gauge network in an area.

Pardo-Iguzquiza (1998) compared and discussed the results of estimating the areal average climatological rainfall mean in the Guadalhorce river basin in Spain using the classical Thiessen method and three different geostatistical approaches (ordinary kriging, co-kriging and

kriging with an external drift). Results revealed that kriging with an external drift seem to give the most coherent results in accordance with cross validation statistics. Kriging with an external drift has the advantage of requiring less demanding variogram analysis than co-kriging.

Holawe and Dutter (1999) used variogram to measure the temporal and spatial behaviour of precipitation over Austria. From the database of daily data from more than 400 precipitation stations having record of 20 years, the most essential properties of the variogram in its general form, namely sill, range and nugget effect were calculated first. Then it was demonstrated how these variables may reveal interesting insights into the spatial structure of the temporal situation of precipitation in Austria

Prudhomme and Reed (1999) applied ordinary kriging and modified residual kriging to map an index of extreme rainfall, the median of the annual maximum daily rainfall in the mountainous region of Scotland. Statistical tests of the performance of the kriging methods, as well as direct comparison between final estimates and observations, showed the modified residual kriging technique to be the most suitable for mapping the median of annual maximum daily rainfall.

Panigrahy and Singh (2000) adopted kriging technique to evaluate the existing raingauge network in Burhi-Gandak river basin, having 15 existing raingauges, with a view to select the optimal network density and location of the raingauge stations for the optimal estimation of average areal rainfall. In order to identify rainfall variation, a variogram is defined and modelled with distance, and parameters contributing to spatial and temporal variations are separated. It is found that only 10 raingauge stations would be sufficient for optimal estimation of average areal rainfall in the basin.

Grewal et al., (2001) investigated spatial variability of exchangeable zinc (Ex-Zn) and carbonate zinc in 5600 km² area of Rohatak and parts of its adjoining district in the Indo-Gangetic alluvial plains of north-west India using 72 surface samples. The semivariogram of Ex-Zn showed that this zinc fraction is spatially dependent up to a distance of 30 km within the study area, while that Carbon-Zn showed no spatial dependence of this fraction, indicating its random distribution. The observed and krigged values were used to draw isarithmic maps of Ex-Zn. The results from geostatistical analysis of the data show that kriging could explain most of the variation in the original data.

Hordofa (2003) developed a geostatistical model for studying spatial variability of pan evaporation measurement taken over twenty agro-meteorological sites of Ethiopia using geostatistical kriging technique. Applying variogram, the spatial structure of mean pan evaporation was analysed and used to reproduce point-kriging estimates. These estimates have been used to produce mean pan evaporation maps for Ethiopia for twelve months.

Satpute (2004) used geostatistical model to study spatial and temporal variability of water deficit (drought pattern) over Maharashtra. Fortnightly water deficit of 18 meteorological

stations that represent as point samples were interpolated applying kriging technique to generate estimates for non sampled points. Applying variogram, the spatial structure of fortnight water deficits were analysed and then modified for use in kriging to produce point kriging estimates. The results indicated that the occurrence and spread of drought has a general tendency to originate in the water deficit region, spreads in different directions of similar deficient region and then dissipates.

2.9 CROP PLANNING

In dry land areas crop production depends on vagaries of nature. Characterization of drought during a crop season helps in planning the most effective cropping pattern and developing suitable supplementary irrigation facilities. Drought studies carried in this direction are presented below.

Narain et al., (1984) made an attempt to characterize the drought in three districts falling in arid and semi-arid regions in Western India in relation to jowar crop. The study revealed that in Jamnagar and Surendranagar in Gujarat State, the occurrence of droughts of 9 week duration during early August and end of September is relatively more frequent and is expected to occur once in five and four years, respectively. The authors also stated that the variability in jowar yield (40 to 70%) was attributable to rainfall deficiency. The drought base values obtained for different durations can be used with sufficient accuracy for evaluating the intensity of agricultural drought in the region.

Tripathi (1992) used Markov-Chain model to predict the sequences of wet and dry days. The analysis was based on rainfall data of 22 years at Pantnagar. Weekly probability and probability of a particular day in the week being wet or dry showed that wheat planted in the first week of December has a 50-70 per cent chance of getting rain at crown root initiation and flowering stages and a sure chance of rain at jointing and milk stages.

Venkateshwarlu (1993) analysed the effect of drought on food grains production on the national scale as well as for individual crops, taking state as a unit. The author suggested that present use of meteorological sub-divisions in crop monitoring is inadequate. So, zones shall be listed based on assured moisture availability periods, hypsography and soil type. It was also suggested that annual amount of rainfall received and its distribution should be related to the various phenophases of crop, which will provide factual position on the performance of the crop. The author concluded that crop is said to be drought affected if AET to PET ratio is less than 0.25.

Ghadekar et al., (1994) conducted studies to quantify the stress during various growth stages in terms of potential evapotranspiration and actual evapotranspiration. The single continuous dry spell of 77 to 83 days and broken dry spells of still longer durations were found to occur during cotton growing season. The dry spells of pentad and decade durations

were more common and coincided with seeding, vegetative and reproductive stages. Mean water stress of 218.6 mm during total life phase and 168.4 mm during maturity were noted. Stress during maturity amounted to about 77.04 per cent of total life stress making crop production risky in the region.

Sarkar (1994b) investigated suitable cropping pattern over the coastal tract of Orissa for maximizing agricultural production based on probabilistic rainfall while giving due importance to soil, topography and salinity problem.

Rath et al., (1996) analysed 20 years (1975-94) daily rainfall data to establish the drought frequency based on Markov-Chain model considering a pentad (5 day period) receiving rainfall less than 15 mm as dry period. The result of the analysis indicated that the safe growing period during kharif season is from 33rd pentad (10th June) to 51st pentad (12th September).

Agnihotri (1999) analysed rainfall data of 39 years (1958-96) at Chandigarh to work out Precipitation Concentration Index (PCI) and Modified Precipitation Concentration Index (MPCI) and found that kharif and rabi season rainfall series are non random as tested through non-parametric test at 5 per cent level of significance. The MPCI values were used to classify drought and flood years. Mean kharif season rainfall during 1958-67, 68-77, 78-87 and 88-96 was found out to be significantly different from each other as treated through statistical 't' test at 5 per cent level of significance.

Chaurasia et al., (1999) analysed rainfall data of 30 years for the monsoon period on weekly basis following Gamma distribution and Weibull's method to predict the occurrence of rainy events of different probability for crop planning in Ludhiana district, Punjab. The analysis revealed that cultural operation of rice after transplanting can possibly be managed with rain water as the average weekly rainfall of the favourable events are in the range of 37 to 62 mm.

Das (1999) investigated the influence of rainfall during the growth phases and total crop season on yield of rice in Konkan region of Maharashtra. Results indicated that the final yield was dependent not as much on the total rainfall during the entire crop season as on the rainfall during tillering to early grain setting stage. Moderate stress conditions are normally observed towards early September, which adversely affect crop production.

Agnihotri and Murti (2000) studied the pattern of weekly soil moisture availability during kharif season and worked out probabilities of moisture stress free weeks under different sowing week systems. Weeks with cumulative actual evapotranspiration more than half of cumulative potential evapotranspiration were considered as moisture free weeks. The authors found that for Chandigarh region, sowing in 25th week is most ideal. The study concluded that there is no association between sowing schedule and amount of rainfall during kharif season.

Dabral (2000) analysed daily rainfall and evaporation data of 34 years (1956-89) for excess and deficit rainfall period. The author termed period as excess if rainfall exceeds the evaporation and as deficit if evaporation exceeds the rainfall. Graphs were plotted for excess deficit period at 30 % and 40 % risk. The study revealed that supplemental irrigation is needed during 42nd to 18th week for the tea crop. It was suggested that in order to minimize risk of tea crop failure due to lack of rain, irrigation planning should be based on 30 per cent risk at level. The author also suggested that irrigation planning based on 30 per cent risk level may increase the irrigation expenses but it will reduce risk of crop failure.

Srivastava et al., (2000) investigated drought in relation to rice productivity for Raipur division. Results on drought analysis using aridity index showed that due to recurring feature of drought spells in October, raising of long duration rice cultivars under rainfed conditions in the region should be avoided.

Gore (2001) applied Markov-Chain model to obtain the probabilities of wet and dry spells over districts of all subdivisions of the country from five homogenous regions and from hilly areas using daily rainfall data of 1901 to 1990 for all the available stations in the subdivisions. It is stated that climatological analysis in the form of probabilities can be very useful in decision making for agricultural operation.

Munamava and Riddoch (2001) experimented the effect of water stress at the vegetative, booting and flowering stages on three cultivars of sorghum in a pot experiment under glasshouse conditions in Bolswana. Results indicated that grain yields were significantly ($P < 0.05$) lowered by stress, especially when this was applied at the booting stage. Cultivars differences in yield were not significant based on overall performance.

Das et al., (2002) developed an index called moisture deficit index from water balance to assess agricultural drought in the dry land farming zone of India and stated that the moisture stress experienced by the crop and its accumulation could be used as a factor in determining the crop yield.

Panigrahi and Panda (2002) studied the sequences of dry and wet spells of Kharagpur in West Bengal so that necessary steps can be taken to prepare contingent crop plan in that rainfall region. It was observed that from 24th to 39th week, the chances of occurring 2 and 3 consecutive dry weeks are only within 0 to 33.3 and 0 to 23.3 per cent respectively. Therefore, a short duration rice crop of about 100 days duration can easily be grown in the region with little fear of drought. Moreover the residual soil moisture after the harvest of rice can be effectively utilized for raising another short duration crop in winter.

Gourangakar (2003) analysed weekly rainfall and concluded that most dependable limit (> 70 % probability) of occurring 10 mm or more rainfall was observed to be from 25th standard week. So sowing operation of rainfed crops may be initiated from 24th week, immediately after onset of monsoon. Winter and summer rainfall is meagre and erratic, so

growing of high value crops without supplementary irrigation would be risky. Crop diversification and substitution of rice in upland may be done to improve productivity and cropping intensity of upland for which monthly rainfall was sufficient even at higher confidence level (90 % probability).

Jat et al., (2003b) proposed crop planning for Bhilwara in Rajasthan using dry and wet spell analysis. The authors suggested that with a rainy season of 12.5 weeks mean duration (CV as 40.60 %), farmers can take short duration crops like maize, sorghum and pulses of 80 to 90 days. Second crop like mustard, taramira and gram can be taken up during 40th to 42nd week.

From review presented above, it is inferred that for better crop planning and understanding the relationship between water deficit and surplus during crop growth period is very important while the knowledge on rainfall related parameters such as data on onset and termination of monsoon and duration and magnitude of water deficit and drought characterisation is limited in Gujarat. This needs immediate attention as more than two third area of the arable land in the state is rainfed. Frequency analysis interprets past record of events to predict the future probabilities of occurrence. Water deficit data at different probabilities of occurrence can be used in designing and managing protective irrigation systems as well as for planning, designing and managing water resource projects. In such studies there is a need to predict the magnitude of extreme water deficit at different return periods.

A stochastic model explains the extent of dependence of the present observation on the past observation. Therefore, stochastic modelling of water deficit may provide good insight and understanding of the process for useful application in crop planning of the region. The Artificial Neural Network models have been found useful and efficient, particularly in problems like water deficit, for which the characteristics of the processes are difficult to describe using physical equations. Geostatistical approach of spatial estimation known as kriging can be used to interpolate water deficit data for unrecorded places and thereby to produce contour maps at suitable time interval for studying spatial and temporal variability of water deficit over the state.

Recognizing the above concern and taking into consideration that no such study has been carried out in different agro-climatic zones of Gujarat, it is necessary to analyse, characterize and model drought situation in the state under changing climatic pattern.

III - MATERIALS AND METHODS

This chapter encompasses the location of the study area and its characteristics features, the methodology adopted in achieving the set of objectives in light of the basic ground data and other relevant components of the study.

3.1 GENERAL FEATURES OF THE STUDY AREA

The details of location of the study area, general features of different agro-climatic zones in Gujarat state and soil information are briefly presented in following subsections:

3.1.1 Location of the Study Area

The state of Gujarat is situated in western part of the country lies between 20.10⁰ to 24.70⁰ N latitude and 68.40⁰ to 74.40⁰ E longitudes. It is flanked by the Arabian sea on the West and South-West with a coast line of nearly 1290 km, Pakistan in the North of the Rann of Kachchh, Rajasthan in the North, Madhya Pradesh in the North-East and Maharashtra in the South and South-East. The state with an area of 19.6 mha, representing 5.96 per cent of the total geographic area of the country, is the seventh largest state of India.

The area selected for the study covers all the eight agro-climatic zones of Gujarat state. Sixteen meteorological stations located in different agro-climatic zones of the state were selected for the study (Table 3.1). These stations are well distributed to represent all the agro-climatic zones of the state (Fig. 3.1).

Table 3.1 Location of stations under different agro-climatic zones of Gujarat

S. No.	Agro-climatic zone	Station	Latitude, °N	Longitude, °E	Altitude, m
1	South Gujarat (I) (Heavy rainfall)	Gandevi	20.80 ⁰	73.00 ⁰	7.60
		Navsari	20.93 ⁰	72.90 ⁰	10.00
2	South Gujarat (II)	Surat	21.20 ⁰	72.83 ⁰	11.50
		Bharuch	21.68 ⁰	73.00 ⁰	16.50
3	Middle Gujarat (III)	Anand	22.58 ⁰	72.97 ⁰	45.10
		Nawagam	22.72 ⁰	72.55 ⁰	32.40
4	North Gujarat (IV)	Khedbrahma	24.05 ⁰	73.00 ⁰	218.39
		S.K.Nagar	24.32 ⁰	72.32 ⁰	154.52
5	North-West Gujarat (V)	Radhanpur	23.82 ⁰	71.55 ⁰	26.50
		Kothara	23.16 ⁰	68.93 ⁰	20.00
6	North Saurashtra (VI)	Rajkot	22.28 ⁰	70.80 ⁰	137.7
		Amreli	21.60 ⁰	71.20 ⁰	130.00
7	South Saurashtra (VII)	Junagadh	21.52 ⁰	70.50 ⁰	61.00
		Mahuva	21.08 ⁰	71.80 ⁰	7.00
8	Bhal and Coastal (VIII)	Dhandhuka	22.40 ⁰	71.98 ⁰	37.50
		Arnej	22.63 ⁰	72.32 ⁰	31.80

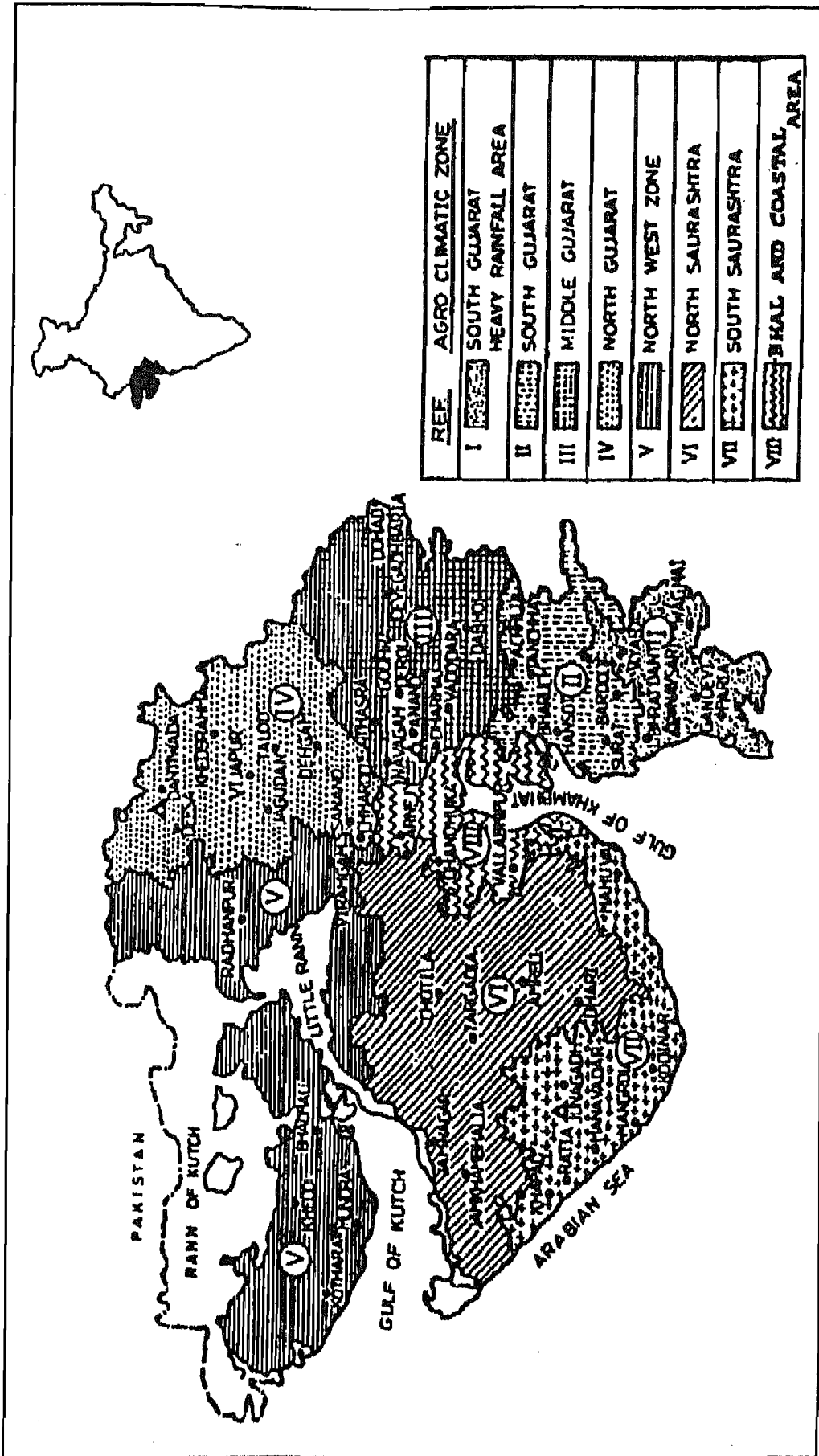


Fig. 3.1 Agro-climatic zones of Gujarat

The annual normal rainfall in different parts of Gujarat varies between 250 mm to 2000 mm with the coefficient of variation of 30-80%. This indicates that there is a large spatial and temporal variation in rainfall amount in the state. The low rainfall areas (< 500 mm) are comprised of Kutchh, western half of Jamnagar and Banaskantha, central and northern parts of Surendranagar and western parts of Patan districts. These areas are characterized by hot arid climate. The high rainfall (>1000 mm) is received in Dang, Valsad, Navsari, Surat, Narmada and eastern parts of Vadodara and Bharuch and south eastern part of Panchmahal districts. These areas are characterized as dry sub humid climate. Rest parts of the state receive rainfall between 500-1000 mm. Most of these areas fall under semi arid climate. Although the annual rainfall in the state increases in the south-east direction, there are large number of places where spot variation in rainfall, e.g. high rainfall at and around Girnar, Modasa, Jambughoda and Dediapada, etc. is observed (Anonymous, 2000).

3.1.2 Agro-climatic Zones of Gujarat

Based on rainfall distribution, soil characteristic, cropping pattern and other physical characteristics, Gujarat is divided into eight agro-climatic zones (Fig.3.1). The characteristic features of these zones are briefly described as under:

3.1.2.1 South Gujarat (Heavy rainfall) zone

The zone includes districts of Dangs, Valsad, Navsari and South part of Surat. The average annual rainfall is more than 1500 mm. The mean daily highest maximum and lowest minimum temperatures are around 37.0°C in May and 11.0°C in January, respectively. Deep black with few patches of coastal alluvial, lateritic and medium black soils of Inceptisols and Entisol orders are predominant in the zone. Most of the mid land flood plains are under cultivation. Some area under hill slope up to 3.5 percent is non cultivated under fallow and pasture forest. The South-East part is mostly covered by deciduous to semi deciduous forests. Paddy, cotton, sorghum, sugarcane, vegetables and horticultural crops are under cultivation in the zone.

3.1.2.2 South Gujarat zone

The zone comprises districts of Bharuch, Narmada and North part of Surat. The average annual rainfall varies between 1000 to 1500 mm. The mean daily highest maximum and lowest minimum temperatures are around 38.0°C in May and 13.0°C in January, respectively. The predominant types of soils are deep black clayey soils of Inceptisols, Vertisols and Entisols orders. Most of the mid land flood plains are under cultivation. Some area under hill slope up to 3.5 percent is non-cultivated under fallow and pasture forest. Cotton, sorghum, wheat, sugarcane, pigeon-pea and horticultural crops are the major cultivation in the zone.

3.1.2.3 Middle Gujarat zone

The zone covers Vadodara, Anand, Kheda, Dahod and Panchmahals districts. The average annual rainfall range from 800 to 1000 mm. The mean daily highest maximum and lowest minimum temperatures are around 40.0°C in May and 11.5°C in January, respectively. The predominant types of soil are deep black and medium black to loamy sand of Inceptisols and Entisols orders. Most of the mid land flood plains are under cultivation. Some area under hill slope up to 3.5 percent is non-cultivated under fallow and pasture forest. Principal crops of the zone are cotton, tobacco, pulses, pearl-millet, sorghum, wheat, maize, sugarcane, pigeon-pea, paddy and horticultural species.

3.1.2.4 North Gujarat zone

The zone covers Gandhinagar, Mehsana, Sabarkantha, North part of Ahmedabad and East part of Banaskantha and Patan districts. The average annual rainfall of the zone ranges between 625 to 875 mm. The mean daily highest maximum and lowest minimum temperatures are around 40.0°C in May and 10.5°C in January, respectively. The soils are deep sandy loam to loam of Inceptisols, Entisols and Aridsols order. The general topography is plain and most of the area is under cultivation. The principal crops of the zone are pearl-millet, pulses, cotton, tobacco, wheat, sorghum, groundnut, oil-seeds, spices and condiments, vegetables and horticultural species.

3.1.2.5 North West Gujarat zone

The zone includes Kutchh, West part of Banaskantha and Patan, North part of Surendranagar and Rajkot and North-West Ahmedabad districts. The rainfall ranges from 250 to 500 mm annually. The mean daily highest maximum and lowest minimum temperatures are around 35.0°C to 43.0°C in May and 12.0°C in January, respectively. Predominantly the soils of this zone are sandy and saline of Aridsols and Inceptisols orders. The principal crops grown are cotton, sorghum, groundnut, pearl millet and wheat.

3.1.2.6 North Saurashtra zone

The zone comprises Amreli, Jamnagar, major part of Rajkot, West part of Surendranagar and North part of Bhavnagar districts. The average annual rainfall of the zone ranges between 400 to 700 mm. The mean daily highest maximum and lowest minimum temperatures are around 40.0°C in May and 12.0°C in January, respectively. The soils are moderately deep to deep, medium black clay loam to clay and of Inceptisols and Entisols orders. The general topography is rolling with slope between 1 to 3 per cent. Groundnut, cotton, pearl millet, sorghum, oil seeds and wheat are the important crops of the zone.

3.1.2.7 South Saurashtra zone

The zone covers Junagadh, Porbandar, South part of Rajkot and coastal area of

Amreli and Bhavnagar districts. The average annual rainfall of the zone ranges between 625 to 750 mm. The mean daily highest maximum and lowest minimum temperatures are around 36.0°C in May and 12.0°C in January, respectively. The soils are moderate to deep, medium black and calcareous and of Inceptisols and Entisols orders. Groundnut, cotton, pulses pearl millet, sorghum, oil seeds, sugarcane, wheat and horticultural cultivation are important in the zone.

3.1.2.8 Bhal and Coastal zone

The zone includes parts of districts of Ahmedabad, Bhavnagar and Bharuch around the gulf of Khambhat. The average annual rainfall of the zone ranges between 625 to 1000 mm. The mean daily highest maximum and lowest minimum temperatures are around 39.0°C in May and 12.0°C in January, respectively. The soils are medium black, poorly drained and saline and medium to heavy in texture. A strip of about 2 km area is under coastal saline and rest of the area is under dry land cultivation. The major crops grown are groundnut, cotton, sorghum, pulses, pearl millet and dry wheat.

3.1.3 Soils of the Study Area

The soils of Gujarat can broadly be classified into nine groups. These are : (i) black soils, (ii) mixed red and black soils,(iii) residual sandy soils,(iv) alluvial soils,(v) saline-alkali soils,(vi) desert soils,(vii) lateritic soils,(viii) hilly soils and (ix)forest soils. Typical soil physical properties for the selected stations are presented in Table 3.2.

Table 3.2 Physical properties of soils of the study area

Station	Type of soils	Texture	Depth, cm	Average AWC, mm
Gandevi	Deep black cotton	Clay	>100	200.0
Navsari	Deep black cotton	Clay	>100	150.0
Surat	Deep black cotton	Clay	>100	200.0
Bharuch	Deep black cotton	Clay	>100	200.0
Anand	Alluvial	Sandy clay loam to clay loam	>100	200.0
Nawagam	Alluvial	Sandy loam to sandy clay loam	>100	150.0
Khedbrahma	Medium black cotton	Silty loam to clay loam	25-50	125.0
S.K.Nagar	Alluvial	Sandy to sandy loam	>100	100.0
Radhanpur	Desert	Sandy to sandy loam	50-100	100.0
Kothara	Desert	Sandy to sandy loam	25-50	100.0
Rajkot	Medium black cotton	Clay loam to clay	50-100	150.0
Amreli	Medium black cotton	Clay loam to clay	50-100	100.0
Junagadh	Medium black cotton	Clay loam to clay	>100	150.0
Mahuva	Medium black cotton	Clay loam to clay	>100	150.0
Dhandhuka	Medium black cotton	Clay loam	>100	200.0
Arnej	Medium black cotton	Clay loam to loam	>100	200.0

Source: Anonymous, 2000

3.2 COLLECTION OF METEOROLOGICAL DATA

In order to carry out the study, weekly meteorological data viz. maximum and minimum temperatures, relative humidity during morning and afternoon hours, bright sunshine duration, wind speed and precipitation for a period of 22 to 30 years (1974-2003) were collected from the Meteorological Observatories of the respective Agricultural Research Stations (ARS) of the Agricultural Universities in the state. The information on other parameters like geographic locations viz. latitude, longitude and altitude of respective stations are also presented in Table 3.1.

3.3 DETERMINATION OF ONSET AND WITHDRAWAL OF RAINY SEASON

Onset and withdrawal of rainy season was computed from weekly rainfall data using Morris and Zandestra (1979) method of forward and backward accumulation, respectively. In this method weekly rainfall can be summed by forward accumulation (20+21+...+52 weeks) until a certain amount of rainfall is accumulated. Seventy five mm of accumulation rainfall has been considered as the onset time for the growing season for dry seeded crops and land preparation (Rath et al., 1996; Babu and Lakshminarayana, 1997; Panigrahi and Panda, 2002).

The withdrawal of rainy season was determined by backward accumulation of rainfall (48+47+46+...+30 weeks) data. Thirty mm of accumulation of rainfall was chosen for the end of rainy season, which may be sufficient for ploughing of fields after harvesting of crops (Babu and Lakshminarayana, 1997).

If for a longer period (at least 25 years) the weekly rainfall is summed forward and backward from the peak of dry season, until the certain amount calculated, then the probability of given amount of rainfall can be obtained for each time interval chosen (Dash and Senapati, 1992). Years with respective weeks of onset and withdrawal of rainy season were assigned with the rank number. The percent probability (P) of each rank was calculated by the following Weibull's formula:

$$P = \frac{m}{N + 1} \times 100 \quad \dots (3.1)$$

where, m is the rank number and N is the number of years

For forward accumulation, the rank order and probability level were arranged in ascending order and the corresponding week numbers were arranged in the same manner. Similarly for backward accumulation the rank order and the probability level were arranged in descending order and the corresponding week numbers were arranged in the same way.

3.4 ESTIMATION OF RAINFALL PROBABILITY BY MARKOV-CHAIN PROCESS

The success or failure of crops particularly under rainfed conditions is closely linked with the rainfall patterns. Simple criteria related to sequential phenomenon like dry and wet spell was used for analysing rainfall data to obtain specific information needed for crop planning and for carrying out agricultural operations. It is useful to ascertain the probability of sequential events like a wet week following another wet week or a dry week following a wet or dry week during the crop growing season. This is the basis for the analysis of rainfall using Markov-Chain process.

Rainfall of 20 mm per week is adequate for all the growth stages of all the crops grown. Thus, if in a given week the rainfall received is less than 20 mm that week can be designated as a dry week and vice versa (Pandharinath, 1991). On the basis of this criterion each week was categorised as a dry week and wet week and respective probabilities were calculated as follows:

(i) **Initial probability:**

$$P(W_j) = \frac{F(W_j)}{N} \quad \dots (3.2)$$

and
$$P(D_j) = \frac{F(D_j)}{N} \quad \dots (3.3)$$

where,

$P(W_j)$ = initial probability of j^{th} week being wet

$P(D_j)$ = initial probability of j^{th} week being dry

$F(W_j)$ = frequency of occurrence of j^{th} week being wet

$F(D_j)$ = frequency of occurrence of j^{th} week being dry

N = number of years of data used

(ii) **Conditional probability:**

$$P(W/W_j) = \frac{F(W/W_j)}{F(W_j)} \quad \dots (3.4)$$

and
$$P(D/D_j) = \frac{F(D/D_j)}{F(D_j)} \quad \dots (3.5)$$

where,

$P(W/W_j)$ = probability of wet weeks preceded by another wet week in j^{th} week

$P(D/D_j)$ = probability of dry weeks preceded by another dry week in j^{th} week

$F(W/W_j)$ = frequency of wet weeks preceded by another wet week in j^{th} week

$F(D/D_j)$ = frequency of dry weeks preceded by another dry week in j^{th} week

(iii) Two consecutive dry and wet week probability:

$$P(2W_j) = P(W_j) \times P(W/W_{j+1}) \quad \dots (3.6)$$

and
$$P(2D_j) = P(D_j) \times P(D/D_{j+1}) \quad \dots (3.7)$$

where,

$P(2W_j)$ = probability of 2 consecutive wet weeks in j^{th} week

$P(2D_j)$ = probability of 2 consecutive dry weeks in j^{th} week

3.5 COMPUTATION OF DIFFERENT ELEMENTS OF WATER BALANCE EQUATION

The water balance is a detailed statement of the law of conservation of mass, which states that matter can neither be created nor be destroyed but can only be changed from one state or location to another. If above statement is applied to the hydrologic equations, it states that in a specified period of time, all water entering a specified area must either go into storage within its boundaries, be consumed there in, be exported there from or flow out either on the surface or underground. So for its computation, procedure introduced by Thornthwaite and Mather, (1955, 1957) was used.

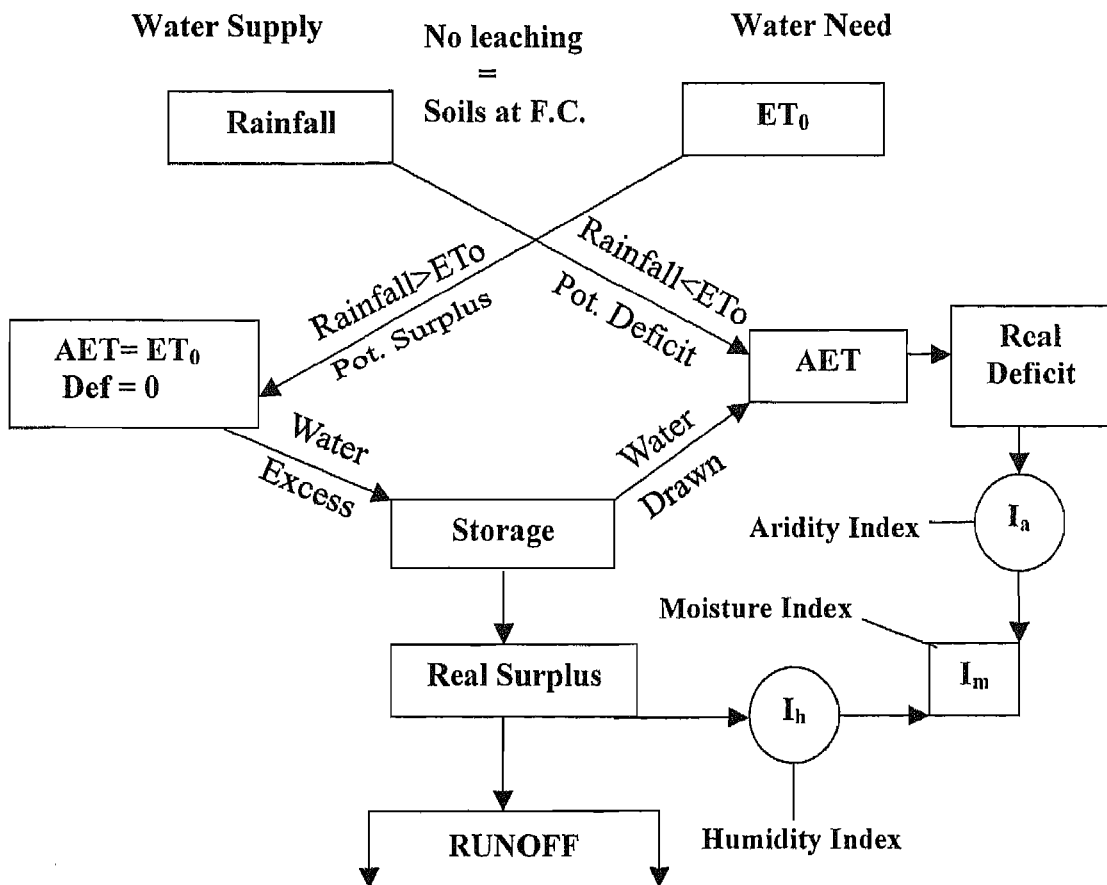


Fig. 3.2 A generalized flow diagram of the climatic water balance

Thornthwaite and Mather (1955) suggested the use of potential evapotranspiration (PET) value for computation of soil water balance. Because of ambiguities in the interpretation of potential evapotranspiration, the term reference evapotranspiration (ET_0) is used throughout the world (Allen et al., 1998). Therefore, the original equation of Thornthwaite and Mather (1955) was modified by using ET_0 in place of PET. The central concept of soil water balance is shown in Figure 3.2. Procedure for computation of different water balance elements is given below.

3.5.1 Available Water Holding Capacity of Soil (AWC)

Available water (AW) is the soil moisture between field capacity and permanent wilting point. Field capacity (FC) is the amount of water that the soil holds against drainage by gravity (at 1/3 bar). Permanent wilting point (PWP) is the moisture content in a soil when plants permanently wilt and will not recover (at 15 bar). The information for the selected stations was used from Natural Resources of Gujarat (Anonymous, 2000)

3.5.2 Reference Evapotranspiration (ET_0)

Reference evapotranspiration (ET_0) is the rate of evapotranspiration from a hypothetical reference with assumed crop height at 0.12 m, a fixed surface resistance of 77 sec per meter and albedo of 0.23 closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, completely shading the ground, and that with adequate water (Allen et al., 1998). According to this definition reference evapotranspiration (ET_0) was computed using Penman-Monthieith equation as per the procedure given by Allen et al., (1998).

$$ET_0 = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_a - e_d)}{\Delta + \gamma (1 + 0.34 U_2)} \quad \dots (3.8)$$

where,

ET_0 = reference evapotranspiration (mm/day)

R_n = net radiation ($MJ/m^2/day$) = $R_{ns} - R_{nl}$

R_{ns} = net short wave radiation ($MJ/m^2/day$)

R_{nl} = net long wave radiation ($MJ/m^2/day$)

Δ = slope of the saturation vapour pressure function ($kPa / ^\circ C$)

G = soil heat flux ($MJm^{-2}day$)

γ = psychrometric constant ($kPa / ^\circ C$)

T = mean daily temperature ($^\circ C$)

e_a = saturation vapour pressure at temperature T (kPa)

e_d = saturation vapour pressure at dew point (kPa)

U_2 = average daily wind speed at 2 m height (m/s)

3.5.3 Weekly Moisture Excess and Deficit (P-ET₀)

Difference between rainfall (P) and reference evapotranspiration gives weekly moisture excess and deficit. A negative value of this difference indicates moisture deficit, which means the amount by which the rainfall fails to supply the potential water need of area. While positive difference is moisture excess, which is the amount of excess water available for soil moisture replenishment and also for a runoff.

3.5.4 Accumulated Potential Water Loss and Gain [Acc (P-ET₀)]

Values of (P-ET₀) are summed up week by week as an aid in the computational steps that follow, which are designated as Acc (P-ET₀).

3.5.5 Storage (STOR)

In order to carry out the calculation of soil moisture storage, it is necessary to know from where one should begin. According to Thornthwaite and Mather (1957), the starting value of soil moisture content can only be obtained by assuming value of soil moisture storage equal to the moisture holding capacity after the period of rain ceases during the wet season of the year.

As the soil dries, the rate of evapotranspiration decreases. According to Thornthwaite and Mather (1957), the release of moisture is an exponential function. Considering the above principle, following formula was used for computing the soil moisture storage at the end of each week:

$$STOR = AWC \times e^{\left(\frac{Acc(P - ET_0)}{AWC}\right)} \quad \dots (3.9)$$

where,

STOR = actual storage of soil moisture, mm

AWC = available water holding capacity of soil, mm

P = rainfall, mm

ET₀ = reference evapotranspiration, mm

3.5.6 Change in Storage (ΔSTOR)

The positive changes in soil storage are termed as soil moisture recharge. The negative changes are termed as soil moisture utilisation, when the value in storage is above the water holding capacity; it is assumed that there is no change in soil storage.

3.5.7 Actual Evapotranspiration (AET)

The actual evapotranspiration (AET) is considered to take place at the potential rate, when precipitation exceeds the reference evapotranspiration during particular week and also when moisture in the soil is near field capacity. However, after the soil moisture was depleted

to a point where the ability of the soil to transmit the moisture was reduced, the actual rate of evapotranspiration was sharply reduced. Therefore, weekly actual evapotranspiration was calculated from the following equations:

(a) When $P > ET_0$

$$AET = ET_0 \quad \dots (3.10)$$

(b) When $P < ET_0$

$$AET = P + \text{abs}(\Delta \text{STOR}) \quad \dots (3.11)$$

From Equations (3.10 and 3.11) it is clear that when precipitation is less than ET_0 , then AET is equal to precipitation plus absolute value of change in the soil moisture storage than previous week.

3.5.8 Water Deficit (DEF)

The amount by which the actual evapotranspiration (AET) and reference evapotranspiration differ in any week is the water deficit (DEF). Water deficit only exists when $(P-ET_0)$ is negative and is calculated by the following equation:

$$DEF = ET_0 - AET \quad \dots (3.12)$$

3.5.9 Water Surplus (SUR)

The water surplus is the amount of positive $(P-ET_0)$ which remains in excess after recharging the soil to the field capacity by the following equation:

$$SUR = P - AET \quad \dots (3.13)$$

3.5.10 Climatological Indices

On the basis of above parameters climatological indices such as humidity index (I_h), aridity index (I_a), moisture index (I_m) and moisture adequacy index (I_{ma}) were computed by using the following expressions (Thornthwaite and Mather, 1955 and 1957):

$$I_h = \frac{SUR}{ET_0} \times 100 \quad \dots (3.14)$$

$$I_a = \frac{DEF}{ET_0} \times 100 \quad \dots (3.15)$$

$$I_{ma} = \frac{AET}{ET_0} \times 100 \quad \dots (3.16)$$

$$I_m = I_h - I_a \quad \dots (3.17)$$

3.6 DETERMINATION OF CLIMATIC SHIFT

Based on moisture index, the type of climate of the study area was determined by the following scheme of Subramanyam and Sastri (1969):

Moisture	Type of climate
> 100	A – Per humid
80 - 100	B4 – Humid
60 - 80	B3 – Humid
40 - 60	B2 – Humid
20 - 40	B1 - Humid
0 - 20	C2 – Moist sub humid
-33.3 - 0	C1 – Dry sub humid
-66.7 - -33.3	D – Semi-arid
-100 - -66.7	E - Arid

3.7 EVALUATION OF DROUGHT

Drought was evaluated in terms of drought intensity. For this study following scheme proposed by Subramanyam and Sastri (1969) was used:

Departure of aridity index from the normal	Drought intensity
< 0	Normal
0 - 0.5 σ	Moderate
0.5 σ - σ	Large
σ - 2 σ	Severe
> 2 σ	Disastrous

where,

σ = the standard deviation of yearly aridity index

3.8 ASSESSMENT OF DURATION AND SEVERITY OF DROUGHT

The cumulative deviation technique of Foley (1957) was used to assess duration and severity of drought in selected agro-climatic zones. In this technique instead of rainfall values, water deficiency deviations have been used in preparing the cumulative deviation curves similar to the residual mass graph. Departures of weekly water deficiency from the cumulative normal were taken and expressed as ratios of the normal water need in units of hundreds. These units were cumulated from an arbitrary origin and plotted against successive weeks. The steepest portion of rise in the mass curve then indicates the core period of drought and the gradient, therefore, gives the drought severity index (DSI) during that period. Based on the DSI the droughts were categorized for all the stations by using following criteria (Subramanyam and Sastri, 1971; Malani, 1981 and Ram Mohan, 1984):

Drought Severity Index	Category
0 - 10	Moderate
10 - 20	Large
20 - 40	Severe
> 40	Disastrous

3.9 FREQUENCY DISTRIBUTION OF WATER DEFICIT

Frequency distribution analysis of largest water deficit during monsoon season was carried out for the selected sixteen stations from eight agro-climatic zones of Gujarat. The study was based on largest weekly water deficit data to understand the distribution pattern of extreme value at the selected stations representing the region and thereby making possible selection of the required water deficit rate for various return periods that may be used in the planning and design of water resources development projects for drought prone areas.

Before undertaking frequency analysis, the adequacy of length of record was determined using the following equation given by Mockus (1960):

$$Y = (4.30 t \log_{10} R)^2 + 6.0 \quad \dots (3.18)$$

where,

Y = minimum acceptable years of record

t = student's statistical value at the 95% level of significance with (Y-6) degree of freedom

R = ratio of magnitude of the 100 years event to the 2 years event

3.9.1 Method of Frequency Analysis

Frequencies of extreme weekly water deficit have been evaluated by fitting the data to the extreme value frequency distribution functions. Three most commonly used extreme probability functions viz. a) Gumbel for maxima, b) Weibull for maxima, and c) log Pearson type-III were selected and the distribution that best fitted the data have been used for determining the extreme values at different return periods (probabilities).

3.9.1.1 Gumbel distribution

The density function of Gumbel (extreme value type-I) for maxima distribution to fit an observed data can be expressed as:

$$f(x) = \frac{e^{-\frac{(x-\gamma)}{\beta}}}{\beta} \cdot e^{-e^{-\frac{(x-\gamma)}{\beta}}} \quad \dots (3.19)$$

where,

X = variate of the sample

β = scale parameter

γ = location parameter

3.9.1.2 Weibull (maxima) distribution

The density function of Weibull (extreme value type-III) for maxima distribution to fit an observed data can be expressed as:

$$f(X) = \frac{\alpha}{\beta} \left(\frac{\gamma - X}{\beta} \right)^{\alpha - 1} e^{-\left(\frac{\gamma - X}{\beta} \right)^{\alpha}} \quad \dots (3.20)$$

where,

- α = shape parameter
- β = scale parameter
- γ = location parameter
- X = variable of the sample

3.9.1.3 Log Pearson type-III distribution

The density function of log Pearson type-III distribution is given by:

$$f(X) = \frac{e^{-\frac{\gamma}{\beta} X} X^{\beta - 1}}{\beta \Gamma(\alpha)} \left(\frac{\ln X - \gamma}{\beta} \right)^{\alpha - 1} \quad \dots (3.21)$$

where,

- α = shape parameter
- β = scale parameter
- γ = location parameter
- X = variate of the sample

3.9.2 Test for Goodness of Fit of Probability Distributions

Of the selected three probability distribution methods of fitting to a data, the best fitting probability density function was selected based on goodness of fit test procedure. A number of statistical tests are available for testing the best fit distribution. In this study, chi-square test was selected among the most commonly useful procedures for testing goodness of fit test. The test statistic (χ^2) has been estimated from the expression:

$$\chi^2 = \sum_{i=1}^k \frac{(O_i - E_i)^2}{E_i} \quad \dots (3.22)$$

where,

- k = number of years
- O_i = observed values in i^{th} year
- E_i = expected value in i^{th} year

The water deficit data occurrences at 1, 2, 5, 10, 20, 50 per cent levels were worked out. The data were analysed by a computer-based routine VTFIT package for fitting probability distribution function that also provides goodness of fit tests.

3.10 ESTIMATION OF WATER DEFICIT BY ARTIFICIAL NEURAL NETWORKS

Artificial neural networks (ANN) are effective tools to model nonlinear systems. Water deficit is a complex process associated with non-linear model and therefore, can be modeled through ANN. The methodology adopted in respect of estimating water deficit through artificial neural networks is described under following heads.

3.10.1 Artificial Neural Network Process

An ANN is a massively parallel-distributed information system that has certain performance characteristics resembling to biological neural networks of the human brain. It is capable of representing arbitrarily complex non-linear processes that relate the inputs and outputs of any system. The fundamental processing element of a neural network is a neuron. This building block of human awareness encompasses a few general capabilities. Basically, a biological neuron receives inputs from other sources, combines them in some way, performs a generally nonlinear operation on the result and then outputs the final result. Figure 3.3 shows the relationship of these four parts.

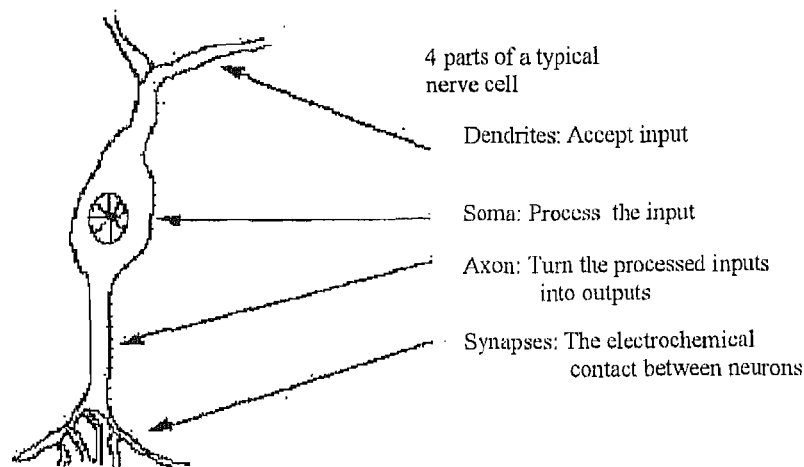


Fig. 3.3 Parts of a simple neuron

ANN performs a particular function by adjusting the values of connections (weights) between elements. Commonly neural networks are adjusted or trained, so that a particular input leads to a specific target output. The network adjusts the weights based on a comparison of the output and the target, until the network output matches the target. The network finishes its learning process if a minimum prediction error reaches. Such a situation is shown in Figure 3.4.

The obtained network thus will have best capability for the given problems specially the non-linear and dynamic system being simulated with an approximate range of accuracy. Basically, all artificial neural networks have a similar structure or topology as shown in Figure 3.5.

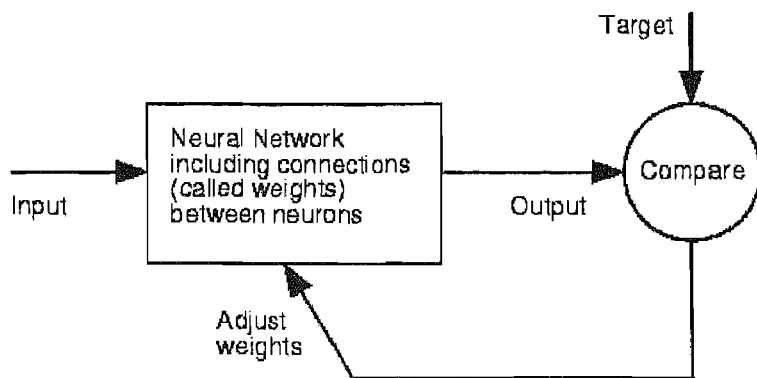


Fig. 3.4 A basic artificial neuron

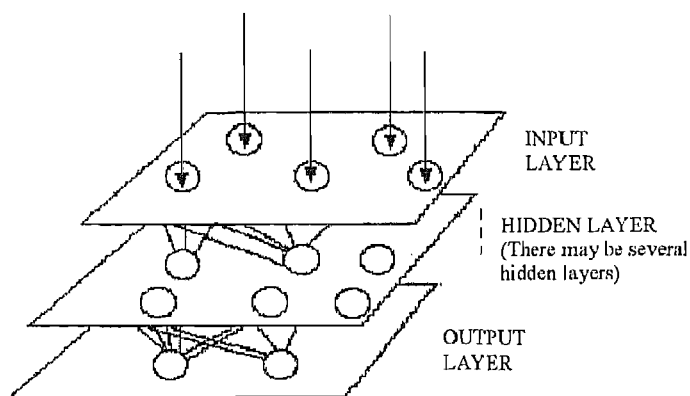


Fig. 3.5 A simple neuron network diagram

Most applications require networks that contain at least the three normal types of layers - input, hidden and output. The layer of input neurons receives the data either from input or output files. Between the input and output layers there can be many hidden layers. These internal layers contain many of the neurons in various interconnected structures. The inputs and outputs of each of these hidden neurons simply go to other neurons. The number of hidden layers, the number of input and output nodes and the number of nodes in the hidden layer depend on the problem. There are no fixed rules as to how many nodes should be included in the hidden layer. They are usually decided by the trial and error method.

However, if there are too few nodes in the hidden layer the network may have difficulty in generalizing the problem it has never encountered before. On the other hand if there are too many nodes in the hidden layer the network may take an acceptably long time to learn anything of any value.

3.10.2 Architecture

Neuron with a scalar input and with and without biases is shown in Figure 3.6. On the left of the figure, the scalar input p is transmitted through a connection that multiplies its strength by the scalar weight w , to form the product wp , again a scalar. Here the weighted input wp is the only argument of the transfer function f , which produces the scalar output a . The neuron on the right of the figure has a scalar bias, b . It can be viewed that the bias as simply being added to the product wp as shown by the summing junction or as shifting the function f to the left by an amount b . The bias is much like a weight, except that it has a constant input of 1. The transfer function net input n , again a scalar, is the sum of the weighted input wp and the bias b . This sum is the argument of the transfer function f . Here f is a transfer function, typically a step function or a sigmoid function, which takes the argument n and produces the output a . Where w and b are both *adjustable* scalar parameters of the neuron. The central idea of neural networks is that such parameters can be adjusted so that the network exhibits some desired or interesting behavior. Thus, we can train the network to do a particular job by adjusting the weight or bias parameters, or perhaps the network itself will adjust these parameters to achieve some desired end.

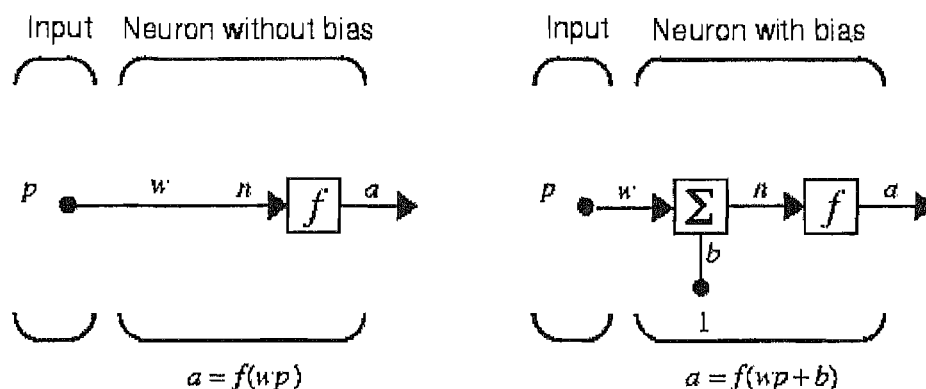


Fig. 3.6 A Neuron with single scalar input

3.10.3 Training

Once the network weights and biases have been initialized, the network is ready for training. The network can be trained for function approximation (nonlinear regression), pattern association or pattern classification. The training process requires a set of examples of proper network behavior - network inputs p and target outputs t . During training the weights and biases of the network are iteratively adjusted to minimize the network performance function. In training, both the inputs and the outputs are provided. The network then processes the inputs and compares its resulting outputs against the desired outputs. Errors are then propagated back through the system, causing the system to adjust the weights that control the network.

3.10.4 Back Propagation Algorithm

Back propagation learning updates the network weights and biases in the direction in which the performance function decreases most rapidly - the negative of the gradient. One iteration of this algorithm can be written as:

$$X_{k+1} = X_k - \alpha_k g_k \quad \dots (3.23)$$

where, X_k is a vector of current weights and biases, g_k is the current gradient, and α_k is the learning rate.

3.10.5 Faster Training

There are several high performance algorithms that can converge from ten to one hundred times faster than the earlier discussed algorithm. These faster algorithms fall into two main categories. The first category uses heuristic techniques, which were developed from an analysis of the performance of the standard steepest descent algorithm. This section discusses a heuristic technique: resilient back propagation *trainrp*, suitable for such studies. The second category of fast algorithms uses standard numerical optimization techniques.

3.10.5.1 Resilient back propagation (*trainrp*)

Multilayer networks typically use sigmoid transfer functions in the hidden layers. These functions are often called "squashing" functions, since they compress an infinite input range into a finite output range. Sigmoid functions are characterized by the fact that their slope must approach zero, as the input gets large. This causes a problem when using steepest descent to train a multilayer network with sigmoid functions, since the gradient can have a very small magnitude; and therefore, cause small changes in the weights and biases, even though the weights and biases are far from their optimal values. The purpose of the resilient back propagation training algorithm is to eliminate these harmful effects of the magnitudes of the partial derivatives. Only the sign of the derivative is used to determine the direction of the weight update; the magnitude of the derivative has no effect on the weight update. The size of the weight change is determined by a separate update value.

3.10.6 Improving Generalization

One of the problems that occur during neural network training is called over-fitting. The error on the training set is driven to a very small value, but when new data is presented to the network the error is large. The network has memorized the training examples, but it has not learned to generalize to new situations. One method for improving network generalization is to use a network that is just large enough to provide an adequate fit. The larger a network is used, the more complex the functions the network can create. If a small enough network is used it will not have enough power to over-fit the data. If the number of parameters in the

network is much smaller than the total number of points in the training set, then there is little or no chance of over-fitting. There are two methods for improving generalization that are ‘regularization’ and ‘early stopping’.

3.10.6.1 Regularization

The first method for improving generalization is called regularization. This involves modifying the performance function, which is normally chosen to be the sum of squares of the network errors on the training set.

3.10.6.2 Early stopping

Another method for improving generalization is called early stopping. In this technique the available data is divided into three subsets. The first subset is the training set, which is used for computing the gradient and updating the network weights and biases. The second subset is the validation set. The error on the validation set is monitored during the training process. The validation error will normally decrease during the initial phase of training, as does the training set error. However, when the network begins to over fit the data, the error on the validation set will typically begin to rise. When the validation error increases for a specified number of iterations, the training is stopped, and the weights and biases at the minimum of the validation error are returned. The test set error is not used during the training, but it is used to compare different models. It is also useful to plot the test set error during the training process. If the error in the test set reaches a minimum at a significantly different iteration number than the validation set error, this may indicate a poor division of the data set. With early stopping, the choice of the data set is also important. The validation set should be true representative of all points in the training set.

3.10.7 Preprocessing and Postprocessing

Neural network training can be made more efficient if certain preprocessing and postprocessing steps are performed on the network inputs and targets. In this section, a few important preprocessing routines are discussed.

3.10.7.1 Mean and standard deviation (*prestd*, *poststd*, *trastd*)

Before training, it is an approach for scaling network inputs and targets to normalize the mean and standard deviation of the training set. This procedure is implemented in the function *prestd*. It normalizes the inputs and targets so that they will have zero mean and unity standard deviation. The following code illustrates the use of *prestd*.

```
[pn, meanp, stdp, tn, meant, stdt] = prestd (p, t);      .... (3.24)
```

The original network inputs and targets are given in the matrices p and t . The normalized inputs and targets, p_n and t_n , that are returned will have zero means and unity standard deviation. The vectors $mean_p$ and std_p contain the mean and standard deviations of the original inputs, and the vectors $mean_t$ and std_t contain the means and standard deviations of the original targets. If $prestd$ is used to scale both the inputs and targets, then the output of the network is trained to produce outputs with zero mean and unity standard deviation. To convert these outputs back into the same units that were used for the original targets, then the routine $poststd$ is used.

3.10.7.2 Principal component analysis

In some situations, the dimension of the input vector is large, but the components of the vectors are highly correlated (redundant). It is useful in this situation to reduce the dimension of the input vectors. An effective procedure for performing this operation is principal component analysis. This technique has three effects: it orthogonalizes the components of the input vectors (so that they are uncorrelated with each other); it orders the resulting orthogonal components (principal components) so that those with the largest variation come first; and it eliminates those components that contribute the least to the variation in the data set.

3.10.7.3 Post training analysis (*postreg*):

The performance of a trained network can be measured to some extent by the errors on the training, validation and test sets, but it is often useful to investigate the network response in more detail. One option is to perform a regression analysis between the network response and the corresponding targets. The routine $postreg$ is designed to perform this analysis.

3.10.8 Adoption of Artificial Neural Networks Methodology

In order to estimate water deficit from various climatological parameters, i.e. maximum and minimum temperatures, maximum and minimum relative humidity, wind speed, bright sunshine hours and rainfall, the mean weekly data for 52 weeks, till the year 2002, for different stations under the study were used. The data set after loading into the workspace, were transformed and normalized and then principal component analysis was carried out. The principal components, which accounted for 99.95% of the variation in the data set were retained. The data, after inspection of the size of the transformed data, were divided into training, validation and test subsets. For this purpose the sets were picked up as equally spaced points through out the data. Hence, every first set was used for testing and every fourth set was used for validation. However, every second, third, fifth, sixth and

seventh set were used for training. So, in all testing and validation subset included seven sets each while training subset included thirty eight sets.

In order to train the network single hidden layer network with tan-sigmoid transfer function in the input layer, sigmoid function in the hidden layer and a linear transfer function in the output layer was used, as this is the useful structure for function approximation (or regression) problems. The network was trained for 5000 epochs and with goal for mean squared error of 0.0001. The number of neurons in the input and output layers were fixed at seven and one, respectively. The number of neurons in the input layer corresponded to the seven basic input parameters, whereas output layer node corresponded to the water deficit. The numbers of neurons in the hidden layer were varied in order to get the minimum mean square error (MSE) and high correlation coefficient. The resilient back propagation (trainrp) algorithm was used for the training. Training, validation and test set errors were plotted to check the progress of the training. The number of iterations when the training stopped and the test set error was observed.

In the next step the network response was analyzed. For this purpose the network outputs were un-normalized and a linear regression between the network outputs and corresponding targets was carried out. Finally, the trained network was tested for predicting the water deficit data for the year 2003. The regression analysis was also carried out between the observed and ANN predicted water deficit for the year 2003. The analysis was carried out using the MATLAB 6.0 software.

3.11 STOCHASTIC MODELLING OF WATER DEFICIT

In this study, a time series analysis by an autoregressive modelling approach has been used to provide weekly forecasts of water deficit (DEF). Time series analysis is of considerable practical use in dealing with any hydrological forecasting. A time series is a sequence of observed data arranged in the chronological order of their occurrence in time.

Weekly water deficit of the selected sixteen stations, representing different agro-climatic zones of Gujarat, were used for this study. From the water deficit data of twenty two to thirty years (1974-2003), depending upon the availability at the respective station, the data upto 2001 were used for model development and the remaining two years data (2002-2003) were used in validating the performance of the model. Details of the procedure followed are explained below:

3.11.1 Statistical Characteristic of Observed Series

Weekly observed water deficit time series was first analysed for the following statistical parameters:

Mean for the series, \bar{X}

$$\bar{X} = \frac{1}{N} \sum_{i=1}^N X_i \quad \dots (3.25)$$

Variance of the series, σ^2

$$\sigma^2 = \frac{1}{N-1} \sum_{i=1}^N (X_i - \bar{X})^2 \quad \dots (3.26)$$

Standard deviation, σ

$$\sigma = \sqrt{\sigma^2} \quad \dots (3.27)$$

Coefficient of variation, CV

$$CV = \frac{\sigma}{\bar{X}} 100 \quad \dots (3.28)$$

Skewness, C_s

$$CS = \frac{N(N-2)}{N-1} \sum_{i=1}^N \left(\frac{X_i - \bar{X}}{\sigma} \right)^3 \quad \dots (3.29)$$

Kurtosis, C_k

$$C_k = \left\{ \frac{N(N+1)}{(N-1)(N-2)(N-3)} \sum_{i=1}^N \left(\frac{X_i - \bar{X}}{\sigma} \right)^4 \right\} - \frac{3(N-1)^2}{(N-2)(N-3)} \quad \dots (3.30)$$

3.11.2 Time Series Model Development

The time series of water deficit was decomposed into a deterministic component in the form of trend and periodic parameter and a stochastic (random) component consisting of chance and chance-dependent effects. Trend is a long smooth movement lasting over a span of observations. It may be rising or falling. Periodic component is non-stationary in the mean and variance and repetitive over fixed interval of time whereas stochastic component can be regarded stationary in the mean and variance and it is constituted by irregular oscillations and random effects which cannot be accounted for physically. Mathematically, a discrete time series is denoted by X_t , $t = 1, 2, 3$, etc., where X_t are at equidistant time interval and decomposed by an additive type. The additive form provides a reasonable model in most cases and is expressed as:

$$X_t = T_t + P_t + S_t \quad \dots (3.31)$$

in which T_t is the trend component; P_t is the periodic component; and S_t is stochastic component having dependent and independent parts, at time t . The first two components in the model that described the time series are deterministic in nature. The presence of such deterministic components in the structure of the time series renders the series to be non-stationary. Since the model is applied to stochastic component, which is treated as random

variable, the trend and periodic components were first removed from the time series. To obtain representative stochastic model of the time series, identification and detection of each component was necessary. Modelling of the water deficit series through decomposing into periodic and stochastic components allows one to develop an improved methodology for generation of weekly water deficit series. Each of the model components is, therefore, analyzed and determined following the stepwise procedure.

3.11.2.1 Trend component, T_t

Steady and regular movements in a time series through which the values are on average either increasing or decreasing is termed a trend (Kottegoda, 1980). In order to model water deficit time series, a null hypothesis of no trend in the series was adopted. For detecting the trend in the time series following two statistical tests were performed:

- (i) Turning point test
- (ii) Kendall's rank correlation test

In this analysis, annual water deficit data have been used for detecting the trend. The annual series has been assumed to give better results for the trend component and suppresses the effect of periodic components in the series (Kottegoda, 1980).

Turning point test: In an observed sequence $X_t, i = 1, 2, \dots, N$, where N represents years, a turning point p occurs at time $t = i$, if X_i is either greater than or less than the two adjacent values X_{i-1} and X_{i+1} . The expected number of turning points in a random series is

$E(p) = \frac{2(N-2)}{3}$ and the variance is given by $\text{var}(p) = \frac{(16N-29)}{90}$. Consequently, p can be expressed as a standard normal deviate, $Z = \frac{(p - E(p))}{(\text{var}(p))^{1/2}}$. The calculated value of Z was

compared with its table value at $P = 0.01$ level of significance, viz. ± 2.58 . When the calculated value of Z has been found to exist within the limits, then hypothesis of no trend was not rejected.

Kendall's rank correlation test: This test, which is also referred to as the τ test is based on proportionate number of subsequent observations that exceed a particular value. For a sequence X_1, X_2, \dots, X_N , the standard procedure is to determine the number of times p occurs in all pairs of observations ($X_i, X_j; j > i$) that X_j is greater than X_i . For a trend-free series, $E(p) = \frac{N(N-1)}{4}$ and the test statistic, $\tau = \left\{ \frac{4p}{N(N-1)} \right\} - 1$. It can also be shown that

$\text{var}(\tau) = \frac{2(2N+5)}{9N(N-1)}$ and a standard normal deviate, $Z = \frac{\tau}{[\text{var}(\tau)]^{1/2}}$. The calculated value of Z

was compared with the table value at $P = 0.05$ or 0.01 level of significance. When the

calculated value of Z has been found to exist within the limits, the null hypothesis of no trend in the series was not rejected.

3.11.2.2 Periodic Component, P_t

The periodic component in a time series is deterministic in nature having the property to repeat itself at regular intervals. The periodicities are attributed to the astronomical cycles and consequently to the energy supply from the sun over various areas of the earth. In a time series periodicity can be represented through a system of sine and cosine functions, after the trend component, if present, has been estimated and removed. The procedure used is termed as harmonic analysis. The existence of P_t was first identified by the serial correlogram, i.e., a graph of autocorrelation coefficients, r_k against lag k .

Autocorrelation analysis: Autocorrelation also called serial correlation, r_k , is a very useful tool for investigating the structure of a time series with regard to how observations separated by a fixed period of time are interrelated, i.e., the degree to which the observations in any one year is dependant upon the magnitude of the observations in the years preceding it; it was assumed for simplification that the trend component was removed. It was also used for identification of the deterministic and stochastic components in a series. The serial correlation coefficient, SCC (r_k) for an observed series was computed using the expression:

$$r_k = \frac{\sum_{i=1}^{N-k} X_i X_{i+k} - \frac{1}{N-k} \left(\sum_{i=1}^{N-k} X_i \right) \left(\sum_{i=1}^{N-k} X_{i+k} \right)}{\left[\sum_{i=1}^{N-k} X_i^2 - \frac{1}{N-k} \left(\sum_{i=1}^{N-k} X_i \right)^2 \right]^{1/2} \left[\sum_{i=1}^{N-k} X_{i+k}^2 - \frac{1}{N-k} \left(\sum_{i=1}^{N-k} X_{i+k} \right)^2 \right]^{1/2}} \quad \dots (3.32)$$

The tolerance limits for the correlogram of an independent series was computed as given by Anderson (1941):

$$r_k (95\%) = \frac{-1 \pm 1.96\sqrt{N-k-1}}{N-k} \quad \dots (3.33)$$

If r_k lies outside the range, then it is evident that r_k is significantly different from zero and the series are time dependant. Also the oscillating shape of the correlogram verifies the presence of P_t , with the seasonal period p , at the multitude of which peak of estimation can be made by Fourier analysis followed by tests for significant harmonics. The correlogram of the time series clearly shows the presence of periodic variation indicating its detection.

Since a periodic time series P_t , usually is not stationary, it was then expanded into a Fourier series representation expressed as:

$$P_t = A_0 + \sum_{K=1}^{\infty} \left[A_K \cos\left(\frac{2\pi Kt}{p}\right) + B_K \sin\left(\frac{2\pi Kt}{p}\right) \right] \quad \dots (3.34)$$

where,

$$A_0 = \frac{1}{N} \sum_{i=1}^N X_t \quad \dots (3.35)$$

$$A_K = \frac{2}{N} \sum_{i=1}^N X_t \cos\left(\frac{2\pi Kt}{p}\right) \quad \dots (3.36)$$

$$B_K = \frac{2}{N} \sum_{i=1}^N X_t \sin\left(\frac{2\pi Kt}{p}\right) \quad \dots (3.37)$$

K = number of significant harmonics

t = time interval within the year

N = number of observation points

p = base period

A_K and B_K = Fourier series coefficients

When p is even, then

$$A_M = \frac{1}{N} \sum_{i=1}^N X_t \cos\left(\frac{2\pi Kt}{p}\right) \quad \dots (3.38)$$

$$B_M = 0 \quad \dots (3.39)$$

These coefficients were obtained by a least square fit of the data to the K^{th} harmonics components and then a least square approximation can be given by the finite series:

$$P_t = A_0 + \sum_{K=1}^M \left[A_K \cos\left(\frac{2\pi Kt}{p}\right) + B_K \sin\left(\frac{2\pi Kt}{p}\right) \right] \quad \dots (3.40)$$

where,

M is the number of significant harmonics (maximum, $p/2$). For later use, it was more convenient to use the alternate form for P_t given as under:

$$P_t = A_0 + \sum_{K=1}^M D_K \cos\left(\frac{2\pi Kt}{p} - \theta_K\right) \quad \dots (3.41)$$

where,

$$D_K = \sqrt{A_K^2 + B_K^2} \quad \dots (3.42)$$

and

$$\theta_K = \text{Arctan}\left(\frac{B_K}{A_K}\right) \quad \dots (3.43)$$

In Equation (3.41) if $M \rightarrow \infty$, $P_t \rightarrow X_t$ then X_t can be represented satisfactorily by Equation (3.34) only. However, it may not be practical or desirable to allow the condition $M \rightarrow \infty$. Thus the appropriate approach would be the selection of M , which contains only those harmonics, which are significantly contributing towards X_t . With this as the objective, following three tests were carried out for determination and selection of the significant harmonic coefficients, A_K and B_K .

- (i) Analysis of variance
- (ii) Fourier decomposition of mean square
- (iii) Cumulative periodogram

In general, periodicities can be represented by one or two harmonics in monthly series and by four to six harmonics in weekly series. In such case the other harmonics are treated as noise and are passed on to stochastic component.

Test for analysis of variance: If the points $\tau = 1, 2, 3, \dots, p$ specify the time span of the periodicity, the periodic means, m_τ , estimated from the observed time series $X_1, X_2, X_3, \dots, X_n$ are given by:

$$m_\tau = \frac{1}{n} \sum_{i=1}^n X_{\tau+p(i-1)} \quad \dots (3.44)$$

where $n = N/p$ is the number of years of data. To estimate the number and coefficients of the significant harmonics, the coefficients α_k and β_k were determined from:

$$\alpha_k = \frac{2}{p} \sum_{\tau=1}^p m_\tau \sin\left(\frac{2\pi K\tau}{p}\right), \quad \text{for } K = 1, 2, \dots, p/2-1 \quad \dots (3.45)$$

$$\alpha_{p/2} = 0 \quad \dots (3.46)$$

$$\beta_k = \frac{2}{p} \sum_{\tau=1}^p m_\tau \cos\left(\frac{2\pi K\tau}{p}\right), \quad \text{for } K = 1, 2, \dots, p/2-1 \quad \dots (3.47)$$

$$\beta_{p/2} = \frac{1}{p} \sum_{\tau=1}^p m_\tau (-1)^\tau \quad \dots (3.48)$$

These coefficients were tested through the analysis of variance for half the base period in order to obtain the F-ratios. In this analysis, null hypothesis was that the variance explained by a harmonic k , which is $(N/2)(\alpha_k^2 + \beta_k^2)$, where N is the total sample size, is zero. F ratio was found out by mean squared values divided by unexplained variance, if the null hypothesis is not rejected, the sum of squares is added to the residual sum of squares. If the value of F-ratio has been found less than the F-distribution table value at $P = 0.05$ level of significance, the corresponding harmonic was selected.

Fourier decomposition of mean square: The contribution of the individual harmonics, towards the mean square, was calculated and the number of harmonics that were dominantly contributing to mean square were selected as the significant harmonics.

Cumulative periodogram test: A graphical method was employed for selecting the significant harmonics in Fourier series fit of a periodic estimate. The mean squared deviation, MSD, of periodic estimate around the mean of the periodic estimate was determined by:

$$\text{MSD}(u) = \frac{1}{p} \sum_{\tau=1}^p (u_\tau - \bar{u})^2 \quad \dots (3.49)$$

where,

MSD(u) = mean squared deviation

u_τ = periodic estimate

\bar{u} = mean of periodic estimate

$$= \frac{1}{p} \sum_{\tau=1}^p u_\tau$$

Mean square deviation MSD (j) of each harmonic j was calculated by the following expression:

$$\text{MSD}(j) = \frac{1}{2} (A_j^2 + B_j^2) \quad j = 1, 2, \dots, p \quad \dots(3.50)$$

The cumulative periodogram, P_i was determined by the following equation:

$$P_i = \frac{\sum_{j=1}^i \text{MSD}(j)}{\text{MSD}(u)} \quad \text{for } i = 1, 2, \dots, p \quad \dots(3.51)$$

A graph was drawn between P_i and number of harmonics for selecting the significant harmonics. The significant harmonics were selected up to the fast increase in P_i and the rest of harmonics were rejected. The periodic component was then removed from the time series using the harmonic constants. The remainder being random was applied to the stochastic component.

3.11.2.3 Stochastic component, S_t

The stochastic component is constituted by various random effects, which cannot be estimated exactly. Therefore, a stochastic model of the form of autoregressive model (AR), was used for the presentation of the time series. In this model, the current value of the process was expressed as a finite, linear aggregate of values of the process and a variate that was completely random. However, the stochastic component was obtained by subtracting periodic component and time dependant structure. Nevertheless, an autoregressive model of order p, AR(p) can mathematically be expressed as:

$$\begin{aligned} S_t &= \phi_{p,1} S_{t-1} + \phi_{p,2} S_{t-2} + \dots + \phi_{p,p} S_{t-p} + a_t \\ &= \sum_{k=1}^p \phi_{p,k} S_{t-k} + a_t \quad \dots (3.52) \end{aligned}$$

where,

$\phi_{p,k}$ = autoregressive model parameters, $k = 1, 2, \dots, p$

a_t = independent random number

The fitting procedure of the AR (p) model involved three steps, viz. model identification, parameter estimation and model diagnostic checking.

Model identification: For selecting the best model and thereby to estimate the parameters of the model structure residual variance criteria method was used. In this method, residual variance, $S_z^2(p)$ was computed from:

$$S_z^2(p) = \frac{1}{N - 2p - 1} S(\mu, \alpha_1, \alpha_2, \dots, \alpha_p) \quad \dots (3.53)$$

in which $S(\mu, \alpha_1, \alpha_2, \dots, \alpha_p)$ is known as the residual sum of squares and has been computed from:

$$S(\mu, \alpha_1, \alpha_2, \dots, \alpha_p) = (N - p)(C_0 - \alpha_1 C_1 - \alpha_2 C_2 - \dots - \alpha_p C_p) \quad \dots (3.54)$$

where,

N = number of observation points

$\alpha_1, \alpha_2, \dots, \alpha_p$ = parameters of the corresponding model

$C_0, C_1, C_2, \dots, C_p$ = autocovariance function at lag p, $p = 0, 1, 2, \dots, p$.

The residual variance values were computed for all estimated lag p. The rule for this criterion is to select the model order with minimum value of $S_z^2(p)$ (Kottegoda, 1980). Based on this criterion, order of the AR model was identified.

Parameter estimation: The autoregression parameters of different orders were estimated before the proper order for AR terms has been identified. These parameters were estimated by the procedure described by Yule-Walker equations. The Yule-Walker estimates of the autoregressive parameters were obtained using the serial correlation coefficients, r_k . In general, the estimates of p^{th} order model has been obtained computing following equations recursively.

$$\phi_{p,p} = \left[\frac{r_p - \sum_{k=1}^{p-1} (\phi_{p-1,k}) (r_{p-k})}{1 - \sum_{k=1}^{p-1} (\phi_{p-1,k}) (r_k)} \right] \quad \dots (3.55)$$

and

$$\phi_{p,k} = \phi_{p-1,k} - \phi_{p,p} \cdot \phi_{p-1,p-k} \quad \text{for } k = 1, 2, \dots, p-1 \quad \dots (3.56)$$

In the estimated parameters, $(\phi_{p,k})$, suffix p and k indicate the order and the number of parameters of AR (p) model.

The sum of the periodic and stochastic component forms the generated value of the observed data. The difference was termed as residual, which was tested to check the adequacy of the formulated model. The residuals of the AR(p) model may be computed from:

$$a_t = S_t - \sum_{k=1}^p \phi_{p,k} S_{t-k} \quad \dots (3.57)$$

3.11.3 Model Diagnostic Checking

Once the proper order for AR terms has been identified, the selected model was validated for its suitability through the diagnostic checking. Serial correlation and sum of square analysis were used as a tool for diagnostic checking.

3.11.3.1 Serial correlation analysis

After fitting the model to stochastic component the residuals, a_t , were obtained. The serial correlation coefficient of the residuals was estimated for lag k and the correlogram with the 95 % upper and lower confidence limits were drawn. The serial correlation coefficients falling well within the tolerance limits indicate the suitability of the model for the water deficit series and the residuals were assumed to be white noise (random). The confidence limits, t_k , for lag k were estimated by the equation:

$$t_k = \frac{-1 \pm 1.96\sqrt{N-k-1}}{N-k} \quad \dots (3.58)$$

3.11.3.2 Sum of squares analysis

In this method sum of squares of residuals and deviation of observed series from their mean value were calculated to get R^2 by ratio and used as a tool to assess the adequacy of the model (Clarke, 1984). If Y_t denotes the observed value of water deficit series, \bar{Y} denotes the mean of observed water deficit series and \hat{Y}_t denotes the fitted value of water deficit, then, the sum of squares of residuals is:

$$A = \sum (Y_t - \hat{Y}_t)^2 \quad \dots (3.59)$$

the sum of squares of deviations of observed values from their means is:

$$B = \sum (Y_t - \bar{Y}_t)^2 \quad \dots (3.60)$$

Then R^2 is the measure required and is given as:

$$R^2 = (B - A)/B \quad \dots (3.61)$$

If all the residuals are zero, i.e., $R^2 = 1$ (or 100, if R^2 is expressed as a percentage), it indicates perfect fitting of the formulated model. Therefore, the closer the value of R^2 to unity the better the goodness of fit.

3.11.4 Validation of Stochastic Model

The major application of modelling time series is to generate or forecast future values or data. Generating the water deficit time series for the entire sampling period was first checked using the weekly developed water deficit models. Forecasting was made for two years ahead from 2002 to 2003. The generated/forecasted values from each model were compared to the observed data. The variation of the generated/forecasted and observed series was presented

graphically with respect to time. Correlation coefficient of mean generated series and mean observed series was determined. Other statistical parameters of generated and observed series were also computed for validation of the model.

3.12 GEOSTATISTICAL MODELLING OF WATER DEFICIT

Geostatistical method of analysis employing semivariogram was used to evaluate spatial and temporal variability of water deficit by producing contour maps of fortnightly water deficit data during monsoon season of 1987, the severe most drought year experienced in the state. The basic aim of geostatistical method is to interpolate values for points or areas that have not been sampled, using data from surrounding sampled points. Water deficit measurements were spatially arrayed in an irregular grid. In geostatistics, the degree of variability of natural phenomena is expressed by the semivariogram and estimation is performed by a procedure called kriging. Kriging attempts to optimize the weights assigned to the neighboring data points in computing the interpolated value.

Kriging consists of three steps: (i) an examination of the covariation of data values depending on their distances apart; (ii) fitting theoretical models to these relationships; and (iii) using these models to calculate the weights for a particular set neighboring points and computing the interpolated value. The first step is referred to as constructing a sample (experimental) semivariogram.

3.12.1 Semivariograms

The semivariogram function gives a measure of the spatial correlation of a random variable(s) as a function of separation distance. It is a graphical representation of semivariance versus lag distance. The semivariance function attempts to define the variation of the parameter of interest with distance. The semivariance function was estimated from the expression:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [E(x)_i - E(x+h)_i]^2 \quad \dots (3.62)$$

where,

$\gamma(h)$ = semivariance value

$N(h)$ = number of data pair of desired property separated by distance h between places

$E(x)$ = value of the property measured at place (x)

$E(x+h)$ = value of the property measured at place $(x+h)$

A common form of the theoretical semivariogram model is usually represented by a mathematical function. The specific terminologies used to describe the shape of the function are: (a) nugget – refers when experimental variograms show a discontinuity near zero

separation, which is apparent variogram at distance $h = 0$, (b) sill - refers to the asymptotic maximum of the semivariogram or $\gamma(\infty)$, and (c) range - refers the correlation length or distance required for the semivariogram to approach the sill.

3.12.2 Drift and Stationary

An additional parameter may be calculated which is an indicator of the validity of assuming first order stationary. This parameter is termed as drift, $D(h)$ and it may be calculated as a function of distance between measured values using following expression:

$$D(h) = \frac{1}{N(h)} \sum_{i=1}^{N(h)} [E(x)_i - E(x+h)_i] \quad \dots (3.63)$$

A value of zero drift is an indicator of first order stationary. If there is a trend to the values of the drift as a function of distance, the mean cannot be assumed to be constant over the domain of analysis. To test the significant trend or drift function, the stability of the variance was examined on measured observations by using above. Further the significance level for the drift function was estimated by using the student t statistics.

$$t(h, c) = \frac{D(h, c)}{V(h, c)} N(h, c) \quad \dots (3.64)$$

where, V is the variance at separation distance h

3.12.3 Choice of Best Variogram Model to Sample Semivariogram

Before the variogram can be used to estimate water deficit, a mathematical model has to be fitted to it. The reason for this is that variograms have to satisfy certain conditions. Selection of model depends on sill, range and nugget of the experimental semivariogram model.

3.12.3.1 Structural analysis of variogram

(a) Behavior of variogram near origin

- (i) **Parabolic shape:** This indicates that the regionalized variable is highly continuous and even differentiable. A parabolic shape can also be associated with the presence of drift.
- (ii) **Linear shape:** In this case the regionalized variable is continuous, but not differentiable and less regular than parabolic shape.
- (iii) **A discontinuous shape:** A discontinuity at the origin, i.e. when the $\gamma(h) = 0$ as h tends to zero. This means that variance is not even continuous in the mean square. It is therefore highly irregular at short distance.
- (iv) **Random shape:** A flat curve (pure randomness or white noise). The regionalized variances $z(x+h)$ and $z(x)$ are uncorrelated for all values of h . This is the limiting case of a total lack of structure.

(b) Anisotropy

When dealing regionalized variables in two or three dimensions, variograms calculated in different directions does not match identically with each other, then only anisotropy exists. If this does not occur, then variogram depends only on the magnitude of the distance between points and is said to be isotropic. Two different types of anisotropy can be distinguished.

(i) Geometric anisotropy (elliptic anisotropy): A semivariogram whose range is a function of direction is said to be geometrically anisotropic. If the curve is ellipse (in 2-D) then geometric anisotropy exists. In these cases a simple change of coordinate transforms the ellipse into circle and eliminates the anisotropy. The over all variogram after correcting for the anisotropy is of the form:

$$\gamma(h) = \gamma_1[(x_1 - x_2)^2 - K^2(Y_1 - Y_2)]^{0.05} \quad \dots(3.65)$$

where,

$$K = \text{Anisotropy ratio} = \frac{\text{Range1}}{\text{Range2}} \quad \text{or} \quad \frac{\text{Slope1}}{\text{Slope2}} \quad \dots (3.66)$$

(ii) Zonal or stratified anisotropy: If sill of the variogram varies with direction then zonal anisotropy exists. This anisotropy usually occurs with three-dimensional problem. In three-dimensional problem, the vertical direction often plays a special role because there is more variation between strata. In such cases it is a standard practice to split the variogram into two components, an isotropic one plus another, which depends only on the vertical component. Anisotropy is removed by superimposition and overall variogram is given by:

$$\begin{aligned} \gamma(h) &= \text{Isotropic variogram} + \text{A vertical component} \\ &= \gamma_0(h) + \gamma_1(h) \end{aligned} \quad \dots(3.67)$$

$$= \gamma_0[(h_1^2 + h_2^2 + h_3^2)]^{0.05} + \gamma_1(h_3) \quad \dots(3.68)$$

(c) Proportional effecting

This often occurs with lognormal distributed data. The variogram for different zones have the same shape but the sill of the variogram in rich zones is much higher than poor zones. Often the sill turns out to be proportional to the square of local mean. So dividing each of local variogram by the square of the local mean and then averaging them before fitting a variogram mode, the underlying variogram model can be found.

(d) Other features of the variogram

In between the origin and infinity, the behaviour of the variogram shows various features of the phenomenon, notably the presence of nested structures and in very rare cases periodicities or a hole effect. Nested structure indicates the presence of variations at different scales and generally variogram exhibits periodic behaviour. Periodicity may occur due to presence of ridges and valley along the direction of experimental variogram. Hole effect

presents a bump in the variogram and caused by too few pairs of points used in calculating the experimental variogram for that distance or to the natural fluctuations.

3.12.3.2 Models for variogram and their mathematical representation

(a) Models with sill (bounded variogram)

- (i) **The random model (pure nugget effect):** The random model corresponds to a case where regionalized variable $x(z)$ is randomly distributed that is covariance between value is zero for all distance h . Corresponding semivariogram is described by:

$$\gamma(h) = c \text{ for all } h \quad \dots (3.69)$$

- (ii) **The spherical model:** Spherical model is probably the most commonly used model. It has a simple polynomial expression and its shape matches well what is often observed. An almost linear growth up to a certain distance of stabilization. The tangent at the origin intersects the sill at a point with an abscissa $2a/3$ and slope of this tangent at the origin is $3c/2a$. This can be useful when fitting models. It is characterized by two parameters c and a and mathematically represented by an equation as:

$$\gamma(h) = C \left(\frac{3h}{2a} - \frac{h^3}{2a^3} \right) \quad \text{for } h < a \quad \dots (3.70)$$

$$\gamma(h) = C \quad \text{for } h > a \quad \dots (3.71)$$

where, C is sill value, a is range and h is lag distance

- (iii) **The exponential model:** The exponential model is characterized by two parameters C and a , where C is the asymptote of the exponential curve and can be equated to sill and a is the distance at which tangent at origin reaches the value c . For practical purpose, the range can be taken as $3a$. Slope of the tangent at the origin is C/a . This model is represented by an equation as:

$$\gamma(h) = C \left[1 - e^{(-h/a)} \right] \quad \dots (3.72)$$

- (iv) **The Gaussian model:** The curve is parabolic near origin and tangent at origin is horizontal indicating low variability for short distances. The Gaussian model represents the extremely continuous phenomenon. The practical range for the model is $1.73a$. The model is represented by equation as:

$$\gamma(h) = C \left[1 - e^{(-h^2/a^2)} \right] \quad \dots (3.73)$$

(b) Model with sill (unbounded variogram)

- (i) **The linear model:** The linear semivariogram is expressed as:

$$\gamma(h) = (a^2 h)/2 \quad \dots (3.74)$$

where, a^2 is a constant and the slope of the line is $a^2/2$.

- (ii) **The logarithmic or de Wijsian model:** The logarithmic semivariogram is expressed as:

$$\gamma(h) = 3a \log_e h \quad \dots (3.75)$$

A logarithmic model becomes inapplicable for distance smaller than h. The logarithmic model can only be representative of the properties of samples with support of finite dimensions. It can only be a regularized semivariogram.

- (iii) **The parabolic model:** The parabolic semivariogram is expressed as:

$$\gamma(h) = \frac{h^2 a^2}{2} \quad \dots (3.76)$$

where, a^2 is constant

3.12.4 Fitting of Variogram Model

The behaviour at the origin (both the nugget effect and slope) plays a crucial role in fitting of the variogram, because it has tremendous influence on the result of kriging and also on the numerical stability of the kriging system. The slope can be assessed from the first three or four variogram values while nugget effect can be estimated by extrapolating back to the origin. The range can usually be assessed visually. The sill value is set at the value where the variogram stabilizes. This should coincide with the overall variances.

Sometimes experimental variogram exhibits nested structure. Range and spatial variance should be visualized for every structure and then fitting of model will be done with anisotropies coefficient to depict the observed pattern of directional smivariogram by selected model.

In general, good fit can be obtained with sum of two or three models. The fitting is done by trial and error preferably with graphic.

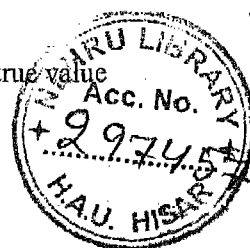
The semivariogram for different stations and spatial variations were generated through the ArcGIS software. The model fitting on the semivariogram is also being done by this software.

3.12.5 Cross Validation

The suitability of the model variogram can be assessed by cross-validation. In cross validation, measured data are removed from data set one at a time. The value at the location of deleted sample is then estimated using kriging with an assumed model variogram. This makes the calculation of the true-error in the estimation procedure possible.

$$E_i = p(x_i) - t(x_i) \quad \dots (3.77)$$

where, E is the error, p(x) is the estimated value and t(x) is the true value



Thus, repeating this estimation for the number of experimental data N , the following cross-validation statistics may be calculated:

Mean error, ME

$$ME = \frac{1}{N} \sum_{i=1}^N E_i \quad \dots (3.78)$$

Mean squared error, MSE

$$MSE = \frac{1}{N} \sum_{i=1}^N E_i^2 \quad \dots (3.79)$$

Mean standardized square error, MSSE

$$MSSE = \frac{1}{N} \sum_{i=1}^N \frac{E_i^2}{\sigma_i^2} \quad \dots (3.80)$$

It is assumed that if the variogram model is correct, ME should be almost zero, MSE a small value and MSSE close to one. If cross-validation works efficiently, it can be used for estimation purposes.

3.12.6 Kriging

Sampling provides accurate information about the property at the sampled places. However, this does not tell what is happening in between them. There is a need to estimate the values at intermediate points as accurately as possible.

Practically the accuracy of the estimates depends not only on the method of estimates but also on the information provided by the observed values which ultimately depends on method of sampling, distribution of sampling points in the area and the characteristics of property itself. In this study linear ordinary block kriging was used to estimate block krigged values. Blocks were formed and arithmetic values were calculated and assigned to centre of blocks when utilized.

For block kriging, the krigged estimate at the center of interpolated block is estimated from:

$$E^*(xp) = \sum_{i=1}^N \lambda_i E(X_i) \quad \dots (3.81)$$

where, $E^*(xp)$ is the value of the parameter at a point xp , and λ_i is the weight assigned to each measured value of estimation. The weights chosen were assumed to be:

- 1) unbiased – $[E^*(xp) - E(xp)] = 0$
- 2) the minimum variance – $E[E^*(xp) - E(xp)]^2$ is minimum

For unbiased condition the sum of individual weight λ_i must be equal to unity:

$$\sum \lambda_i = 1 \quad \dots (3.82)$$

The minimum variance condition leads to set of $n + 1$ linear equations:

$$\begin{aligned} \sum \lambda_i \gamma(X_i - X_j) - \mu &= \gamma(X_i, A) & i = 1, 2, \dots, N \\ & & j = 1, 2, \dots, N \end{aligned} \quad \dots (3.83)$$

$$\sum \gamma_j = 1 \quad \dots (3.84)$$

For solving the kriging system of equations numerically, it was transformed into the matrix form as: $AX = B$

$$\begin{bmatrix} \gamma_{11} & \gamma_{12} & \dots & \gamma_{1N} & 1 \\ \gamma_{21} & \gamma_{22} & \dots & \gamma_{2N} & 1 \\ \vdots & \vdots & \dots & \vdots & \vdots \\ \gamma_{N1} & \gamma_{N2} & \dots & \gamma_{NN} & 1 \\ 1 & 1 & \dots & 1 & 1 \end{bmatrix} \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \vdots \\ \lambda_N \\ \mu \end{bmatrix} = \begin{bmatrix} \gamma(X_1, A) \\ \gamma(X_2, A) \\ \vdots \\ \gamma(X_N, A) \\ 1 \end{bmatrix} \quad \dots (3.85)$$

where,

$\gamma(X_i, A)$ = average semivariance value between block to be interpolated and surrounding points

γ_{ij} = semivariance between pairs of the surrounding values considered for the kriging

μ = lagrangian parameter

Matrix A is always non-singular and the solution is:

$$X = A^{-1} \times B$$

and kriging variance is:

$$\gamma^2 K = X^T B - \gamma(A, A) \quad \dots (3.86)$$

where,

X^T = Transpose matrix of X

$\gamma(A, A)$ = average of the variogram between any two point X and X^1 sweeping independently throughout area A.

$$\gamma(A, A) = 1/A^2 \iint \gamma(X - X') dX dX' \quad \dots (3.87)$$

where,

$\gamma(A, A)$ is = spatial variance of semivariogram

Kriging variance is given by:

$$\sigma^2 K = \sum \lambda_i \gamma(X_i, A) - \gamma(A, A) + \mu \quad \dots (3.88)$$

The ArcGIS software was used for determination of kriging of the water deficit data and the estimated krigged values based on the variogram model was also calculated for each station.

3.12.7 Preparation of Isodeficit Line Map

ArcGIS 8.3 software package was used to draw water deficit maps for Gujarat. The package analyzes the same sample data in the same manner as has been done in geostatistical package and produces a isodeficit line map. These maps exhibit how water deficit changes over the study area spatially and temporally.

3.13 CROP PLANNING UNDER DIFFERENT AGRO-CLIMATIC ZONES OF GUJARAT

Selection of crops and cropping pattern depends on the length of growing season and occurrences of dry spells if temperature is not a limiting factor. Length of growing season is decided on the basis of period of moisture availability for crop growth. The length of growing season was determined by Thornthwaite and Mather (1955) method. Growing season starts when $I_{ma} > 0.5$ and ends when $I_{ma} < 0.25$, where I_{ma} is the moisture adequacy index which is the ratio of AET/ET_0 . The crops and cropping patterns for different agro-climatic zones were selected on the basis of results of rainfall analysis, dry spell analysis and water availability period as under:

I_{ma}	Water availability
0.00 – 0.24	Dry
0.25 – 0.49	Semi-dry
0.50 – 0.74	Sub-moist
0.75 – 0.99	Moist
> 1.00	Humid

IV - RESULTS AND DISCUSSION

The study has been undertaken with the objective of modelling drought under different agro-climatic zones of Gujarat. For this study weekly meteorological data for a period of 22 to 30 years (1974-2003), as per availability of records, for the selected stations were collected from the respective Agricultural Research Stations of the erstwhile Gujarat Agricultural University. Soil resources information for selected stations were obtained from the joint publication of the Gujarat Agricultural University, Navsari and National Bureau of Soil Survey and Land Use Planning, Regional Centre, Udaipur (Anonymous, 2000). Weekly reference evapotranspiration values were computed by the Penman-Monteith equation and used for determination of water balance for all the stations.

An attempt has been made to analyze rainfall pattern, moisture status and water deficit through water balance and artificial neural networks technique. Initial and conditional probabilities of dry spells have been determined. Water deficit data are stochastic in nature and therefore, stochastic analysis of water deficit has been carried out. Validation of developed time series models has been made by comparing generated and observed values of water deficit. Spatial and temporal variation of water deficit in the state in a most severe drought year has been studied by plotting water deficit contour maps using geostatistical model and Geographic Information System software package. The length of crop growing season has also been analyzed for determination of suitability of crops and cropping systems under eight different agro-climatic zones of Gujarat. The results are discussed under the different sub heads as under:

4.1 ANALYSIS OF RAINFALL PATTERN

Rainfall being the only source of water under dryland agriculture, a more complete and quantitative understanding of this natural resource, provides a lot more insight for proper planning with respect to crop production. The weekly rainfall data of sixteen stations under different agro-climatic zones of Gujarat for 22 to 30 years period (1974–2003) were analysed for annual, seasonal and weekly patterns and the results are presented as under:

4.1.1 Annual Rainfall

Annual rainfall data of the selected stations were analysed statistically and the statistical parameters like mean, standard deviation (SD), coefficient of variation (CV) and coefficient of skewness (C_s) are presented in Table 4.1. It is observed from Table 4.1 that Gandevi is the highest rainfall receiving zone having an average annual rainfall of 1580.53 mm with SD of 509.66 mm and CV of 32.25 per cent. Radhanpur receives the lowest mean annual rainfall, 368.74 mm with SD of 202.63 mm and CV of 54.95 per cent. The maximum

and minimum annual values of rainfall of different stations also given in Table 4.1 shows that Junagadh and Kothara received maximum (2786.50 mm) and minimum (3.0 mm) annual rainfall, respectively. It is pointed out that there is a large spatial and temporal variation in the rainfall pattern in the state. The low rainfall areas (< 500 mm) comprised of Kothara and Radhanpur, characterized by arid climate, are located in western part of the state. Surat, Navsari and Gandevi, located in the southern part, received high rainfall (> 1000 mm). Rest of the locations, most of under the semi-arid climate, received rainfall between 500-1000 mm. The annual rainfall variation expressed in terms of coefficient of variation indicates that the high CV (> 50%) is observed in low rainfall areas whereas low CV (30-45%) in high rainfall areas.

Table 4.1 Annual rainfall parameters under different agro-climatic zones of Gujarat

Station	Mean, mm	Max., mm	Min., mm	Standard Deviation, mm	Coeff. of Variation, %	Skewness
Kothara	379.50	984.00	3.00	256.75	67.65	0.75
Radhanpur	368.74	788.00	44.00	202.63	54.95	0.26
Rajkot	565.56	1489.20	177.00	293.45	51.89	1.30
Amreli	578.42	1365.40	153.00	267.12	46.18	1.01
SK Nagar	630.19	1634.10	68.40	404.06	64.12	0.97
Khedbrahma	713.55	1401.90	185.10	287.40	40.28	0.35
Arnej	627.83	1041.70	232.70	210.01	33.45	0.11
Dhandhuka	584.36	952.50	215.00	198.92	34.04	0.32
Junagadh	890.56	2786.50	145.90	496.75	55.78	2.02
Mahuva	574.35	1058.70	244.30	262.44	45.69	0.53
Anand	829.09	1632.97	286.90	331.42	39.97	0.44
Nawagam	810.88	1904.50	315.00	324.63	40.03	1.43
Bharuch	906.92	2083.80	266.20	368.75	40.66	0.92
Surat	1212.49	2387.50	583.00	512.90	42.30	0.97
Navsari	1467.98	2436.60	715.40	441.36	30.07	0.70
Gandevi	1580.53	2676.30	378.00	509.66	32.25	0.18

The values of coefficient of skewness, presented in Table 4.1 indicate that all the stations are having positively skewed distribution of annual rainfall. The least C_s is noticed in respect of Arnej and Gandevi, which have considerably low variability in the annual rainfall. The high skewness (> 0.25) observed in respect of rest of the stations indicates an asymmetric distribution of annual rainfall. Table 4.1 also shows that for different agro-climatic zones of the state the SD and CV of annual rainfall range from 198.92 to 512.90 mm and 30.07 to 67.65 per cent, respectively. These significant variations indicate that the annual rainfall pattern in the state is very much erratic from zone to zone.

4.1.2 Seasonal Rainfall

Different parameters of seasonal rainfall received from June to September under different agro-climatic zones of Gujarat are shown in Table 4.2. It is seen from Table 4.2 that Gandevi and Kothara receives maximum (1541.33 mm) and minimum (337.68 mm) mean seasonal rainfall with CV of 33.30 and 77.06 per cent, respectively. Further, it is observed that Junagadh and Kothara have got the maximum (2773.50 mm) and minimum (3.00 mm) seasonal rainfall, respectively. Contribution of mean seasonal rainfall to mean annual rainfall in different agro-climatic zones varies from 88.98 (Kothara) to 97.52 (Gandevi) per cent on an average. However, it was found that individual year wise contribution of seasonal rainfall to annual rainfall in different zones has significant variability.

Table 4.2 Seasonal rainfall parameters under different agro-climatic zones of Gujarat

Station	Mean, mm	Max., mm	Min., mm	Standard Deviation, mm	Coeff. of Variation, %	Skewness	% of annual rainfall
Kothara	337.68	984.00	3.00	260.23	77.06	1.01	88.98
Radhanpur	341.98	733.00	44.00	200.55	58.64	0.43	92.74
Rajkot	530.53	1370.10	167.00	277.81	52.36	1.26	93.81
Amreli	531.23	1362.40	115.50	267.19	50.30	1.30	91.84
SK Nagar	577.48	1634.10	50.00	403.87	69.94	1.20	91.64
Khedbrahma	684.35	1401.30	161.00	283.30	41.40	0.50	95.91
Arnej	584.93	968.40	228.70	209.39	35.80	0.10	93.17
Dhandhuka	523.54	845.20	202.00	172.06	32.87	0.12	89.59
Junagadh	850.50	2773.50	138.20	501.32	58.94	2.09	95.50
Mahuva	531.48	1023.20	230.00	246.20	46.32	0.62	92.54
Anand	773.17	1530.10	285.10	326.19	42.19	0.43	93.26
Nawagam	766.85	1895.00	295.10	324.16	42.27	1.65	94.57
Bharuch	860.92	2083.80	185.90	375.32	43.60	0.96	94.93
Surat	1166.90	2364.00	488.00	508.30	43.56	1.06	96.24
Navsari	1398.28	2424.60	647.00	450.77	32.24	0.75	95.25
Gandevi	1541.33	2598.20	378.00	513.33	33.30	0.25	97.52

The analysis of rainfall data presented in Table 4.2 reveals that the CV and SD ranges from 32.24 per cent (Navsari) to 77.06 per cent (Kothara) and 172.06 mm (Dhandhuka) to 513.33 mm (Gandevi), respectively. The CV of seasonal rainfall in comparison with annual rainfall at all the stations was found similar. These significant variations of rainfall indicate that the seasonal rainfall pattern in the state is very much erratic. Even then the rainfall from south-west monsoon was found to be reliable in most of the agro-climatic zones.

4.1.3 Weekly Rainfall

The data of normal weekly rainfall and corresponding coefficient of variation for each standard meteorological week (Appendix-A) for all the stations are given in Appendix B1 to B 4, respectively. Since CV gives an idea of variation of rainfall amount about its mean, the adequacy of the measure depends upon the use to which it is put. For modern agriculture, information on climatic features is required for a shorter period. Annual rainfall only indicates trends of certain climatic patterns, which may be useful to indicate agro-climatic homogeneous zones, but it does not give any picture as to the erratic behavior of rainfall during the growing season, particularly in the different phenological stages of crop growth. Even the use of monthly rainfall data suffers from many shortcomings. Therefore, in this study weekly rainfall pattern is considered. Maximum and minimum weekly rainfall during rainy season (23rd to 40th weeks) and range of coefficient of variation of weekly rainfall for different stations are presented in Table 4.3.

Table 4.3 Weekly mean rainfall and coefficient of variation during monsoon season in different agro-climatic zones of Gujarat

Station	Maximum rainfall, mm	Minimum rainfall, mm	Range of coefficient of variation, %
Kothara	52.59 (29)	02.10 (38)	169.03 (33) -537.26 (40)
Radhanpur	50.94 (29)	04.45 (26)	143.03 (29) -442.02 (23)
Rajkot	61.64 (29)	09.91 (36)	107.89 (23) -259.60 (23)
Amreli	46.91 (28)	16.69 (36)	121.17 (35) -246.99 (23)
SK Nagar	68.80 (30)	16.25 (25)	111.53 (29) -353.34 (40)
Khedbrahma	89.58 (31)	12.07 (38)	085.32 (36) -268.52 (38)
Arnej	65.37(25)	07.18(23)	116.03(32)-280.74(40)
Dhandhuka	51.66 (26)	11.91 (39)	119.58 (31) -389.48 (40)
Junagadh	102.33 (25)	12.89 (23)	105.18 (34) -253.06 (26)
Mahuva	57.86 (29)	14.18 (37)	086.11 (32) -259.83 (23)
Anand	72.80 (30)	12.30 (39)	102.60 (30) -375.37 (23)
Nawagam	83.93 (31)	13.85 (38)	105.81 (27) -351.39 (40)
Bharuch	90.36 (29)	29.96 (38)	109.16 (28) -367.23 (23)
Surat	137.00 (29)	24.37 (38)	097.40 (28) -410.20 (23)
Navsari	150.00 (29)	21.44 (40)	092.71 (29) -258.88 (23)
Gandevi	197.55 (29)	42.48 (38)	076.34 (29) -250.14 (23)

Figures in parenthesis indicate standard meteorological week.

It is evident from Table 4.3 that the maximum and minimum normal weekly rainfall range from 46.91 mm (Amreli) to 197.55 mm (Gandevi) and 2.10 mm (Kothara) to 42.48 mm (Gandevi), respectively, in different agro-climatic zones during the monsoon season. Table 4.3 also reveals that the highest range of CV of weekly rainfall was observed at Kothara (169.03 to 537.26%) while lowest range was observed at Amreli (121.17 to 246.99%). Normal weekly rainfall variations along with CV for different agro-climatic zones are shown in Figures 4.1a to 4.1d. It is interesting to note from the Figures 4.1a to 4.1d that in general at

all the stations the normal weekly rainfall increases from beginning of the season (23rd smw), reaches to its maximum during 28th to 31st standard meteorological week (smw) and thereafter decreases till the end of season. It is also seen from the Figures 4.1a to 4.1d that CV is generally low in rainy season and very high in summer or winter season. However, the considerably high value of CV over that of seasonal and annual rainfall indicates that weekly rainfall distribution is highly erratic in all the zones under study. Normal weekly rainfall during monsoon season at different stations (Figures 4.1a to 4.1d) also indicate in general low rainfall in arid areas (Kothara and Radhanpur), high rainfall in southern region (Surat, Navsari and Gandevi) and moderate rainfall at rest of the stations.

The common characteristics observed in the above discussion of annual, seasonal and weekly rainfall of sixteen stations, representing different agro-climatic zones, indicate that the coefficient of variation at the stations situated in arid climate (Kothara and Radhanpur) is highest amongst all in each section followed by the stations situated in semi-arid and sub humid climate. This clearly highlights the extremely erratic rainfall distribution of north-west, south-west and western Gujarat scarcity zone as compared to other areas.

4.1.4 Characteristics of Rainy Season

Onset, withdrawal and length of the rainy season for different agro-climatic zones of Gujarat were worked out by forward and backward accumulation of weekly rainfall (Moris and Zandstra, 1979) and are presented in Table 4.4.

4.1.4.1 Onset of rainy season

In the beginning of the rainy season, there should be adequate rainfall for land preparation and sowing of crops. The onset of the rainy season is considered as the week by which the rainfall accumulates to 75 mm after 20th standard meteorological week (smw). In the study, considerable variation in the onset of the rainy season is observed from year to year. Therefore, the mean, earliest and latest week during which the onset of rainy season has commenced are given zone wise in Table 4.4. From Table 4.4, it is evident that onset of rainy season occurs earliest at Kothara, Arnej and Surat in 21st smw (May 21-27) while delayed maximum upto 32nd smw (August 6-12) at Kothara, Radhanpur, SK Nagar, Khedbrahma, Dhandhuka, Junagadh, Mahuva and Anand. Under normal condition, onset of rainy season commences from 25th smw (June 18-24) in south Gujarat (Gandevi, Navsari, Surat and Bharuch); from 26th smw (June 25-July 1) at Arnej, Junagadh, Anand and Nawagam; from 27th smw (July 2-8) at Rajkot, Amreli, SK Nagar, Khedbrahma, Dhandhuka and Mahuva and from 28th smw (July 9-15) in western arid (Kothara and Radhanpur) zone.

The percentage probabilities of onset of rainy season during different standard meteorological weeks in various zones of Gujarat are presented in Table 4.5. Onset of rainy

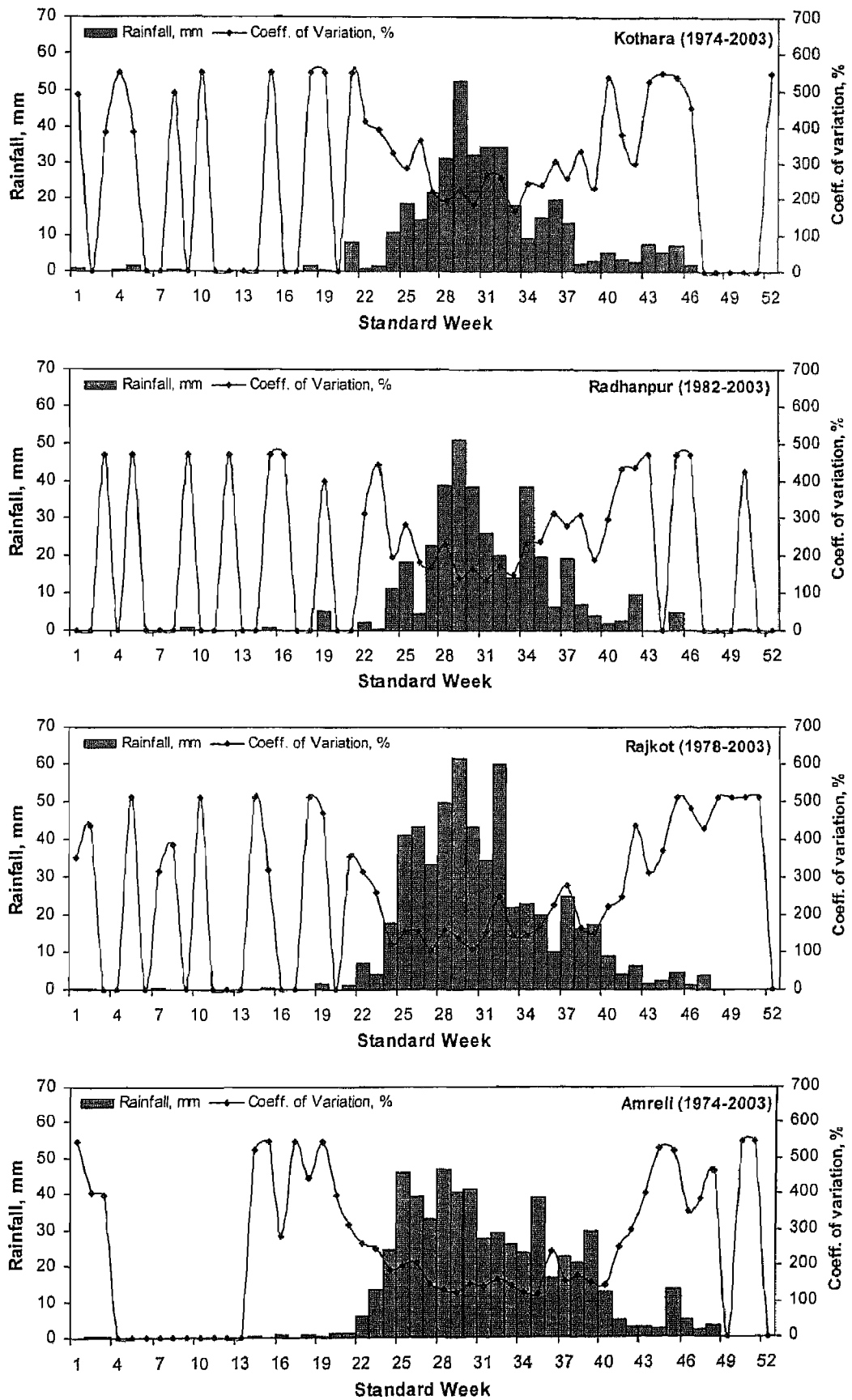


Fig. 4.1a Normal weekly variation of rainfall at Kothara, Radhanpur, Rajkot and Amreli

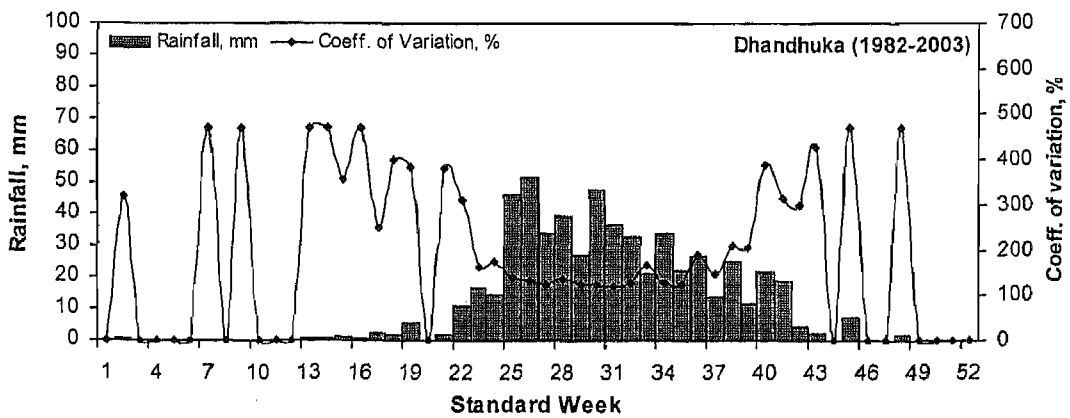
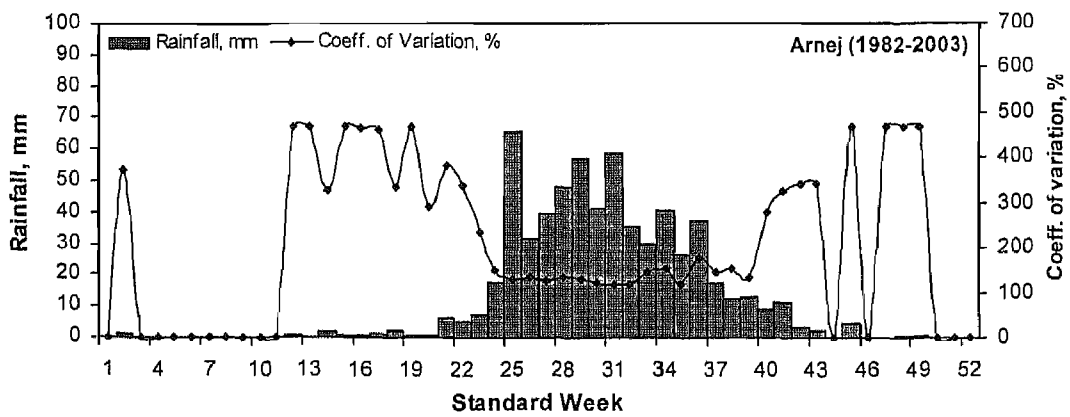
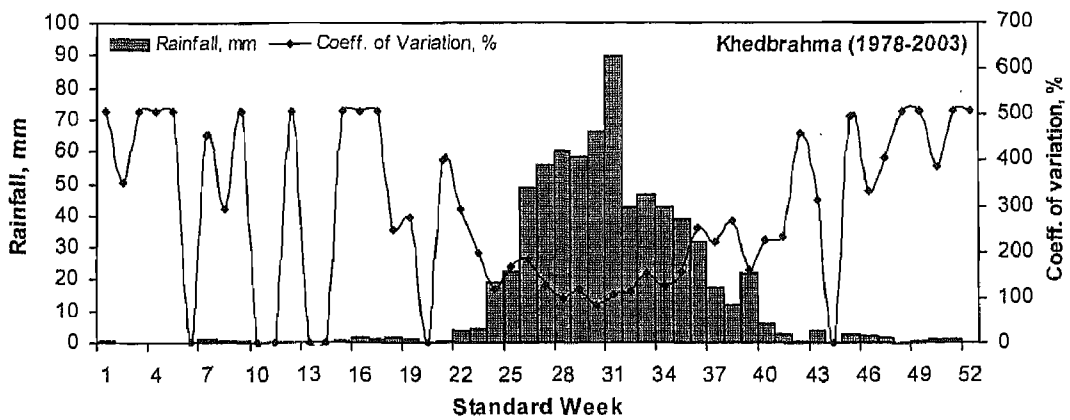
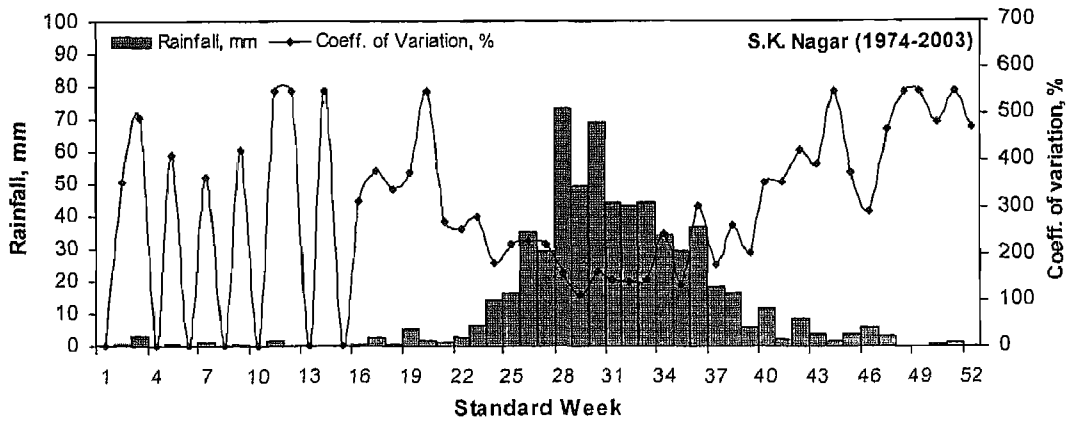


Fig. 4.1b Normal weekly variation of rainfall at S.K. Nagar, Khedbrahma, Arnej and Dhandhuka.

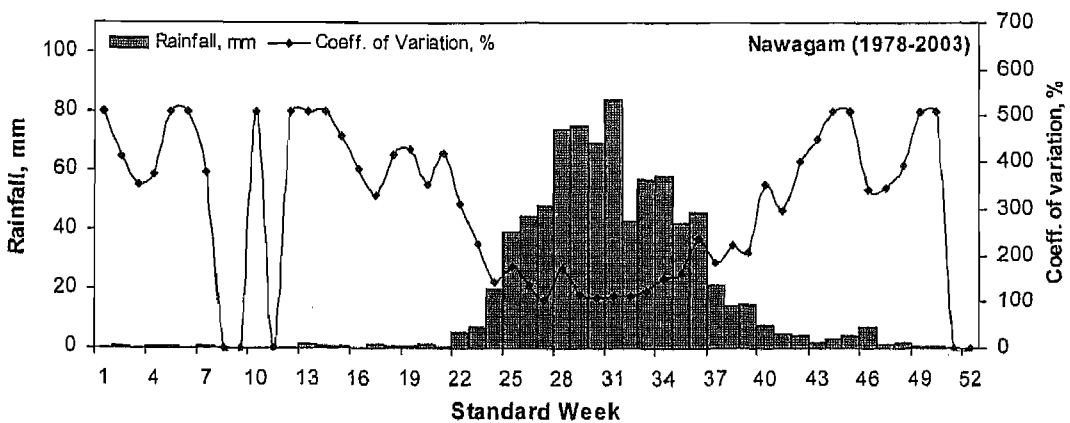
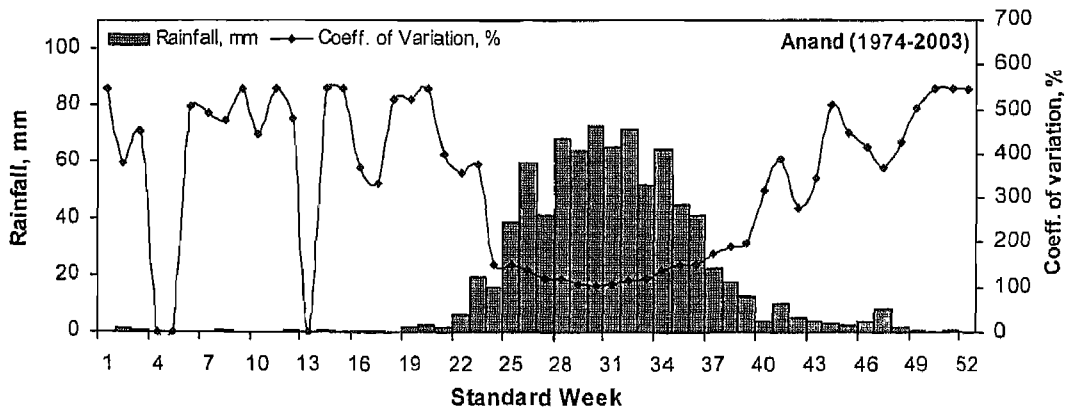
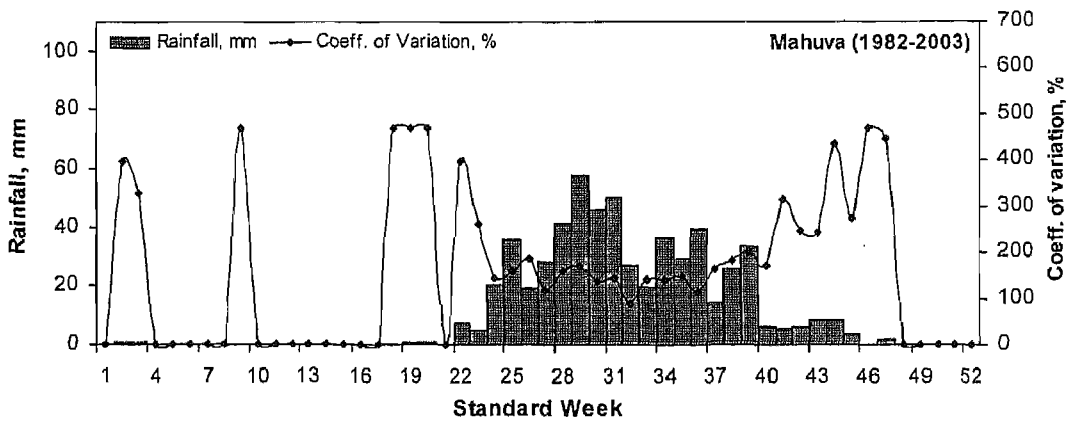
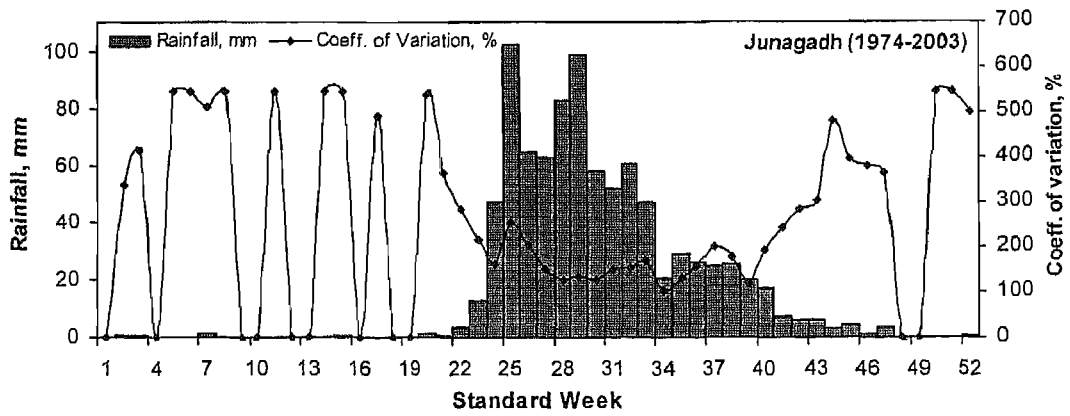


Fig. 4.1c Normal weekly variation of rainfall at Junagadh, Mahuva, Anand and Nawagam

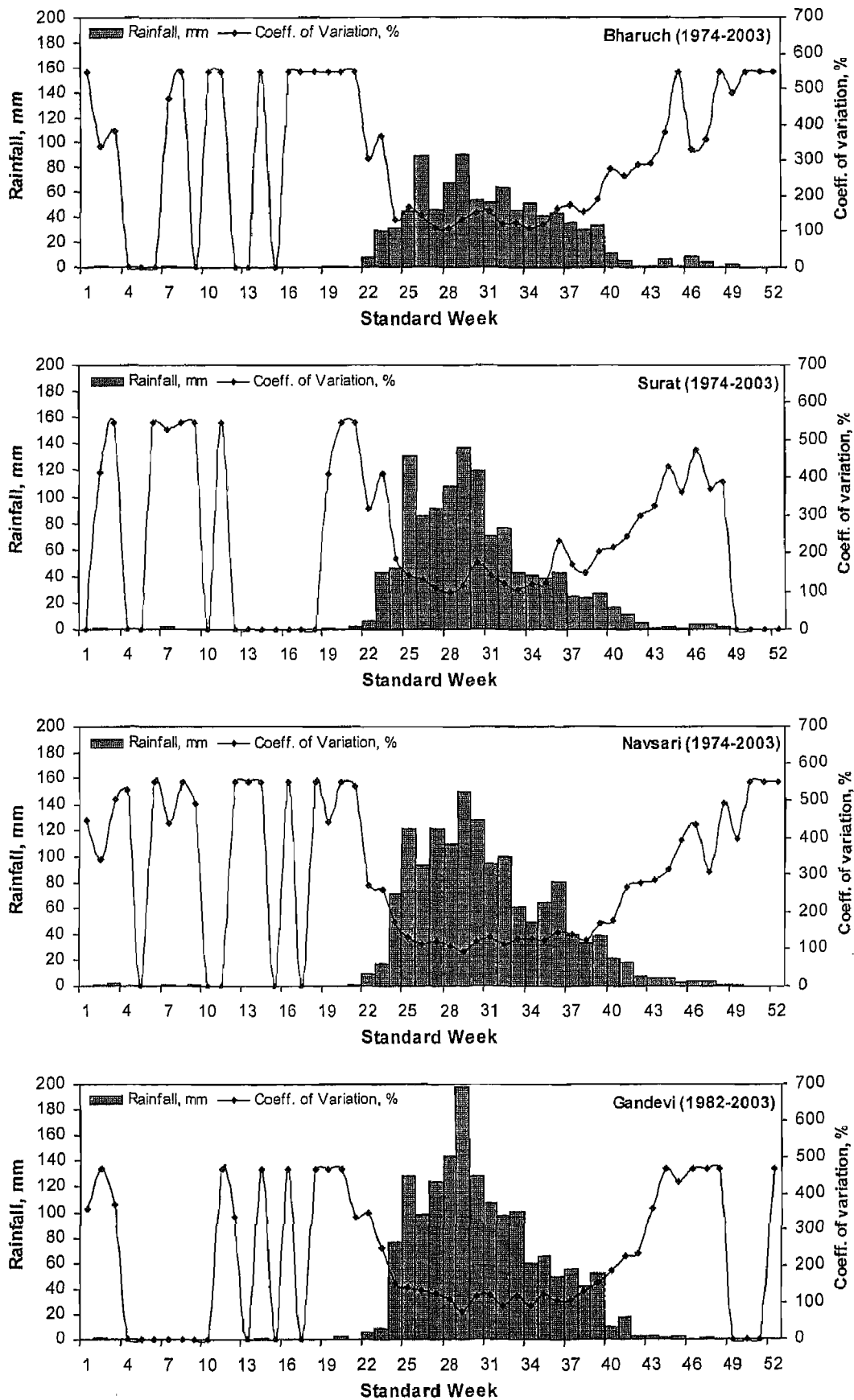


Fig. 4.1d Normal weekly variation of rainfall at Bharuch, Surat, Navsari and Gandevi

Table 4.4 Characteristics of rainy season in different agro-climatic zones of Gujarat

Station	Onset of rainy season, std. met. week			Withdrawal of rainy season, std. met. week			Length of rainy season, weeks		
	Early	Late	Mean	Early	Late	Mean	Max.	Min.	Mean
Kothara	21 (1)	32 (3)	28.00	30 (2)	46 (1)	36.30	20	4	9.60
Radhanpur	24 (1)	32 (1)	28.20	31 (2)	45 (1)	35.90	17	5	9.60
Rajkot	22 (1)	31 (1)	26.50	32 (1)	47 (1)	37.80	21	5	11.20
Amreli	22 (1)	31 (2)	26.90	30 (1)	48 (1)	39.40	22	6	13.60
SK Nagar	23 (1)	32 (2)	26.50	31 (1)	47 (1)	38.90	23	6	13.00
Khedbrahma	24 (2)	32 (1)	26.80	31 (1)	46 (1)	37.80	20	6	11.80
Arnej	21 (2)	30 (1)	25.70	32 (1)	45 (1)	38.00	19	7	12.70
Dhandhuka	22 (1)	32 (1)	26.70	32 (1)	48 (1)	38.50	18	7	12.20
Junagadh	23 (2)	32 (1)	26.00	32 (1)	47 (2)	39.30	22	6	13.70
Mahuva	22 (1)	32 (1)	27.00	31 (2)	47 (1)	37.80	20	6	11.90
Anand	22 (1)	32 (1)	26.10	32 (1)	48 (1)	39.00	24	7	13.20
Nawagam	22 (1)	30 (1)	26.20	32 (1)	48 (1)	39.00	26	7	13.40
Bharuch	22 (2)	29 (1)	25.20	34 (1)	47 (2)	39.10	21	8	14.10
Surat	21 (1)	28 (4)	24.80	30 (1)	48 (1)	39.10	24	7	14.60
Navsari	22 (1)	31 (1)	25.10	34 (1)	47 (2)	40.20	24	10	15.30
Gandevi	22 (1)	31 (1)	25.20	33 (1)	47 (1)	39.30	25	10	14.70

Figures in parenthesis indicate number of the event.

Table 4.5 Probability (%) of onset of rainy season during standard meteorological weeks under different agro-climatic zones of Gujarat

Station\ Week	21	22	23	24	25	26	27	28	29	30	31	32
	Probability(%) of onset of rainy season											
Kothara	3.2	-	-	6.5	12.9	-	19.4	29.0	32.3	58.1	61.3	71.0
Radhanpur		-	-	4.4	8.7	17.4	26.1	34.8	52.2	78.3	82.6	95.7
Rajkot	-	3.7	-	-	7.4	33.3	51.8	77.7	88.8	92.5	96.2	-
Amreli	-	3.2	6.5	12.9	25.8	38.7	54.8	67.7	86.2	-	93.5	-
SK Nagar	-	-	3.2	6.5	12.9	25.8	41.9	48.4	64.5	83.9	87.1	93.6
Khedbrahm		-	-	3.7	11.1	22.2	48.1	70.3	85.1	-	-	96.2
Arnej	4.4	8.7	-	13.0	21.7	60.9	-	78.3	82.6	95.7	-	-
Dhandhuka	4.4	8.7	-	-	17.4	34.8	65.2	78.3	82.6	-	91.3	95.7
Junagadh	-	-	3.2	9.7	22.6	58.1	-	70.8	83.9	-	-	96.8
Mahuva	-	4.4	-	8.7	21.7	39.1	52.2	56.5	73.9	82.6	87.0	95.7
Anand	-	3.2	6.5	12.9	19.4	45.2	67.7	80.6	87.1	93.6	-	96.8
Nawagam	-	3.7	-	7.4	25.9	40.7	59.2	70.3	81.4	96.2	-	-
Bharuch	-	3.2	9.7	19.4	38.7	61.3	80.6	83.9	96.8	-	-	-
Surat	3.2	6.5	9.7	22.6	41.9	74.2	-	87.1	-	-	-	-
Navsari	-	3.2	6.5	12.9	38.7	74.2	83.9	93.6	-	-	96.8	-
Gandevi	-	4.4	8.7	13.0	43.5	69.6	78.3	91.3	-	-	95.7	-

season may be expected by 25th smw at Gandevi, Navsari, Surat and Bharuch with a probability of 43.5, 38.7, 41.9 and 38.7 per cent; by 26th smw at Arnej, Junagadh, Anand and Nawagam with a probability of 60.9, 58.1, 45.2 and 40.7 per cent; by 27th smw at Rajkot, Amreli, SK Nagar, Khedbrahma, Dhandhuka and Mahuva with a probability of 51.8, 54.8, 41.9, 48.1, 65.2 and 52.2 per cent and by 28th smw at Kothara and Radhanpur with a probability of 29.0 and 34.8 percent, respectively.

4.1.4.2 Withdrawal of rainy season

Withdrawal of rainy season is determined by backward accumulation of rainfall from 48th smw accounting to an amount of 30 mm. Table 4.4 shows the withdrawal of rainy season from different agro-climatic zones of Gujarat. The percentage probabilities for the withdrawal of rainy season for different zones are given in Table 4.6.

Table 4.4 indicates that earliest withdrawal of rainy season is in 30th smw (July 23-29) at Kothara, Amreli and Surat; in 31st smw (July 30- August 5) at Radhanpur, SK Nagar, Khedbrahma and Mahuva; in 32nd smw (August 6-12) at Rajkot, Arnej, Dhandhuka, Junagadh, Anand and Nawagam; in 33rd smw (August 13-19) at Gandevi and in 34th smw (August 20-26) at Bharuch and Navsari. Similarly, late withdrawal of rainy season was observed in 45th smw (November 5-11) at Radhanpur and Arnej; in 46th smw (November 12-18) at Kothara and Khedbrahma; in 47th smw (November 19-25) at Rajkot, SK Nagar, Junagadh, Mahuva, Bharuch, Navsari and Gandevi and in 48th smw (Nov. 26- Dec. 2) at Amreli, Dhandhuka, Anand, Nawagam and Surat. Further, Tables 4.4 and 4.6 show that under normal condition the rainy season withdraws in 36th smw (September 3-9) at Kothara and Radhanpur with 54.8 and 56.6 per cent probability; in 38th smw (September 17-23) at Rajkot, Khedbrahma, Arnej and Mahuva with 51.8, 48.1, 43.5 and 47.9 per cent probability; in 39th smw (September 24-30) at Amreli, SK Nagar, Dhandhuka, Junagadh, Anand, Nawagam, Bharuch, Surat and Gandevi with 41.9, 51.6, 52.2, 41.9, 58.1, 55.5, 51.6, 48.4 and 43.5 per cent and in 40th smw (October 1-7) at Navsari with 45.2 per cent probability, respectively.

4.1.4.3 Length of rainy season

The length of rainy season is the period between onset and withdrawal of the rainy season. Length of rainy season for different stations is presented in Table 4.4. Minimum and maximum length of rainy season was observed at Kothara (4 weeks) and Gandevi (25 weeks), respectively. Table 4.4 also indicates that the mean length of rainy season at Surat, Navsari and Gandevi was of 15 weeks; at Amreli, Junagadh and Bharuch 14 weeks; at SK Nagar, Arnej, Anand and Nawagam 13 weeks; at Khedbrahma, Dhandhuka and Mahuva 12 weeks; at Rajkot 11 weeks and at Kothara and Radhanpur 10 weeks, respectively. The length of rainy season may be curtailed due to early withdrawal of south-west monsoon.

Table 4.6 Probability (%) of withdrawal of rainy season during standard meteorological weeks under different agro-climatic zones of Gujarat

Station\Week	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
	Probability(%) of withdrawal of rainy season															
Kothara	3.23	9.68	19.36	13.16	41.94	51.62	54.84	61.29	-	74.20	-	77.20	80.65	83.88	87.10	90.33
Radhanpur		4.35	17.40	34.80	39.15	52.20	56.55	60.90	69.60	-	-	78.30	82.65	-	87.00	91.35
Rajkot	-	-	3.70	7.40	11.10	29.60	37.00	44.40	51.80	55.50	77.70	81.40	85.10	-	88.80	92.50
Amreli	3.23	-	6.45	9.68	12.90	-	19.36	29.03	35.49	41.94	48.39	67.75	74.20	77.42	80.65	83.88
SK Nagar	-	3.23	6.45	16.13	-	19.36	25.81	32.26	41.94	51.62	54.48	64.52	67.75	74.20	77.42	80.65
Khedbrahma		3.70	7.40	11.20	18.50	-	25.90	33.30	48.10	55.50	77.70	-	-	85.10	-	92.50
Arnej	-	-	4.35	8.70	17.40	21.75	21.75	26.10	43.50	47.85	52.20	69.60	73.95	87.00	91.35	-
Dhandhuka		-	4.35	8.70	13.05	21.75	30.45	45.30	47.85	52.20	60.90	65.25	78.30	87.00	-	91.35
Junagadh	-	-	3.23	6.45	9.68	12.90	16.13	25.81	32.26	41.94	51.62	74.20	77.40	80.65	87.10	90.33
Mahuva	-	4.35	13.05	17.40	21.75	30.45	39.15	43.50	47.85	60.90	-	69.60	78.30	82.65	-	91.35
Anand	-	-	3.23	-	6.45	12.90	19.36	32.26	41.94	58.07	67.75	70.97	77.42	80.65	83.88	87.10
Nawagam	-	-	3.70	7.40	14.80	18.50	25.90	40.70	48.10	55.50	59.20	62.90	70.30	74.00	81.40	85.10
Bharuch	-	-	-	-	3.23	6.45	16.13	29.03	38.71	51.62	67.75	74.20	80.65	-	83.88	-
Surat	3.23	-	6.45	-	9.68	16.13	25.81	29.03	32.26	48.39	-	64.52	74.20	-	80.65	-
Navsari	-	-	-	-	3.23	6.45	16.13	22.58	29.03	35.49	45.16	58.07	67.75	-	77.42	87.10
Gandevi	-	-	-	4.35	-	8.70	13.05	21.75	30.45	43.50	56.55	69.60	82.65	87.00	-	91.35

4.1.5 Dry and Wet Spell Analysis

Initial and conditional probabilities and probable periods of occurrence of two consecutive dry weeks for the selected sixteen stations representing different agro-climatic zones under study were analysed by Markov-Chain process.

4.1.5.1 Initial and conditional probability

The initial and conditional probabilities of rainfall for the amount of 20 mm during 1 to 52 weeks were estimated by using Equations (3.2) to (3.5). The results for 23rd to 45th standard meteorological weeks for different agro-climatic zones are given in Tables 4.7a to 4.7p. It is seen from Table 4.7a to 4.7p that at all the stations the probability of occurrence of dry week [P(D)] is high (> 70%) in the beginning of monsoon season, reduces in the mid of season (28th to 32nd smw) and again reaches high at the end of season. Wet spell probability of occurrence [P(W)] is just reverse of the [P(D)].

The conditional probability of dry week preceded by a dry week [P(D/D)], as presented in Tables 4.7a to 4.7p indicate that at all the stations it is high (> 50%) at the beginning of the rainy season (upto 26th smw), which then remains low in mid of the season and again start increasing onwards. However, the [P(D/D)] remains high (> 50%) through out rainy season in arid zone (Kothara and Radhanpur). Similarly, probability of occurrence of wet week preceded by a wet week P(W/W), as evident from Tables 4.7a to 4.7p, indicates that it is high (> 50%), except in the beginning and end of season, at SK Nagar, Khedbrahma, Anand, Nawagam, Bharuch, Surat, Navsari and Gandevi. Whereas, mixed trend is obtained for Kothara, Radhanpur, Rajkot, Amreli, Arnej, Dhandhuka, Junagadh and Mahuva.

4.1.5.2 Probability of two consecutive dry weeks

Dry spell due to inadequate rainfall may occur through out the rainy season. The weekly evaporative demand of different agro-climatic zones of Gujarat varies from 38 to 62 mm during beginning of rainy season to 21 to 39 mm during active rainy season. A week receiving rainfall of about 20 mm will be able to meet half to full evaporative demand. During the early stages of growth, the crop water requirements will be about half of the evaporative demand and subsequently increase during the reproductive stage of crop growth. Therefore, week with rainfall less than 20 mm was considered as a dry spell week (Pandarinath, 1991; Dash and Senapati, 1992). If the rainfall is less than 20 mm per week for two or more consecutive weeks, the crops are likely to be subjected to moisture stress in the absence of adequate stored soil moisture.

The probability of two consecutive dry weeks and wet weeks for different agro-climatic zones of Gujarat are calculated from Equations (3.6) and (3.7) and shown in Tables 4.7a to 4.7p. Tables 4.7a to 4.7p reveal that the probability of two consecutive dry weeks

Table 4.7a Probability (%) of dry and wet weeks at Kothara

Std. met. week	P (D)	P (D/D)	P (2D)	P (W)	P (W/W)	P (2W)
23	96.67	96.55	93.09	3.33	0.00	0.00
24	90.00	96.30	78.26	10.00	0.00	0.00
25	76.67	86.96	58.27	23.33	0.00	4.67
26	83.33	76.00	72.46	16.67	20.00	4.76
27	76.67	86.96	65.17	23.33	28.57	9.33
28	66.67	85.00	50.98	33.33	40.00	15.38
29	56.67	76.47	37.78	43.33	46.15	28.89
30	70.00	66.67	48.70	30.00	66.67	8.57
31	76.67	69.57	65.71	23.33	28.57	10.37
32	70.00	85.71	57.83	30.00	44.44	21.43
33	76.67	82.61	58.97	23.33	71.43	5.83
34	86.67	76.92	76.67	13.33	25.00	3.33
35	86.67	88.46	83.20	13.33	25.00	8.00
36	83.33	96.00	73.33	16.67	60.00	6.67
37	83.33	88.00	68.97	16.67	40.00	0.00
38	96.67	82.76	96.67	3.33	0.00	1.11
39	90.00	100.00	83.79	10.00	33.33	10.00
40	96.67	93.00	96.67	3.33	66.67	1.67
41	93.33	100.00	86.67	6.67	50.00	0.00
42	93.33	92.86	86.90	6.67	0.00	0.00
43	96.67	93.10	93.33	3.33	0.00	0.00
44	96.67	96.55	93.33	3.33	0.00	0.00
45	96.67	96.55	93.33	3.33	0.00	0.00

Table 4.7b Probability (%) of dry and wet weeks at Radhanpur

Std. met. week	P (D)	P (D/D)	P (2D)	P (W)	P (W/W)	P (2W)
23	96.67	96.55	93.09	3.33	0.00	0.00
24	90.00	96.30	78.26	10.00	0.00	0.00
25	76.67	86.96	58.27	23.33	0.00	4.67
26	83.33	76.00	72.46	16.67	20.00	4.76
27	76.67	86.96	65.17	23.33	28.57	9.33
28	66.67	85.00	50.98	33.33	40.00	15.38
29	56.67	76.47	37.78	43.33	46.15	28.89
30	70.00	66.67	48.70	30.00	66.67	8.57
31	76.67	69.57	65.71	23.33	28.57	10.37
32	70.00	85.71	57.83	30.00	44.44	21.43
33	76.67	82.61	58.97	23.33	71.43	5.83
34	86.67	76.92	76.67	13.33	25.00	3.33
35	86.67	88.46	83.20	13.33	25.00	8.00
36	83.33	96.00	73.33	16.67	60.00	6.67
37	83.33	88.00	68.97	16.67	40.00	0.00
38	96.67	82.76	96.67	3.33	0.00	1.11
39	90.00	100.00	83.79	10.00	33.33	10.00
40	96.67	93.00	96.67	3.33	66.67	1.67
41	93.33	100.00	86.67	6.67	50.00	0.00
42	93.33	92.86	86.90	6.67	0.00	0.00
43	96.67	93.10	93.33	3.33	0.00	0.00
44	96.67	96.55	93.33	3.33	0.00	0.00
45	96.67	96.55	93.33	3.33	0.00	0.00

Table 4.7c Probability (%) of dry and wet weeks at Rajkot

Std. met. week	P (D)	P (D/D)	P (2D)	P (W)	P (W/W)	P (2W)
23	92.31	91.67	81.45	7.69	0.00	0.00
24	65.38	88.24	39.23	34.62	0.00	9.44
25	57.69	60.00	30.77	42.31	27.27	15.38
26	57.69	53.33	36.71	42.31	36.36	19.74
27	42.31	63.64	21.15	57.69	46.67	38.46
28	53.85	50.00	35.90	46.15	66.67	24.43
29	34.62	66.67	12.59	65.38	52.94	43.59
30	42.31	36.36	19.74	57.69	66.67	36.71
31	57.69	46.67	36.06	42.31	63.64	21.15
32	61.54	62.50	41.03	38.46	50.00	19.23
33	69.23	66.67	38.94	30.77	50.00	3.08
34	61.54	56.25	42.11	38.46	10.00	21.98
35	73.08	68.42	54.01	26.92	57.14	8.97
36	88.46	73.91	75.19	11.54	33.33	0.00
37	76.92	85.00	56.68	23.08	0.00	3.30
38	73.08	73.68	60.90	26.92	14.29	13.46
39	69.23	83.33	50.35	30.77	50.00	15.38
40	84.62	72.73	74.04	15.38	50.00	7.69
41	92.31	87.50	84.92	7.69	50.00	0.00
42	96.15	92.00	92.46	3.85	0.00	0.00
43	100.00	96.15	100.00	0.00	0.00	0.00
44	92.31	100.00	84.92	7.69	0.00	0.00
45	96.15	92.00	92.31	3.85	0.00	0.00

Table 4.7d Probability (%) of dry and wet weeks at Amreli

Std. met. week	P (D)	P (D/D)	P (2D)	P (W)	P (W/W)	P (2W)
23	83.33	96.00	71.97	16.67	20.00	4.17
24	73.33	86.36	64.71	26.67	25.00	12.31
25	56.67	88.24	38.96	43.33	46.15	24.76
26	53.33	68.75	26.67	46.67	57.14	20.00
27	53.33	50.00	30.48	46.67	42.86	23.33
28	46.67	57.14	20.42	53.33	50.00	26.67
29	53.33	43.75	34.51	46.67	50.00	28.72
30	56.67	64.71	34.63	43.33	61.54	21.67
31	60.00	61.11	34.74	40.00	50.00	14.55
32	63.33	57.89	35.19	36.67	36.36	9.17
33	60.00	55.56	38.82	40.00	25.00	18.46
34	56.67	64.71	40.48	43.33	46.15	24.37
35	46.67	71.43	24.27	53.33	56.25	42.67
36	83.33	52.00	64.39	16.67	80.00	0.00
37	73.33	77.27	56.67	26.67	0.00	10.00
38	73.33	77.27	57.04	26.67	37.50	8.89
39	60.00	77.78	40.91	40.00	33.33	25.00
40	73.33	68.18	53.59	26.67	62.50	6.67
41	86.67	73.08	74.71	13.33	25.00	0.00
42	96.67	86.21	93.21	3.33	0.00	0.00
43	93.33	96.43	86.90	6.67	0.00	0.00
44	96.67	93.10	93.21	3.33	0.00	0.00
45	93.33	96.43	86.42	6.67	0.00	0.00

Table 4.7e Probability (%) of dry and wet weeks at SK Nagar

Std. met. week	P (D)	P (D/D)	P (2D)	P (W)	P (W/W)	P (2W)
23	86.67	96.15	76.27	13.33	0.00	2.67
24	83.33	88.00	68.84	16.67	20.00	2.38
25	76.67	82.61	60.00	23.33	14.29	6.67
26	76.67	78.26	69.00	23.33	28.57	11.67
27	66.67	90.00	47.06	33.33	50.00	12.82
28	56.67	70.59	37.78	43.33	38.46	21.67
29	40.00	66.67	24.62	60.00	50.00	45.88
30	43.33	61.54	27.58	56.67	76.47	38.77
31	36.67	63.64	13.10	63.33	68.42	39.58
32	46.67	35.71	27.45	53.33	62.50	36.92
33	56.67	58.82	33.06	43.33	69.23	21.67
34	80.00	58.33	71.58	20.00	50.00	7.27
35	63.33	89.47	46.81	36.67	36.36	26.19
36	76.67	73.91	62.06	23.33	71.43	7.78
37	70.00	80.95	50.40	30.00	33.33	12.00
38	83.33	72.00	70.51	16.67	40.00	4.17
39	86.67	84.62	73.33	13.33	25.00	0.00
40	86.67	84.62	74.71	13.33	0.00	0.00
41	96.67	86.21	93.21	3.33	0.00	0.00
42	93.33	96.43	86.67	6.67	0.00	0.00
43	93.33	92.86	86.90	6.67	0.00	0.00
44	96.67	93.10	93.21	3.33	0.00	0.00
45	93.33	96.43	86.42	6.67	0.00	0.00

Table 4.7f Probability (%) of dry and wet weeks at Khedbrahma

Std. met. week	P (D)	P (D/D)	P (2D)	P (W)	P (W/W)	P (2W)
23	88.46	86.96	82.93	11.54	0.00	2.31
24	61.54	93.75	32.58	38.46	20.00	8.55
25	65.38	52.94	43.59	34.62	22.22	12.59
26	57.69	66.67	31.07	42.31	36.36	16.27
27	50.00	53.85	21.43	50.00	38.46	23.68
28	26.92	42.86	20.19	73.08	47.37	59.79
29	15.38	75.00	4.40	84.62	81.82	75.71
30	26.92	28.57	16.15	73.08	89.47	59.16
31	19.23	60.00	7.69	80.77	80.95	75.72
32	38.46	40.00	13.74	61.54	93.75	35.90
33	53.85	35.71	30.77	46.15	58.33	23.08
34	53.85	57.14	35.90	46.15	50.00	34.62
35	69.23	66.67	57.01	30.77	75.00	17.09
36	65.38	82.35	52.31	34.62	55.56	28.85
37	76.92	80.00	62.94	23.08	83.33	11.54
38	84.62	81.82	75.21	15.38	50.00	3.85
39	69.23	88.89	49.04	30.77	25.00	15.38
40	92.31	70.83	84.62	7.69	50.00	0.00
41	92.31	91.67	85.21	7.69	0.00	0.00
42	100.00	92.31	100.00	0.00	0.00	0.00
43	92.31	100.00	85.21	7.69	0.00	0.00
44	100.00	92.31	100.00	0.00	0.00	0.00
45	96.15	100.00	92.31	3.85	0.00	0.00

Table 4.7g Probability (%) of dry and wet weeks at Arnej

Std. met. week	P (D)	P (D/D)	P (2D)	P (W)	P (W/W)	P (2W)
23	86.36	94.74	80.61	13.64	0.00	3.90
24	68.18	93.33	43.39	31.82	28.57	8.68
25	50.00	63.64	27.27	50.00	27.27	27.27
26	50.00	54.55	27.27	50.00	54.55	27.27
27	50.00	54.55	30.00	50.00	54.55	29.17
28	45.45	60.00	27.27	54.55	58.33	36.36
29	45.45	60.00	22.73	54.55	66.67	32.73
30	54.55	50.00	38.18	45.45	60.00	26.52
31	45.45	70.00	22.73	54.55	58.33	34.09
32	63.64	50.00	47.73	36.36	62.50	18.18
33	54.55	75.00	25.17	45.45	50.00	15.15
34	59.09	46.15	39.39	40.91	33.33	23.38
35	68.18	66.67	58.44	31.82	57.14	19.89
36	63.64	85.71	43.75	36.36	62.50	18.18
37	72.73	68.75	59.89	27.27	50.00	16.36
38	77.27	82.35	62.78	22.73	60.00	7.58
39	72.73	81.25	57.42	27.27	33.33	18.18
40	86.36	78.95	81.82	13.64	66.67	9.09
41	86.36	94.74	74.03	13.64	66.67	0.00
42	95.45	85.71	90.91	4.55	0.00	0.00
43	95.45	95.24	91.12	4.55	0.00	0.00
44	100.00	95.45	100.00	0.00	0.00	0.00
45	95.45	100.00	91.12	4.55	0.00	0.00

Table 4.7h Probability (%) of dry and wet weeks at Dhandhuka

Std. met. week	P (D)	P (D/D)	P (2D)	P (W)	P (W/W)	P (2W)
23	72.73	100.00	55.61	27.27	33.33	10.91
24	77.27	76.47	53.50	22.73	40.00	2.53
25	59.09	69.23	42.98	40.91	11.11	22.31
26	50.00	72.73	18.18	50.00	54.55	18.18
27	50.00	36.36	22.73	50.00	36.36	22.73
28	50.00	45.45	30.77	50.00	45.45	33.33
29	59.09	61.54	34.47	40.91	66.67	16.36
30	54.55	58.33	39.67	45.45	40.00	28.93
31	50.00	72.73	25.00	50.00	63.64	25.00
32	45.45	50.00	29.22	54.55	50.00	47.73
33	63.64	64.29	40.50	36.36	87.50	13.22
34	50.00	63.64	32.14	50.00	36.36	37.50
35	63.64	64.29	44.06	36.36	75.00	16.16
36	59.09	69.23	35.45	40.91	44.44	17.53
37	68.18	60.00	45.45	31.82	42.86	7.95
38	81.82	66.67	67.38	18.18	25.00	3.64
39	77.27	82.35	61.82	22.73	20.00	11.36
40	90.91	80.00	90.91	9.09	50.00	4.55
41	81.82	100.00	69.55	18.18	50.00	9.09
42	90.91	85.00	82.25	9.09	50.00	0.00
43	95.45	90.48	91.12	4.55	0.00	0.00
44	100.00	95.45	100.00	0.00	0.00	0.00
45	95.45	100.00	91.12	4.55	0.00	0.00

Table 4.7i Probability (%) of dry and wet weeks at Junagadh

Std. met. week	P (D)	P (D/D)	P (2D)	P (W)	P (W/W)	P (2W)
23	76.67	91.30	72.41	23.33	14.29	11.67
24	60.00	94.44	31.76	40.00	50.00	12.31
25	56.67	52.94	38.77	43.33	30.77	27.58
26	63.33	68.42	42.22	36.67	63.64	14.67
27	50.00	66.67	30.00	50.00	40.00	27.50
28	33.33	60.00	23.33	66.67	55.00	56.67
29	33.33	70.00	20.51	66.67	85.00	58.82
30	43.33	61.54	21.67	56.67	88.24	35.42
31	46.67	50.00	21.78	53.33	62.50	28.44
32	50.00	46.67	26.67	50.00	53.33	26.67
33	50.00	53.33	23.53	50.00	53.33	23.08
34	56.67	47.06	32.81	43.33	46.15	19.70
35	63.33	57.89	50.67	36.67	45.45	25.67
36	66.67	80.00	51.52	33.33	70.00	20.83
37	73.33	77.27	57.89	26.67	62.50	9.70
38	63.33	78.95	45.74	36.67	36.36	18.33
39	60.00	72.22	35.45	40.00	50.00	15.00
40	73.33	59.09	54.32	26.67	37.50	8.89
41	90.00	74.07	83.57	10.00	33.33	5.00
42	93.33	92.86	89.74	6.67	50.00	1.67
43	86.67	96.15	74.71	13.33	25.00	0.00
44	96.67	86.21	93.21	3.33	0.00	0.00
45	93.33	96.43	86.90	6.67	0.00	0.00

Table 4.7j Probability (%) of dry and wet weeks at Mahuva

Std. met. week	P (D)	P (D/D)	P (2D)	P (W)	P (W/W)	P (2W)
23	90.91	90.00	78.79	9.09	0.00	0.00
24	68.18	86.67	48.70	31.82	0.00	11.93
25	63.64	71.43	35.80	36.36	37.50	6.06
26	72.73	56.25	60.61	27.27	16.67	10.91
27	54.55	83.33	29.37	45.45	40.00	20.20
28	59.09	53.85	44.32	40.91	44.44	20.45
29	36.36	75.00	15.15	63.64	50.00	44.55
30	54.55	41.67	27.27	45.45	70.00	18.94
31	45.45	50.00	20.66	54.55	41.67	29.75
32	50.00	45.45	21.87	50.00	54.55	16.67
33	72.73	43.75	59.50	27.27	33.33	9.92
34	50.00	81.82	28.57	50.00	36.36	31.25
35	63.64	57.14	52.07	36.36	62.50	19.83
36	50.00	81.82	29.41	50.00	54.55	40.00
37	77.27	58.82	61.82	22.73	80.00	6.49
38	68.18	80.00	51.14	31.82	28.57	15.91
39	72.73	75.00	50.91	27.27	50.00	0.00
40	90.91	70.00	81.82	9.09	0.00	0.00
41	90.91	90.00	86.12	9.09	0.00	3.03
42	86.36	94.74	77.27	13.64	33.33	4.55
43	86.36	89.47	74.03	13.64	33.33	0.00
44	95.45	85.71	95.45	4.55	0.00	2.27
45	90.91	100.00	82.64	9.09	50.00	0.00

Table 4.7k Probability (%) of dry and wet weeks at Anand

Std. met. week	P (D)	P (D/D)	P (2D)	P (W)	P (W/W)	P (2W)
23	86.67	92.31	73.67	13.33	25.00	1.33
24	66.67	85.00	45.61	33.33	10.00	12.12
25	63.33	68.42	42.22	36.67	36.36	14.26
26	40.00	66.67	20.00	60.00	38.89	42.86
27	53.33	50.00	26.67	46.67	71.43	21.00
28	33.33	50.00	23.33	66.67	45.00	56.67
29	33.33	70.00	11.11	66.67	85.00	44.44
30	30.00	33.33	19.09	70.00	66.67	62.63
31	36.67	63.64	20.37	63.33	89.47	45.24
32	30.00	55.56	10.71	70.00	71.43	52.50
33	46.67	35.71	23.33	53.33	75.00	30.00
34	46.67	50.00	24.89	53.33	56.25	32.00
35	50.00	53.33	36.11	50.00	60.00	41.67
36	60.00	72.22	40.91	40.00	83.33	25.00
37	73.33	68.18	56.67	26.67	62.50	10.00
38	73.33	77.27	58.06	26.67	37.50	13.33
39	80.00	79.17	62.86	20.00	50.00	0.00
40	93.33	78.57	90.00	6.67	0.00	3.33
41	93.33	96.43	86.67	6.67	50.00	0.00
42	93.33	92.86	86.42	6.67	0.00	0.00
43	90.00	92.59	80.69	10.00	0.00	0.00
44	96.67	89.66	93.33	3.33	0.00	0.00
45	96.67	96.55	93.21	3.33	0.00	0.00

Table 4.7l Probability (%) of dry and wet weeks at Nawagam

Std. met. week	P (D)	P (D/D)	P (2D)	P (W)	P (W/W)	P (2W)
23	84.62	95.45	75.71	15.38	50.00	4.40
24	73.08	89.47	51.58	26.92	28.57	5.98
25	65.38	70.59	35.66	34.62	22.22	9.23
26	42.31	54.55	17.63	57.69	26.67	32.97
27	46.15	41.67	27.69	53.85	57.14	39.16
28	57.69	60.00	38.46	42.31	72.73	19.91
29	34.62	66.67	17.31	65.38	47.06	47.22
30	30.77	50.00	23.08	69.23	72.22	61.54
31	30.77	75.00	10.26	69.23	88.89	49.45
32	46.15	33.33	25.17	53.85	71.43	32.31
33	42.31	54.55	19.23	57.69	60.00	34.62
34	42.31	45.45	24.68	57.69	60.00	41.21
35	46.15	58.33	25.64	53.85	71.43	40.38
36	69.23	55.56	51.92	30.77	75.00	15.38
37	76.92	75.00	58.61	23.08	50.00	4.62
38	80.77	76.19	72.69	19.23	20.00	9.62
39	76.92	90.00	60.90	23.08	50.00	11.54
40	92.31	79.17	88.46	7.69	50.00	3.85
41	92.31	95.83	84.92	7.69	50.00	0.00
42	96.15	92.00	92.31	3.85	0.00	0.00
43	96.15	96.00	92.31	3.85	0.00	0.00
44	96.15	96.00	92.31	3.85	0.00	0.00
45	96.15	96.00	91.97	3.85	0.00	0.00

Table 4.7m Probability (%) of dry and wet weeks at Bharuch

Std. met. week	P (D)	P (D/D)	P (2D)	P (W)	P (W/W)	P (2W)
23	73.33	90.91	65.19	26.67	12.50	13.33
24	60.00	88.89	34.74	40.00	50.00	14.55
25	63.33	57.89	42.22	36.67	36.36	14.67
26	50.00	66.67	25.00	50.00	40.00	25.00
27	46.67	50.00	25.93	53.33	50.00	30.48
28	30.00	55.56	15.00	70.00	57.14	54.09
29	26.67	50.00	10.26	73.33	77.27	60.39
30	43.33	38.46	26.00	56.67	82.35	41.56
31	50.00	60.00	21.43	50.00	73.33	23.91
32	23.33	42.86	7.18	76.67	47.83	63.14
33	43.33	30.77	19.70	56.67	82.35	32.81
34	36.67	45.45	17.11	63.33	57.89	46.44
35	50.00	46.67	34.21	50.00	73.33	40.91
36	63.33	68.42	38.00	36.67	81.82	11.00
37	66.67	60.00	44.44	33.33	30.00	11.11
38	60.00	66.67	37.14	40.00	33.33	17.78
39	70.00	61.90	51.85	30.00	44.44	20.00
40	90.00	74.07	83.57	10.00	66.67	5.00
41	93.33	92.86	87.11	6.67	50.00	0.00
42	100.00	93.33	100.00	0.00	0.00	0.00
43	96.67	100.00	96.67	3.33	0.00	1.67
44	93.33	100.00	86.90	6.67	50.00	0.00
45	96.67	93.10	93.21	3.33	0.00	0.00

Table 4.7n Probability (%) of dry and wet weeks at Surat

Std. met. week	P (D)	P (D/D)	P (2D)	P (W)	P (W/W)	P (2W)
23	76.67	95.65	60.53	23.33	14.29	6.36
24	63.33	78.95	49.76	36.67	27.27	18.33
25	46.67	78.57	26.67	53.33	50.00	33.33
26	46.67	57.14	25.93	53.33	62.50	30.48
27	30.00	55.56	12.00	70.00	57.14	52.50
28	33.33	40.00	19.05	66.67	75.00	49.28
29	23.33	57.14	9.33	76.67	73.91	65.17
30	33.33	40.00	18.18	66.67	85.00	52.63
31	36.67	54.55	18.33	63.33	78.95	43.18
32	26.67	50.00	13.33	73.33	68.18	62.33
33	33.33	50.00	16.67	66.67	85.00	57.14
34	53.33	50.00	31.37	46.67	85.71	25.13
35	56.67	58.82	39.67	43.33	53.85	30.33
36	66.67	70.00	50.00	33.33	70.00	16.67
37	66.67	75.00	49.12	33.33	50.00	15.15
38	63.33	73.68	45.24	36.67	45.45	20.37
39	70.00	71.43	53.33	30.00	55.56	13.33
40	70.00	76.19	56.54	30.00	44.44	30.00
41	86.67	80.77	76.67	13.33	36.70	3.33
42	86.67	88.46	77.70	13.33	25.00	13.33
43	96.67	89.66	96.67	3.33	36.70	1.67
44	93.33	100.00	86.90	6.67	50.00	0.00
45	96.67	93.10	93.33	3.33	0.00	0.00

Table 4.7o Probability (%) of dry and wet weeks at Navsari

Std. met. week	P (D)	P (D/D)	P (2D)	P (W)	P (W/W)	P (2W)
23	80.00	91.67	61.18	20.00	16.67	3.08
24	56.67	76.47	34.87	43.33	15.38	20.39
25	43.33	61.54	25.28	56.67	47.06	37.78
26	40.00	58.33	22.86	60.00	66.67	39.13
27	23.33	57.14	16.67	76.67	65.22	70.00
28	23.33	71.43	11.67	76.67	91.30	63.89
29	20.00	50.00	5.45	80.00	83.33	67.37
30	36.67	27.27	15.71	63.33	84.21	41.30
31	23.33	42.86	15.56	76.67	65.22	62.47
32	10.00	66.67	0.83	90.00	81.48	80.00
33	40.00	8.33	18.67	60.00	88.89	40.00
34	50.00	46.67	30.00	50.00	66.67	27.50
35	33.33	60.00	19.05	66.67	55.00	58.33
36	46.67	57.14	24.89	53.33	87.50	32.00
37	50.00	53.33	32.14	50.00	60.00	31.25
38	46.67	64.29	29.47	53.33	62.50	43.64
39	63.33	63.16	37.42	36.67	81.82	9.17
40	73.33	59.09	59.23	26.67	25.00	20.00
41	86.67	80.77	76.67	13.33	75.00	3.33
42	86.67	88.46	77.04	13.33	25.00	4.44
43	90.00	88.89	80.00	10.00	33.33	0.00
44	90.00	88.89	80.69	10.00	0.00	0.00
45	96.67	89.66	93.33	3.33	0.00	0.00

Table 4.7p Probability (%) of dry and wet weeks at Gandevi

Std. met. week	P (D)	P (D/D)	P (2D)	P (W)	P (W/W)	P (2W)
23	90.91	90.00	80.81	9.09	0.00	0.70
24	40.91	88.89	16.36	59.09	7.69	34.47
25	45.45	40.00	27.27	54.55	58.33	36.36
26	45.45	60.00	22.73	54.55	66.67	30.68
27	27.27	50.00	20.45	72.73	56.25	60.61
28	18.18	75.00	12.12	81.82	83.33	73.21
29	13.64	66.67	2.73	86.36	89.47	76.20
30	22.73	20.00	11.36	77.27	88.24	64.39
31	18.18	50.00	0.00	81.82	83.33	64.59
32	13.64	0.00	3.41	86.36	78.95	76.77
33	18.18	25.00	4.55	81.82	88.89	68.18
34	18.18	25.00	3.64	81.82	83.33	67.38
35	22.73	20.00	7.58	77.27	82.35	65.38
36	40.91	33.33	23.38	59.09	84.62	39.39
37	31.82	57.14	17.36	68.18	66.67	61.98
38	50.00	54.55	32.14	50.00	90.91	37.50
39	63.64	64.29	42.42	36.36	75.00	18.18
40	81.82	66.67	68.18	18.18	50.00	4.55
41	81.82	83.33	66.94	18.18	25.00	0.00
42	100.00	81.82	100.00	0.00	0.00	0.00
43	95.45	100.00	91.12	4.55	0.00	0.00
44	100.00	95.45	100.00	0.00	0.00	0.00
45	95.45	100.00	91.12	4.55	0.00	0.00

[P(2D)] is in general low during rainy season, but start increasing (> 50%) during withdrawal of rainy season in most of the zones. The standard meteorological weeks (during which dry spells of two consecutive weeks is likely to commence) with different probabilities of occurrence in selected agro-climatic zones are presented in Table 4.8.

Table 4.8 Weeks with different probabilities of occurrence of two consecutive dry weeks under different agro-climatic zones of Gujarat

Station	Dry weeks (rainfall < 20 mm per week) occurring consecutively starting with different probability levels			
	< 25 %	26 - 50 %	51 -75 %	> 75 %
Kothara	-	-	30,32	23-29,31,33 onwards
Radhanpur	-	29	27-28,30,32,34	23-26,31,33,35 onwards
Rajkot	-	27, 29-30	24-26,28,31-35,38-39	23,36-37,40 onwards
Amreli	-	28, 35	24-27,29-34,37-40	23, 36, 41 onwards
SK Nagar	-	29- 32	27-28,33,35,37	23-26,34,36,38 onwards
Khedbrahma	29, 31	27-28,30,32	24-26,33-36	23, 37 onwards
Arnej	-	25-31	24,32-37,39	23,38,40 onwards
Dhandhuka	-	26-28,31-32	23,25,29-30,33-37	24, 38 onwards
Junagadh	-	27- 33	24-26, 34-40	23, 41 onwards
Mahuva	-	29,31-32,34	24-28,30,33,35-36,38,39	23,37,40 onwards
Anand	-	26, 28-35	24-25,27,36,38	23,39 onwards
Nawagam	-	26-27,29-35	24-25, 28,36	23,37 onwards
Bharuch	32	26-31,33-35	23-25,36-39	40 onwards
Surat	29	25-28,30-33	24, 34-40	23,41 onwards
Navsari	27-29,31-32	25-26,30,33-38	24,39-40	23,41 onwards
Gandevi	28- 35	24-27,36-38	39	23,40 onwards

It is seen from Table 4.8 that mid season droughts are likely to occur with 26 to 50 per cent probabilities at SK Nagar, Junagadh, Anand, Nawagam, Bharuch, Surat and Navsari; with 51 to 75 per cent probability at Rajkot, Amreli, Khedbrahma, Arnej, Dhandhuka and Mahuva, and < 25 per cent probability at Gandevi. Kothara and Radhanpur experienced mid season drought with high probability on regular basis.

The possibilities of late season droughts during maturity period are high (> 50%) at all the stations except Gandevi where it is 25 percent. The probability of two consecutive wet weeks [P(2W)] as given in Tables 4.7a to 4.7p indicates that it is sufficiently high (>50%) during some of the weeks in rainy season to generate surface runoff, which can be harvested to reduce the impact of forthcoming dry spells, in most of the zones except arid location i.e. Kothara and Radhanpur and semi-arid locations i.e. Rajkot, Amreli, SK Nagar, Arnej, Dhandhuka and Mahuva, respectively.

This study can be used as a tool for detecting deficient period with regard to water availability during the crop growth periods. Alternative arrangements can be made during water deficient period coinciding with critical growth stages. Therefore, the probabilities of occurrence of dry and wet spells during crop growth season and conditional probabilities

which take into account the sequential events, provides the basic information on rainfall distribution characteristics necessary for different agricultural operations.

4.2 REFERENCE EVAPOTRANSPIRATION UNDER DIFFERENT AGRO-CLIMATIC ZONES OF GUJARAT

Reference evapotranspiration (ET_0) refers to total water losses through evaporation from soil and transpiration from vegetation under unlimited water supply. Recently, Allen et al., (1998) modified the concept of reference evapotranspiration and suggested Penman-Monteith equation for estimation of reference evapotranspiration. Weekly reference evapotranspiration values for different agro-climatic zones of Gujarat were computed by using Equation (3.9).

4.2.1 Annual Reference Evapotranspiration

The annual reference evapotranspiration (ET_0) values for different stations are presented in Table 4.9. The mean ET_0 value (Table 4.9) varies from 1437.31 mm with CV of 5.10 per cent at Gandevi to 2026.55 mm with CV of 9.05 per cent at Rajkot. The annual ET_0 values vary from maximum 2631.40 mm at Rajkot to minimum 1283.32 mm at Khedbrahma. Table 4.9 also reveals that minimum and maximum CV is observed at Kothara (4.02 %) and Rajkot (9.05%), respectively. Comparison of annual rainfall with annual ET_0 shows that evaporative needs are higher than rainfall received in different agro-climatic zones of the state.

Table 4.9 Annual reference evapotranspiration (ET_0) under different agro-climatic zones of Gujarat

Station	Mean ET_0 , mm	Max. ET_0 , mm	Min. ET_0 , mm	SD, mm	CV, %
Kothara	1847.11	2012.58	1682.43	74.25	4.02
Radhanpur	1973.04	2174.15	1851.53	80.1	4.06
Rajkot	2026.55	2631.40	1768.82	183.39	9.05
Amreli	1914.25	2481.90	1698.84	155.54	8.13
SK Nagar	1731.56	1941.11	1406.39	122.51	7.08
Khedbrahma	1444.35	1676.03	1283.32	94.20	6.52
Arnej	1895.26	2035.78	1615.87	98.05	5.17
Dhandhuka	1874.20	2063.39	1607.60	100.87	5.38
Junagadh	1765.48	2172.88	1562.06	151.71	8.59
Mahuva	1729.17	1977.63	1544.96	108.83	6.29
Anand	1599.67	1752.60	1467.17	77.16	4.82
Nawagam	1690.34	2076.52	1293.48	141.77	8.39
Bharuch	1858.79	1687.85	1348.44	155.03	8.34
Surat	1624.72	1874.44	1728.26	99.63	6.13
Navsari	1571.27	1861.49	1362.96	111.22	7.08
Gandevi	1437.31	1609.72	1322.23	73.29	5.10

4.2.2 Weekly and Seasonal Reference Evapotranspiration

Variation of normal weekly reference evapotranspiration (ET_0) for different agro-climatic zones of Gujarat are shown in Figures 4.2 and also presented in Appendices C 1 to C 16. It is observed from Figures 4.2 that weekly ET_0 values start increasing from 20 to 30 mm in 4th to 7th smw to 41 to 67 mm in 18th to 21st smw in different agro-climatic zones.

The increase in ET_0 during summer period may be due to higher temperature, longer daylight length, lesser humidity and high windy conditions. ET_0 starts declining after start of rainy season and becomes minimum (15 to 28 mm) in winter season, may be due to lower temperature, higher humidity and shorter daylight lengths. It is interesting to note from Figure 4.2 that ET_0 values are in decreasing order as shifting towards northern, central, eastern and southern part of the state. In south, seasonal variability in ET_0 is smaller as compared to the other parts of the state. Amongst the stations selected for study. Rajkot and Gandevi observed the highest and lowest reference evapotranspiration, respectively.

Comparison of normal weekly ET_0 of different agro-climatic zones (Figures 4.2 and Appendices C1 to C 16) indicate a decreasing trend starting from Rajkot, Radhanpur, Amreli, Arnej, Dhandhuka, Kothara, Junagadh, SK Nagar, Mahuva, Nawagam, Bharuch, Surat, Anand, Navsari, Khedbrahma and to Gandevi. Higher values of weekly ET_0 were observed in rainy season at Radhanpur as compared to all other stations. This may be due to dry weather conditions prevailing at Radhanpur.

Mean seasonal reference evapotranspiration values at Kothara, Radhanpur, Rajkot, Amreli, SK Nagar, Khedbrahma, Arnej, Dhandhuka, Junagadh, Mahuva, Anand, Nawagam, Bharuch, Surat, Navsari, and Gandevi were found to be 631.46 mm, 693.89 mm, 655.59 mm, 598.51 mm, 658.17 mm, 510.28 mm, 641.65 mm, 634.17 mm, 514.08 mm, 557.97 mm, 563.52 mm, 584.50 mm, 548.70 mm, 530.51 mm, 492.36 mm, and 468.97 mm, respectively (Appendices C1 to C 16). Comparison of seasonal rainfall with seasonal ET_0 shows that normal evaporative demand of crops grown in rainy season is fulfilled at all the stations except Kothara, Radhanpur, Rajkot, Amreli, SK Nagar, Arnej, Dhandhuka and Mahuva.

4.3 MOISTURE STATUS UNDER DIFFERENT AGRO-CLIMATIC ZONES OF GUJARAT

The concept of climatic water balance has come to be understood universally as a basis for understanding the moisture status of a place (Kerkides et al., 1996). The weekly water balance elements for all the stations (16) under different agro-climatic zones have been computed by Thornthwaite and Mather (1955) method. Normal weekly water balance for different stations under study is presented in Appendices C1 to C 16. Estimated water balance elements at all the stations are used to study spatial and temporal variability of water deficit in

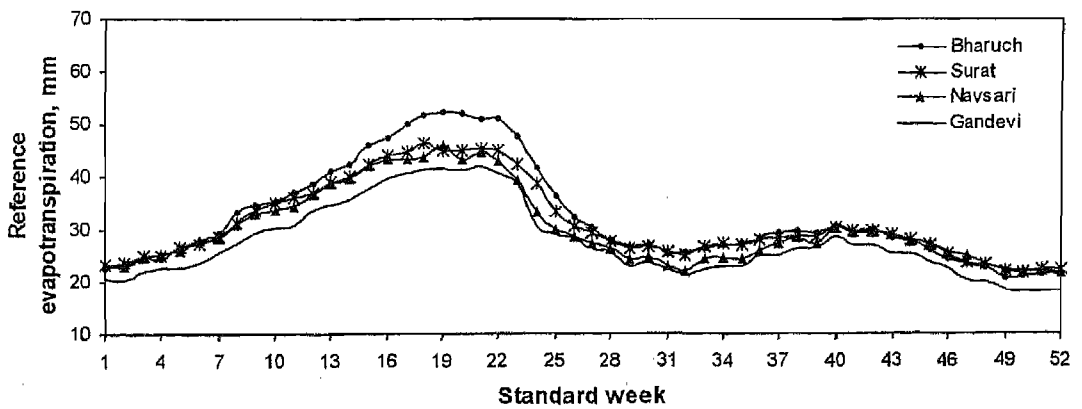
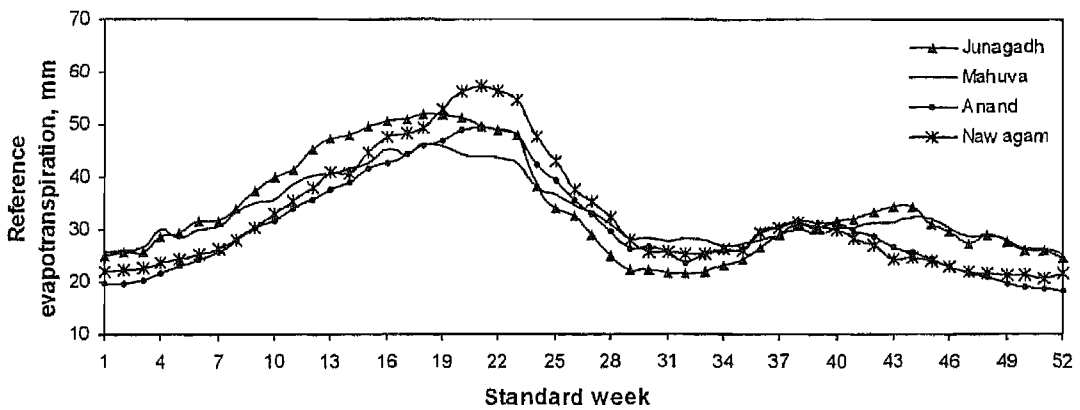
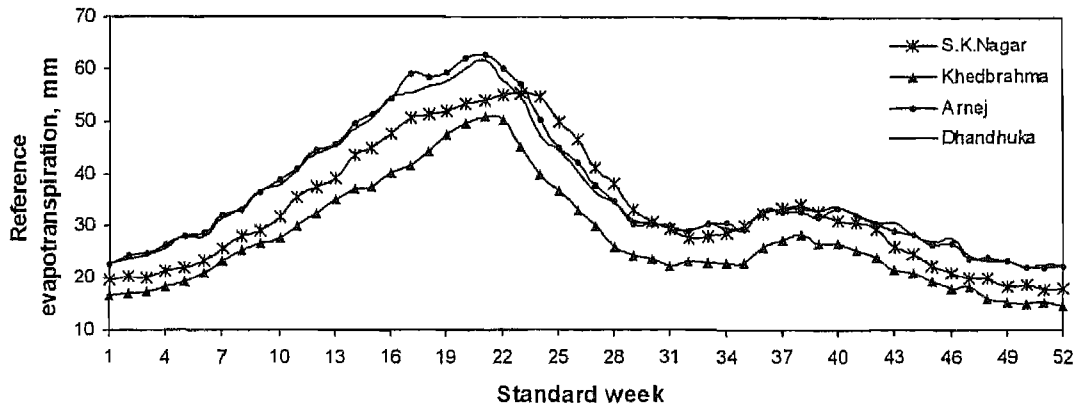
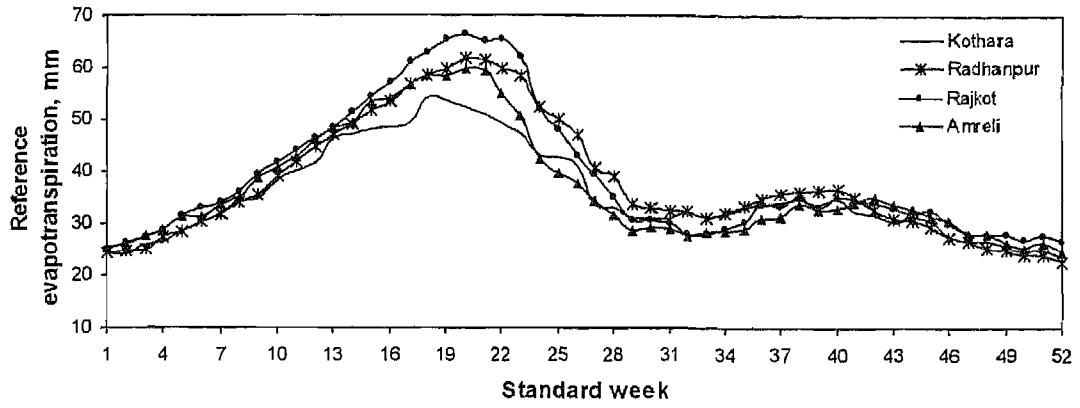


Fig. 4.2 Variation of weekly reference evapotranspiration at different stations

the state using geostatistical model. However, water balance for the selected stations representing respective agro-climatic zones are used to study moisture status in the state under the following sub-heads:

4.3.1 Annual Moisture Status

The elements of annual water balance for different rainfall years have been computed and are given for normal rainfall (near to average annual value), wettest and driest year in Table 4.10. It is seen from Table 4.10 that reference evapotranspiration (ET_0) at different stations during the normal year varies from 1414.9 mm (Gandevi) to 1992.6 mm (Radhanpur), while during the wettest and driest year it ranges from 1453.7 mm (Gandevi) to 1851.5 mm (Radhanpur) and 1514.3 mm (Gandevi) to 2481.9 mm (Amreli), respectively. The value of actual evapotranspiration (AET) during the normal year ranges from 215.3 mm at Radhanpur to 602.9 mm at Gandevi, while in wettest and driest year it ranges from 198.2 mm at Kothara to 765.6 mm at Arnej and 3.1 mm at Kothara to 515.4 mm at Surat, respectively.

The value of annual water deficit during the normal year ranges from 812.0 mm at Gandevi to 1777.3 mm at Radhanpur, while in the wettest and driest year it ranges from 875.2 mm at Gandevi to 1614.4 mm at Kothara and 1197.3 mm at Navsari to 2328.8 mm at Amreli, respectively. Table 4.10 also shows that water surplus during normal year ranges from 21.9 mm at Amreli to 1029.3 mm at Gandevi, while in the wettest and driest year it ranges from 220.5 mm at Dhandhuka to 2097.7 mm at Gandevi and 0.0 mm at all the stations [except Gandevi (75.4 mm) and Surat (71.7 mm)] to 203.7 mm at Navsari, respectively.

The above results of annual moisture status in different zones indicate that, high water deficit prevails during driest year followed by normal and wettest year. Similarly, surplus water (which includes both surface runoff and deep percolation) remains high during wettest year and very low to no in driest year, indicating corresponding moisture status in respective years.

4.3.2 Weekly Moisture Status

The weekly water balance parameters for different agro-climatic zones are shown in Figures 4.3a to 4.3d and are presented in Appendices C1 to C 16. Figure 4.3a shows the normal water balance at Kothara, Radhanpur, Rajkot and Amreli. It is observed from the Figure 4.3a that differences between reference (ET_0) and actual (AET) evapotranspiration decreases during 28th to 31st smw at Kothara and Radhanpur, from 28th to 33rd smw at Rajkot and from 28th to 35th smw at Amreli, which indicate the increasing moisture status (or decreasing water deficit) at the respective stations. The weekly water deficit during active crop growing period at Kothara, Radhanpur, Rajkot and Amreli varies from 13.73 to 25.44 mm, 12.08 to 24.94 mm, 5.80 to 16.02 and 6.84 to 14.00 mm, respectively (Appendices

Table 4.10 Annual water balance under different agro-climatic zones of Gujarat

Station	Category	Year	Rainfall, mm	ET ₀ , mm	AET, mm	Water deficit, mm	Water surplus, mm
Kothara	Normal year	1999	373.0	1771.7	285.9	1485.7	87.1
	Wettest year	1979	984.0	1812.3	198.2	1614.1	785.7
	Driest year	1987	3.0	1870.4	3.1	1867.3	0.0
Radhanpur	Normal year	1995	368.0	1992.6	215.3	1777.3	152.7
	Wettest year	1990	788.0	1851.5	384.7	1466.8	403.3
	Driest year	1999	44.0	2119.6	55.1	2064.5	0.0
Rajkot	Normal year	1992	568.6	1768.8	467.9	1300.9	100.7
	Wettest year	1979	1489.2	1775.5	525.6	1249.9	963.6
	Driest year	1985	177.0	2111.2	184.4	1926.8	0.0
Amreli	Normal year	1976	578.0	1953.4	556.1	1397.3	21.9
	Wettest year	1988	1365.4	1798.0	544.3	1253.7	821.1
	Driest year	1987	153.0	2481.9	153.1	2328.8	0.0
SK Nagar	Normal year	1976	653.4	1741.4	466.2	1275.2	187.2
	Wettest year	1994	1634.1	1406.4	436.0	970.4	1198.1
	Driest year	1987	68.4	1941.1	68.7	1872.4	0.0
Khedbrahma	Normal year	1988	719.5	1552.6	473.7	1078.9	245.8
	Wettest year	1994	1401.9	1433.2	403.9	1029.3	998.0
	Driest year	1987	185.1	1507.4	188.9	1318.5	0.0
Arnej	Normal year	1992	620.5	1932.4	466.4	1466.1	154.1
	Wettest year	1997	1041.7	1765.6	765.6	1000.1	276.1
	Driest year	1987	232.7	1939.6	234.5	1705.1	0.0
Dhandhuka	Normal year	1990	555.0	1883.4	503.9	1379.5	51.1
	Wettest year	1997	952.5	1760.0	732.0	1028.1	220.5
	Driest year	1987	215.0	2063.4	219.8	1843.6	0.0
Junagadh	Normal year	2001	848.1	1713.9	571.7	1142.2	276.4
	Wettest year	1980	1671.7	1716.3	522.3	1194.1	1149.4
	Driest year	1987	145.9	2122.0	148.8	1973.2	0.0
Mahuva	Normal year	1997	600.5	1769.8	573.0	1196.8	27.5
	Wettest year	1983	1058.7	1666.9	570.9	1096.1	487.8
	Driest year	1986	244.3	1926.0	247.0	1678.9	0.0
Anand	Normal year	1978	824.3	1602.8	480.4	1122.5	343.9
	Wettest year	1976	1633.0	1615.1	637.9	977.2	995.1
	Driest year	1986	286.9	1739.2	341.3	1398.0	0.0
Nawagam	Normal year	1984	790.2	1778.4	498.2	1280.2	292.0
	Wettest year	1994	1904.5	1506.5	446.7	1059.8	1457.8
	Driest year	1987	315.0	2076.5	314.9	1761.6	0.1
Bharuch	Normal year	2001	900.4	1790.1	575.9	1214.2	324.5
	Wettest year	1976	2083.8	1760.3	687.9	1072.4	1395.9
	Driest year	1974	266.2	1834.6	266.3	1568.4	0.0
Surat	Normal year	1982	1165.7	1658.9	521.2	1137.7	644.5
	Wettest year	1976	2387.5	1655.3	675.1	980.3	1712.4
	Driest year	1974	587.1	1728.3	515.4	1212.9	71.7
Navsari	Normal year	1984	1448.5	1605.3	523.6	1081.7	924.9
	Wettest year	2003	2436.6	1539.6	523.0	1016.7	1913.6
	Driest year	1974	715.4	1709.1	511.7	1197.3	203.7
Gandevi	Normal year	1996	1632.2	1414.9	602.9	812.0	1029.3
	Wettest year	1983	2676.3	1453.7	578.6	875.2	2097.7
	Driest year	1987	378.0	1514.3	302.6	1211.7	75.4

C1 to C 4). In some of the weeks during the rainy season, very low weekly surplus water values are observed at Kothara (0 to 22.61 mm), Radhanpur (0 to 19.51 mm), Rajkot (0 to 40.72 mm) and Amreli (0.38 to 20.30 mm), respectively.

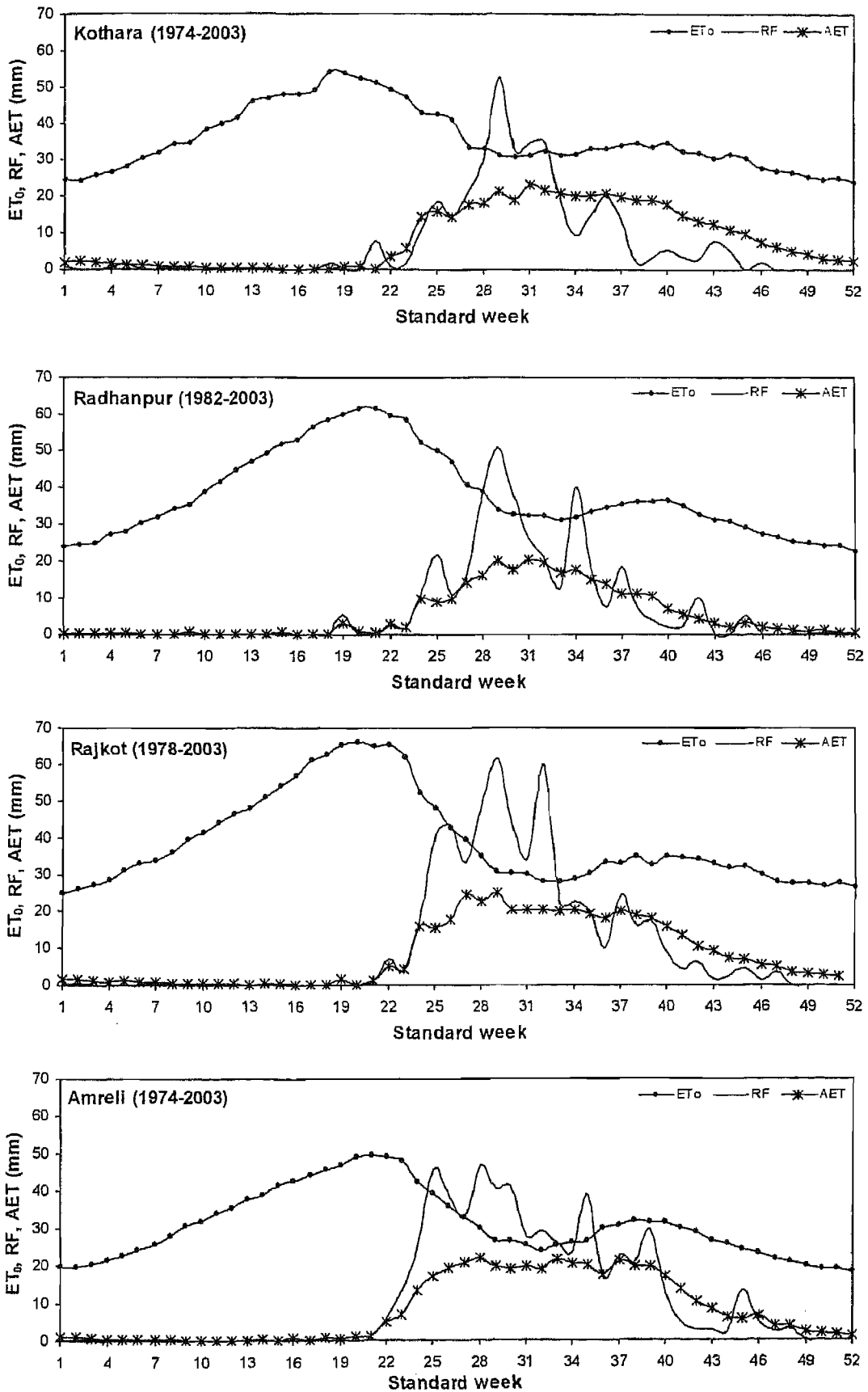


Fig. 4.3a Normal weekly water balance at Kothara, Radhanpur, Rajkot and Amreli

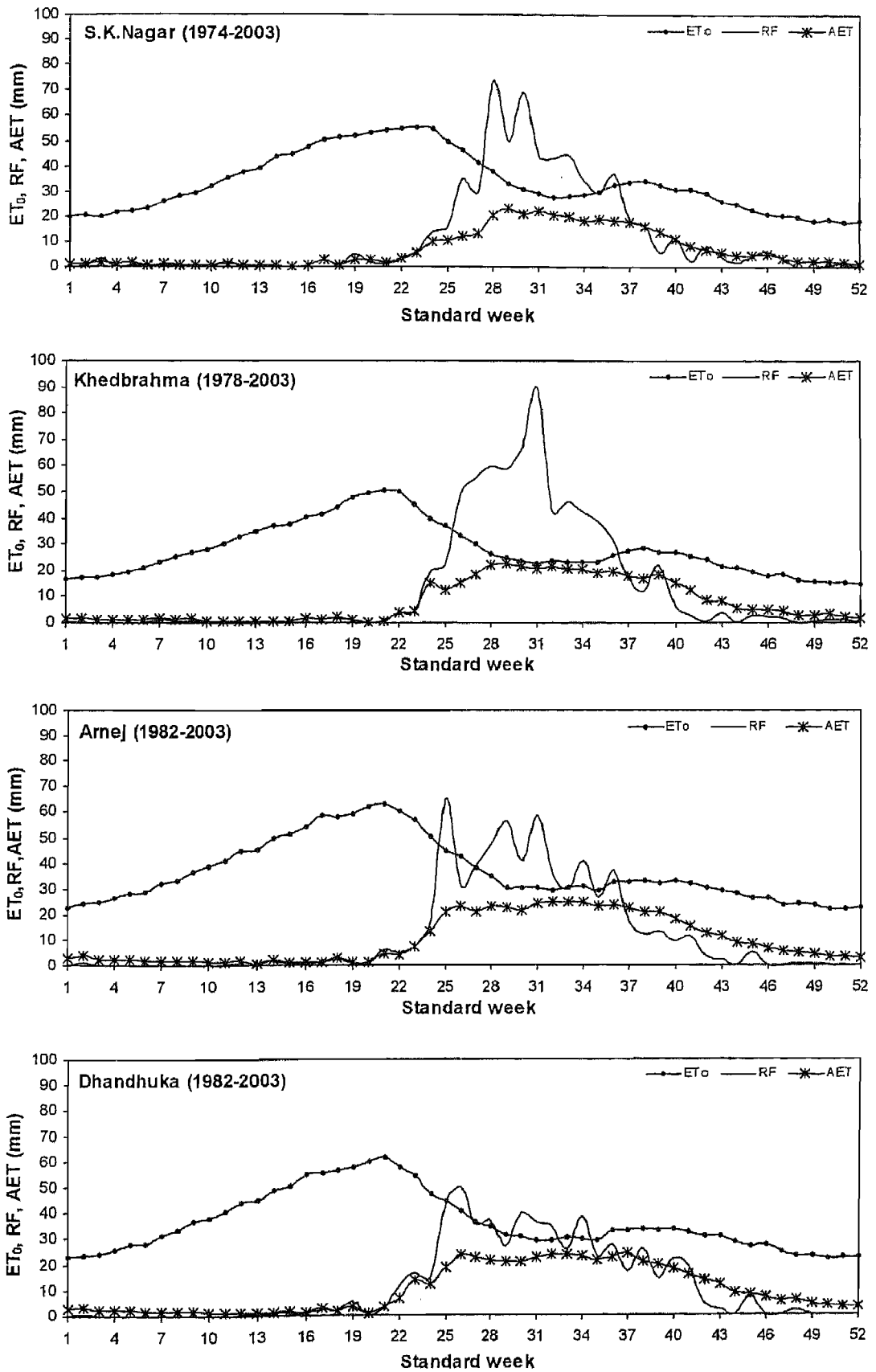


Fig. 4.3b Normal weekly water balance at S.K. Nagar, Khedbrahma, Arnej and Dhandhuka

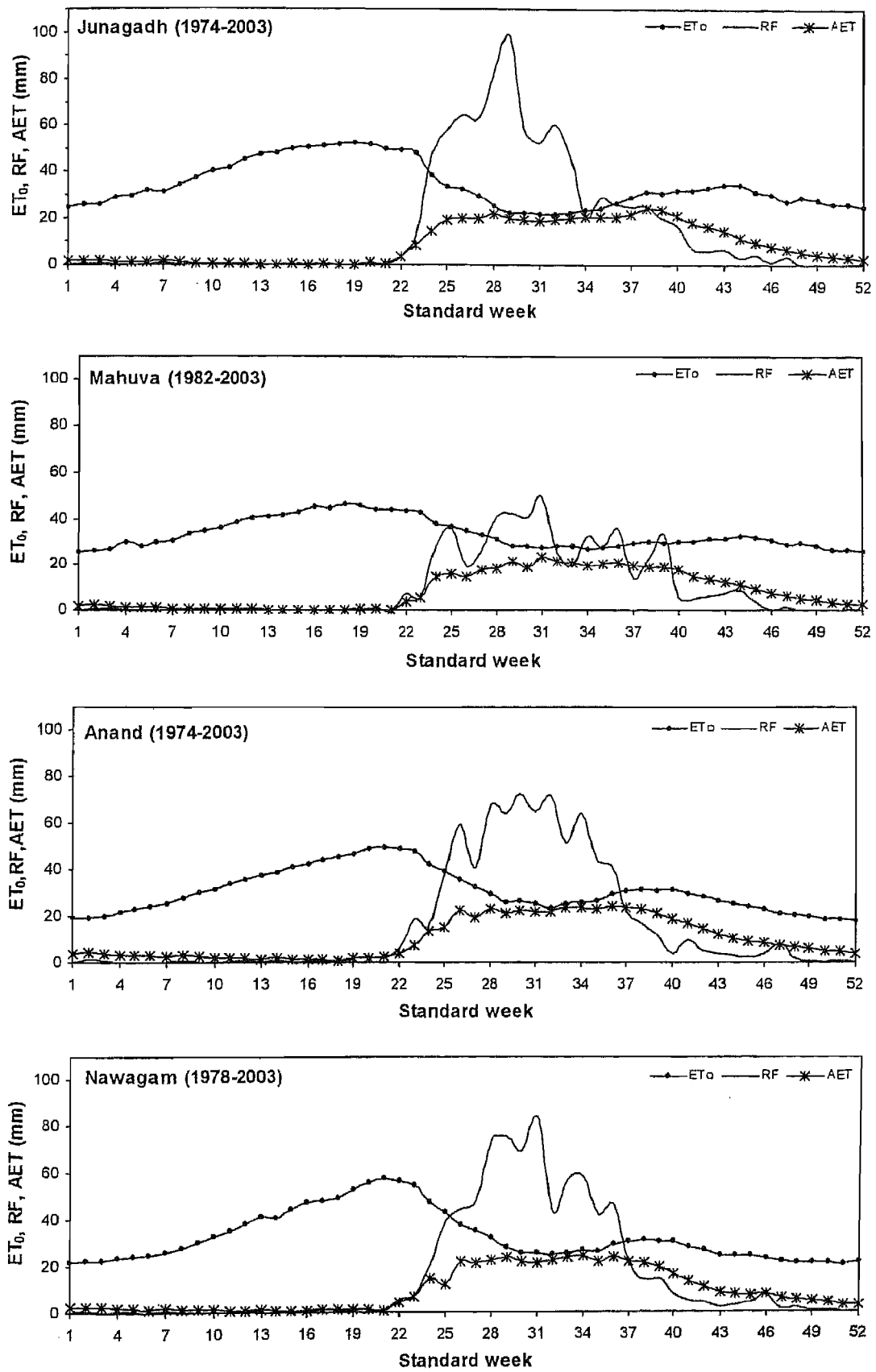


Fig. 4.3c Normal weekly water balance at Junagadh, Mahuva, Anand and Nawagam

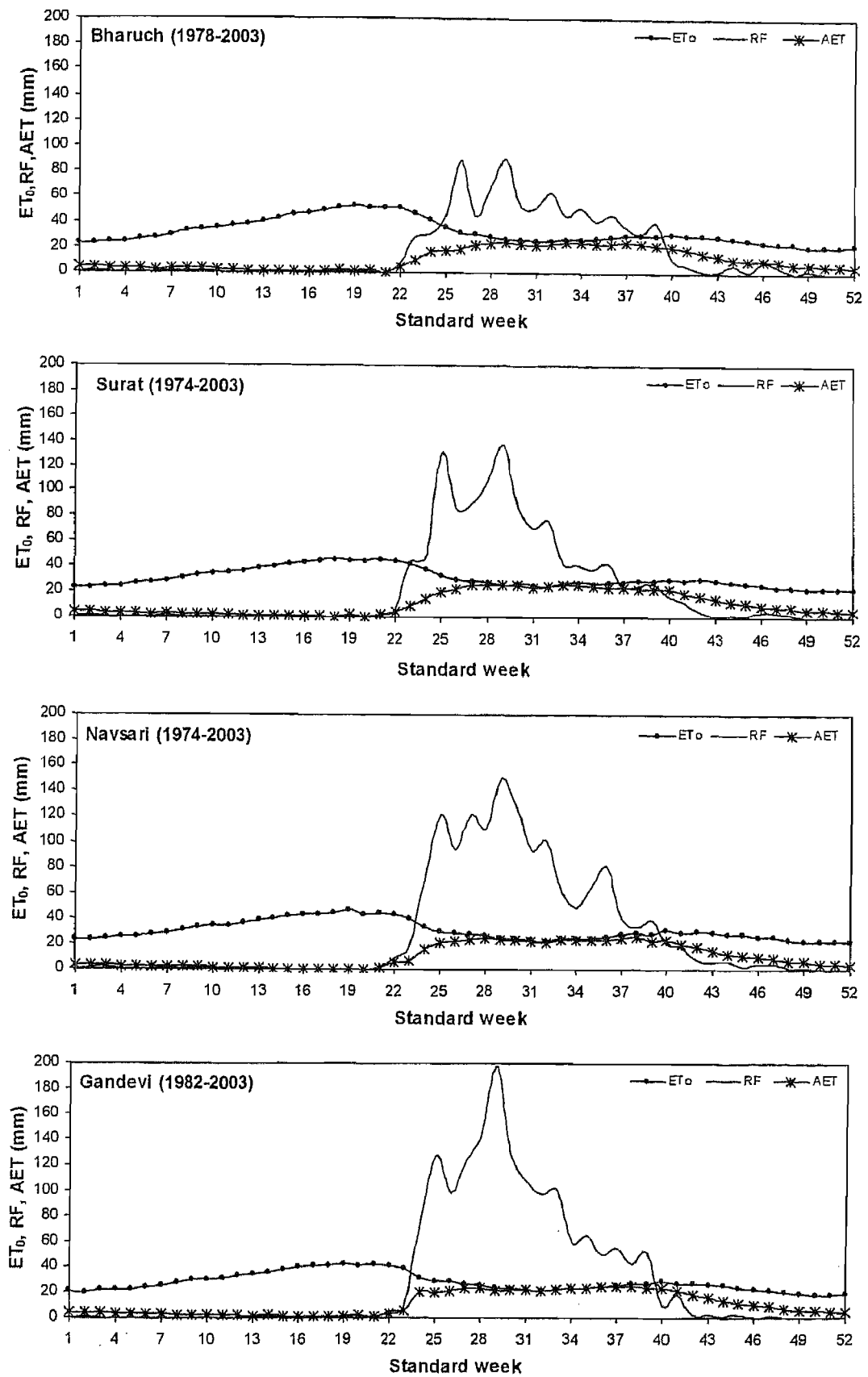


Fig. 4.3d Normal weekly water balance at Bharuch, Surat, Navsari and Gandevi

Figure 4.3b shows the normal water balance at SK Nagar, Khedbrahma, Arnej and Dhandhuka. It is observed from Figure 4.3b that rainfall during 28th to 35th smw is sufficient to meet the evaporative demand at all the stations but afterwards falls short resulting to slight water deficit at all the stations. The weekly water deficit at SK Nagar, Khedbrahma, Arnej and Dhandhuka varies from 7.16 to 18.30 mm, 1.76 to 11.81 mm, 4.24 to 11.91 mm and 5.28 to 12.79 mm, respectively during active crop growing period. Considerable surplus water is generated in the zones of SK Nagar, Khedbrahma, Arnej and Dhandhuka, which may be stored in soil to recharge ground water or runs off the field to contribute to surface storages and streams.

Figure 4.3c shows the normal water balance at Junagadh, Mahuva, Anand and Nawagam. It is seen from the Figure 4.3c that rainfall during 28th to 38th smw is sufficient to meet the evaporative demand at all the stations barring sporadic short fall resulting to slight water deficit at all the stations. The weekly water deficit at Junagadh, Mahuva, Anand and Nawagam varies from 2.16 to 7.47 mm, 4.74 to 13.01 mm, 1.95 to 8.35 mm and 1.56 to 10.09 mm, respectively during active crop growing period. During the season, considerable surplus water is generated in the zones of Junagadh, Mahuva, Anand and Nawagam, which may be stored in soil to recharge ground water or runs off the field to contribute to surface storages and streams.

Figure 4.3d shows the normal water balance at Bharuch, Surat, Navsari and Gandevi. It is observed from the Figure 4.3d that rainfall during 25th to 39th smw is sufficient to meet the evaporative demand at all the stations. The weekly water deficit at Bharuch, Surat, Navsari and Gandevi varies between 2.08 to 6.82 mm, 0.80 to 5.98 mm, 0.86 to 3.31 mm and 0.08 to 2.62 mm, respectively during active crop growing period. During the season, considerable surplus water is generated in the zones of Bharuch, Surat, Navsari and Gandevi, which may be stored in soil to recharge ground water or runs off the field to contribute to surface storages and streams.

The results for different agro-climatic zones indicate that under normal condition, moisture status at all the stations (Khedbrahma, Anand, Nawagam, Bharuch, Surat, Navsari and Gandevi) situated in half of the eastern part of the state is sufficient for satisfactory growth of rainfed crops, whereas, all the stations located in the other half (western part, includes SK Nagar, Arnej, Dhandhuka, Mahuva, Junagadh, Radhanpur and Kothara) experienced moisture deficit during the crop growth period. However, it is seen from Section 4.1.3 that the distribution of weekly rainfall is highly erratic and uncertain resulting to moisture stress of different categories in different agro-climatic zones.

4.3.3 Mean Aridity Index

A better understanding of moisture status can be studied using water deficit parameter in comparison with reference evapotranspiration. The aridity index (I_a) has been worked out as percentage ratio of water deficit and water need. The mean aridity index and droughtiness factor [worked out as $(I_{a\max} - I_{a\min}) / I_{a\text{mean}}$] for different zones are shown in Table 4.11.

Table 4.11 Mean aridity index and droughtiness factor under different agro-climatic zones of Gujarat

Station	Latitude, °N	Longitude, °E	Mean Aridity index, %	Standard deviation, %	Coefficient of variation, %	Droughti- ness factor
Kothara	23.16	68.93	85.83	6.68	7.78	0.35
Radhanpur	23.82	71.55	83.53	7.19	8.60	0.26
Rajkot	22.28	70.80	73.39	8.44	11.50	0.45
Amreli	21.60	71.20	73.37	7.65	10.43	0.42
SK Nagar	24.32	72.32	76.22	8.74	11.46	0.45
Khedbrahma	24.05	73.00	68.29	6.58	9.63	0.43
Arnej	22.63	72.32	67.45	7.10	10.52	0.42
Dhandhuka	22.40	71.98	68.46	7.68	11.22	0.53
Junagadh	21.52	70.50	65.81	7.23	10.99	0.58
Mahuva	21.08	71.80	71.07	8.38	11.79	0.43
Anand	22.58	72.97	66.97	11.64	17.39	1.21
Nawagam	22.72	72.55	66.69	6.81	10.20	0.45
Bharuch	21.68	73.00	61.21	7.55	12.33	0.56
Surat	21.20	72.83	59.66	6.45	10.74	0.19
Navsari	20.93	72.90	59.29	5.14	8.67	0.36
Gandevi	20.80	73.00	55.71	6.68	11.99	0.55

Table 4.11 reveals that the highest mean aridity index of 85.83 per cent with CV of 7.78 per cent was observed at Kothara, while the lowest of 55.71 per cent with CV of 11.99 per cent was observed at Gandevi. The mean aridity index (Table 4.11) decreases from Kothara towards east and south direction in the state. It is also seen from Table 4.11 that the droughtiness factor varies between 0.19 (Surat) to 1.21 (Anand), generally in proportion with CV of corresponding aridity indices. Droughtiness factors thus clearly indicate the variability of aridity indices at respective stations during the study period.

Figures 4.4a and 4.4b show the meridional variation of mean aridity index and droughtiness factor in the state. It is visualized from the Figure 4.4a that mean aridity index shows slight declining trend in high rainfall zone. The droughtiness factors as depicted in Figure 4.4b do not follow any specific trend.

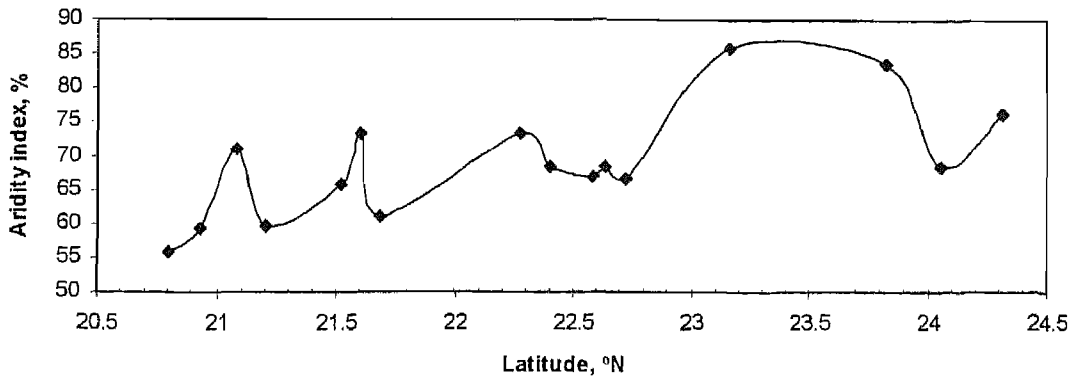
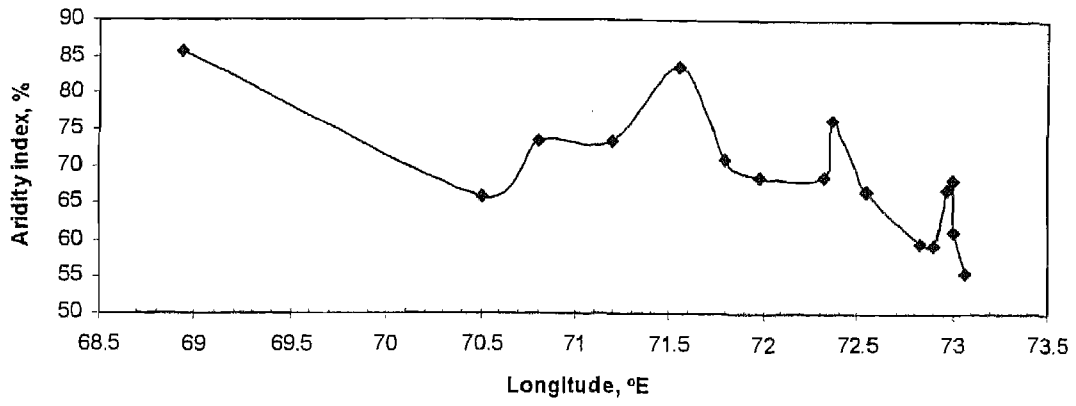


Fig. 4.4a Meridional variation of aridity index in Gujarat

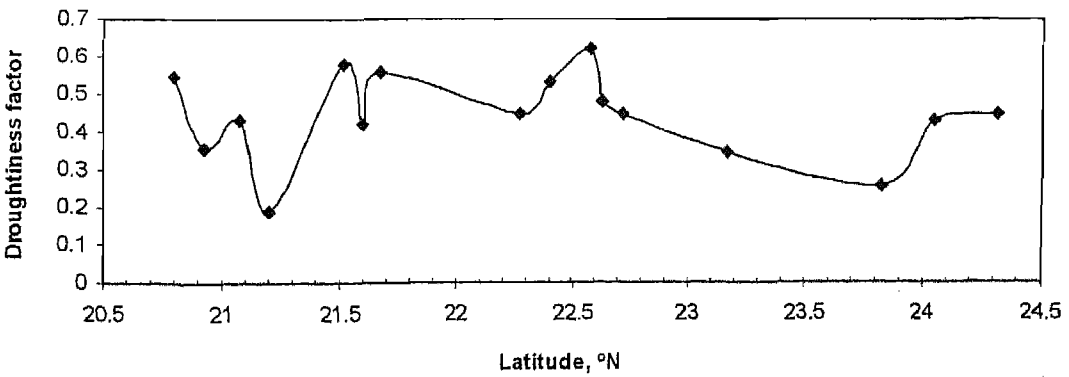
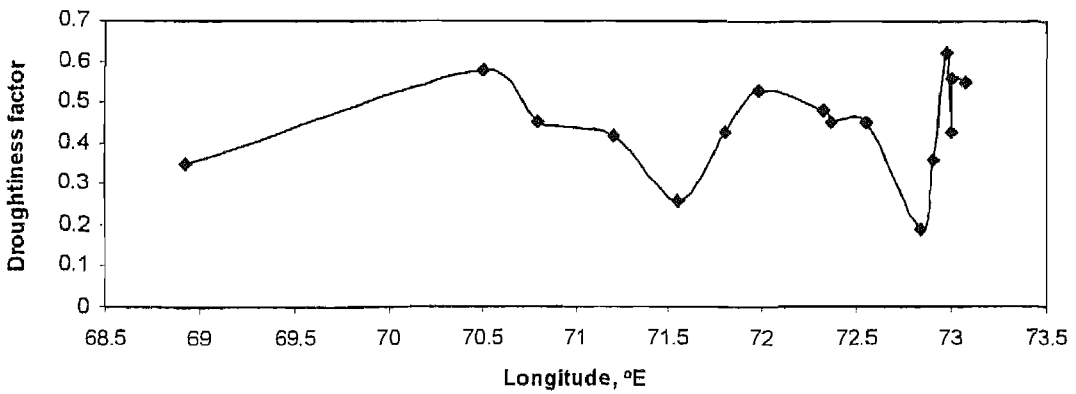


Fig. 4.4b Meridional variation of droughtiness factor in Gujarat

4.3.4 Climatic Shift

The moisture index, which is the basis for climatic classification has been studied for year to year change in the climate. Such diagrams for different agro-climatic zones are presented from Figures 4.5a to 4.5d. These figures indicate the fluctuation of moisture index (I_m) in different years of study period. Climatic conditions at different stations are given in Table 4.12.

It is observed from Table 4.12 that the climate at Kothara and Radhanpur was stable in arid condition, as more than 75 per cent years were arid. The climatic condition at Rajkot, Amreli, SK Nagar and Mahuva was found to swing from arid to semi-arid for 34.61, 36.66, 40.0 and 36.36 % years, and to dry sub-humid for 7.69, 13.33, 10.0 and 9.09 % years, respectively. The climatic condition for Amreli and SK Nagar was shifted to moist sub-humid each for 3.33 % years. Similarly, climatic condition of Rajkot and SK Nagar was shifted to humid for 3.85 and 3.33 % years, respectively.

Table 4.12 Climatic conditions under different agro-climatic zones of Gujarat

Station	Arid	Semi arid	Dry sub humid	Moist sub humid	Humid	Total year
	Number of years of shift					
Kothara	23	7	0	0	0	30
Radhanpur	17	5	0	0	0	22
Rajkot	14	9	2	0	1	26
Amreli	14	11	4	1	0	30
SK Nagar	13	12	3	1	1	30
Khedbrahma	5	12	8	0	1	26
Arnej	8	14	0	0	0	22
Dhandhuka	10	12	0	0	0	22
Junagadh	3	14	7	2	4	30
Mahuva	12	8	2	0	0	22
Anand	4	14	9	2	1	30
Nawagam	2	14	6	2	2	26
Bharuch	3	11	10	3	3	30
Surat	0	8	10	4	8	30
Navsari	0	1	8	6	15	30
Gandevi	1	0	1	7	13	22

The semi-arid climatic condition at Arnej (63.63 % years) and Dhandhuka (54.54 % years) was found to swing towards arid condition for 36.36 and 45.45 % years, respectively.

Khedbrahma, Junagadh, Anand, Nawagam and Bharuch mostly experienced semi-arid to dry sub-humid climatic condition. The semi arid condition of Khedbrahma (46.15 % years) was found to swing towards arid, dry sub-humid and humid condition for 19.23, 30.77 and 3.84 % years, respectively. Similarly, the semi-arid climatic condition of Junagadh (46.67% years), Anand (46.67% years), Nawagam (53.84 % years) and Bharuch (36.67 % years) also found to swing towards arid 10.0, 13.33, 7.69 and 10.0 % years; dry sub-humid

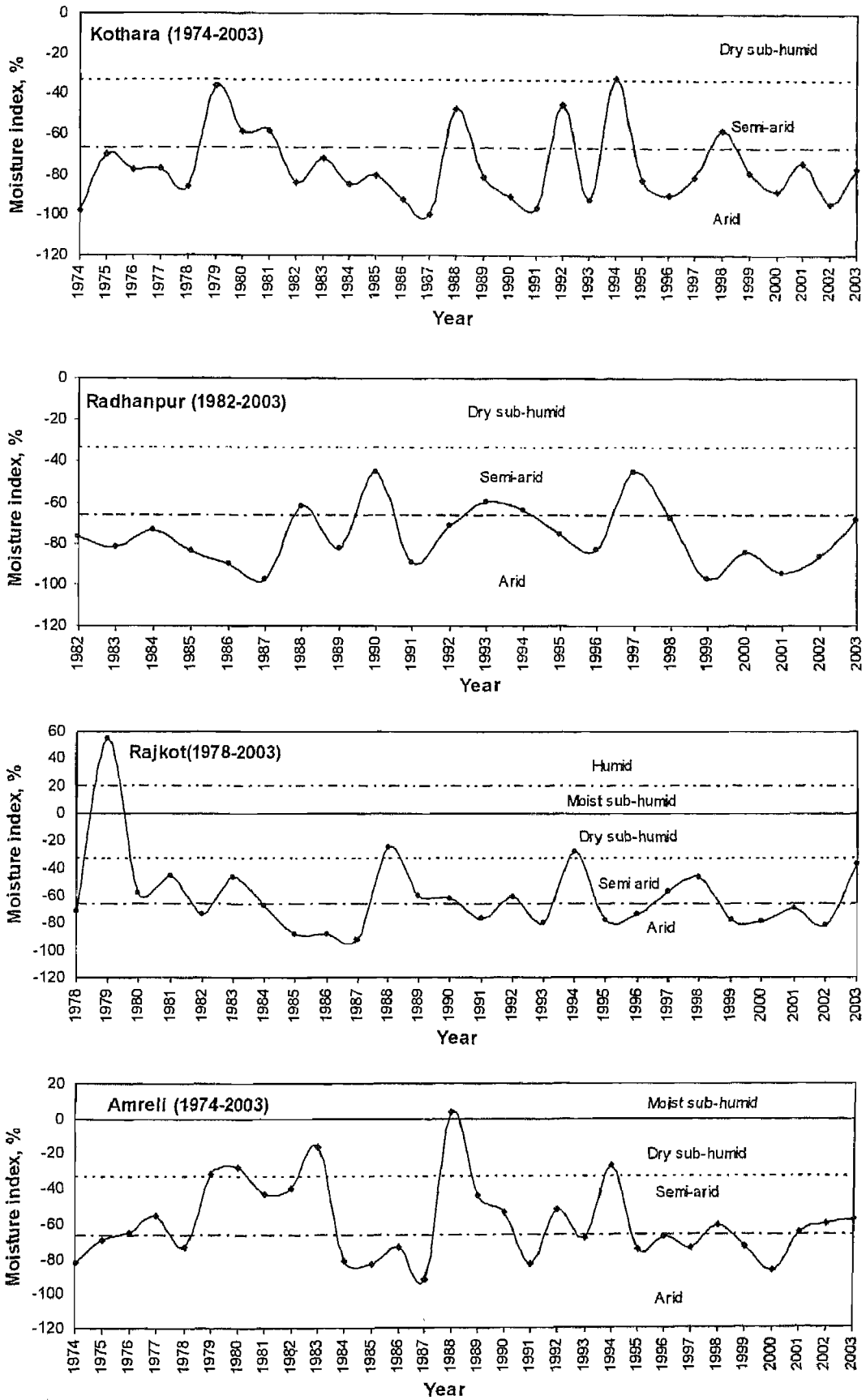


Fig. 4.5a Climatic shift at Kothara, Radhanpur, Rajkot and Amreli

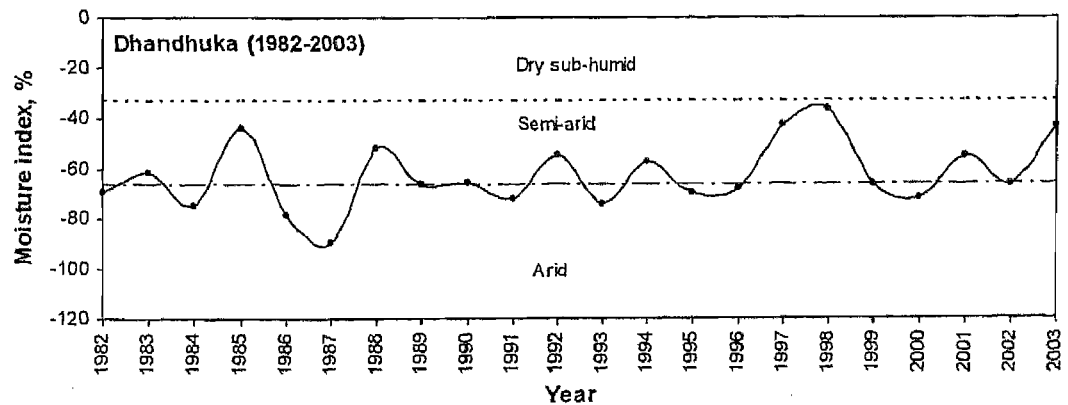
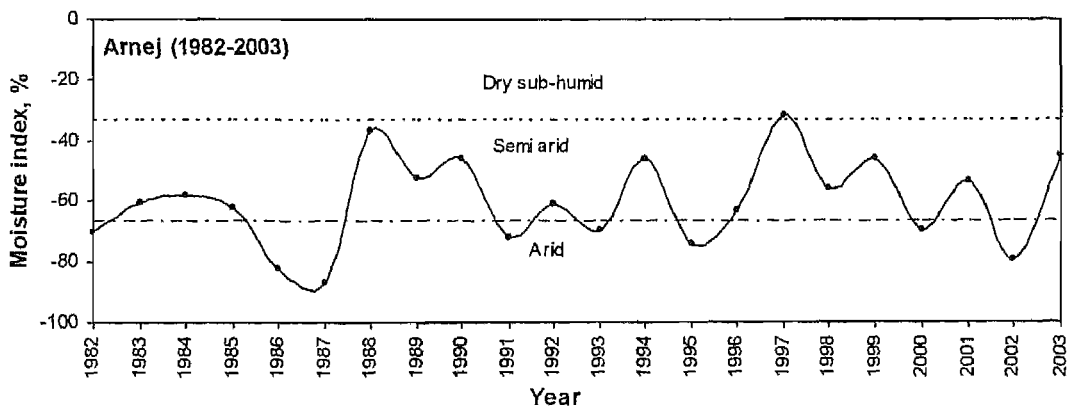
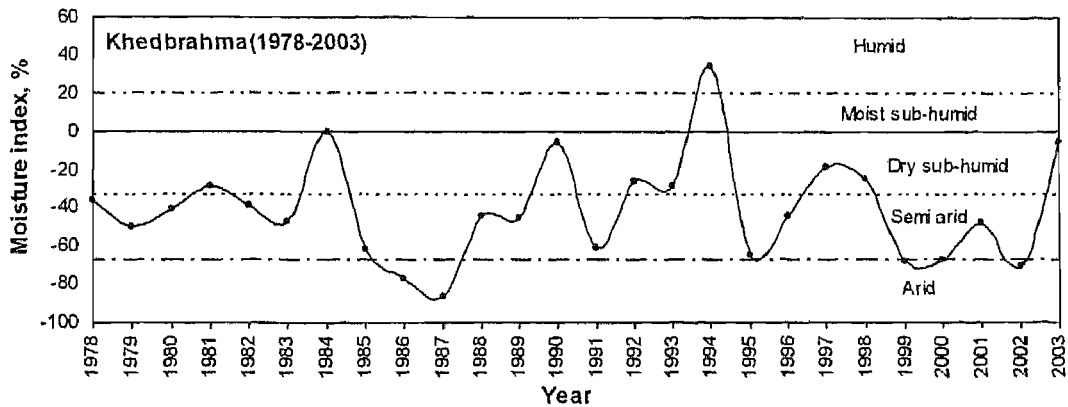
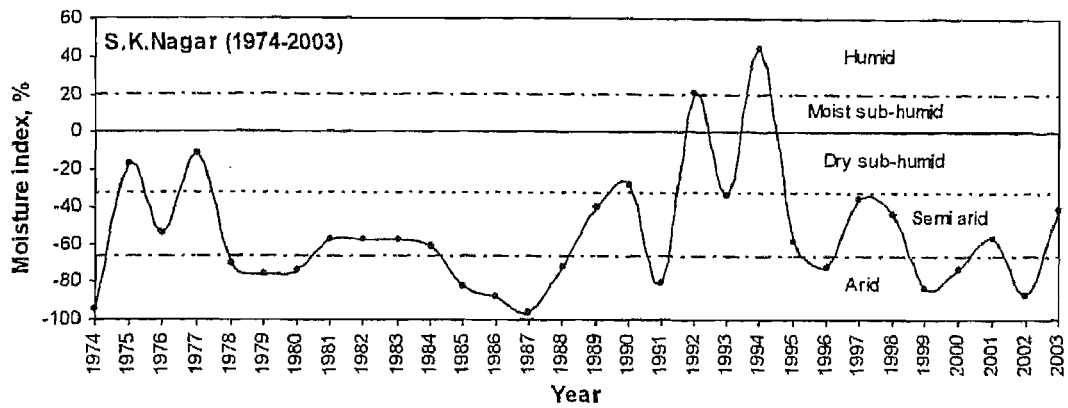


Fig. 4.5b Climatic shift at S.K. Nagar, Khedbrahma, Arnej and Dhandhuka

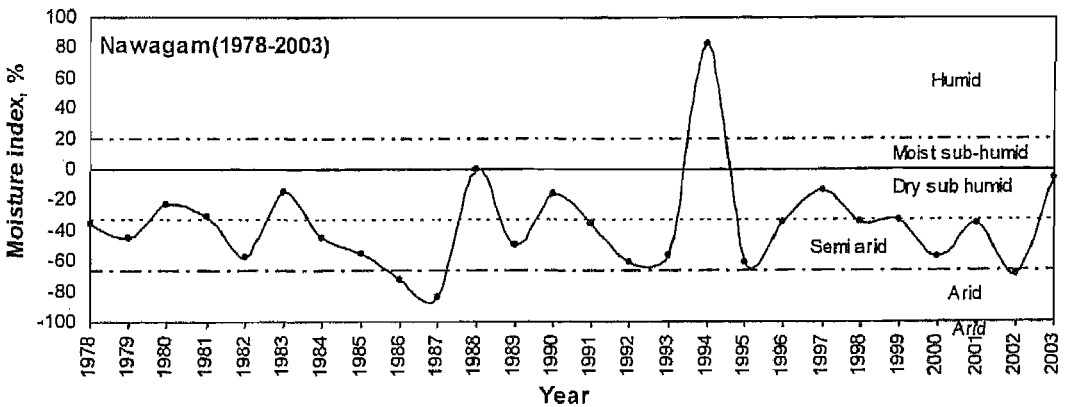
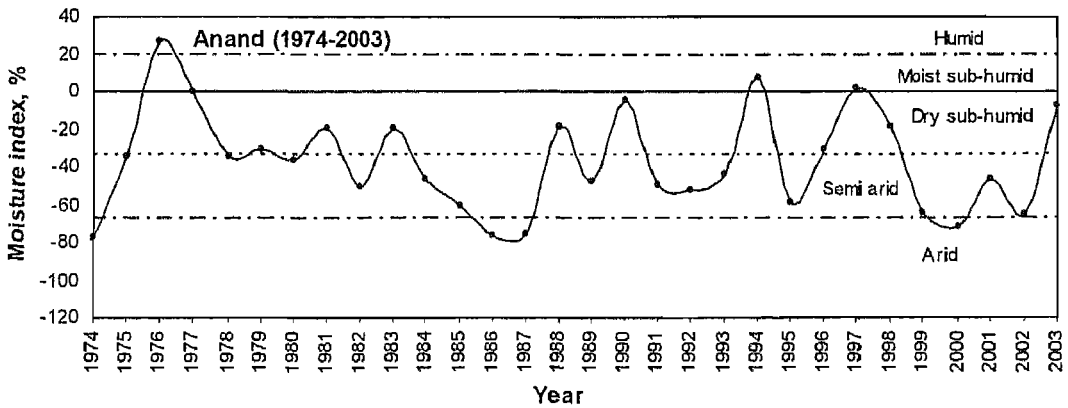
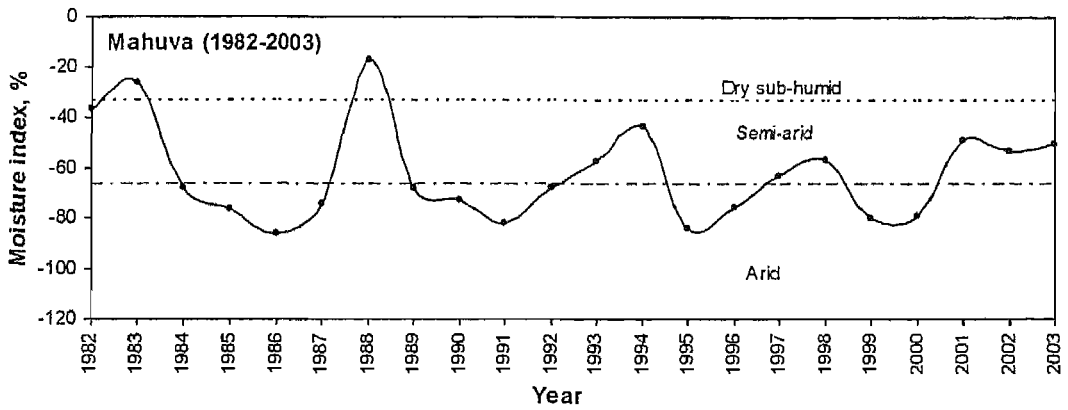
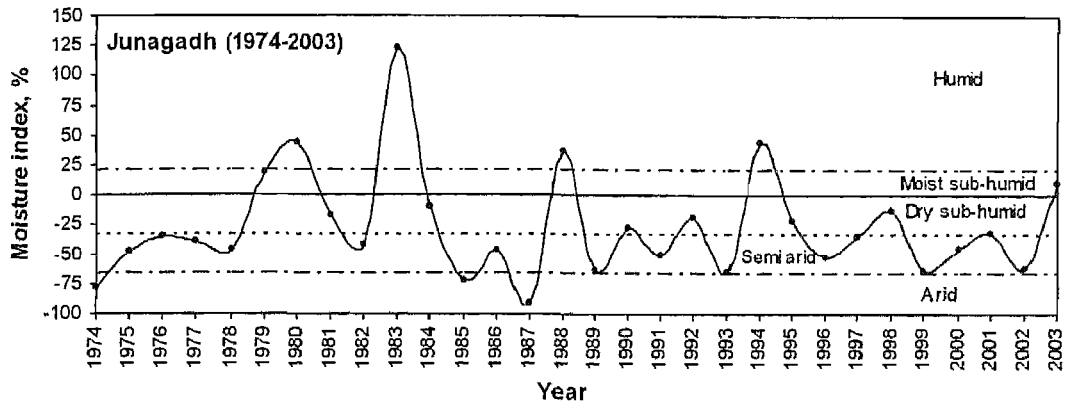


Fig. 4.5c Climatic shift at Junagadh, Mahuva, Anand and Nawagam

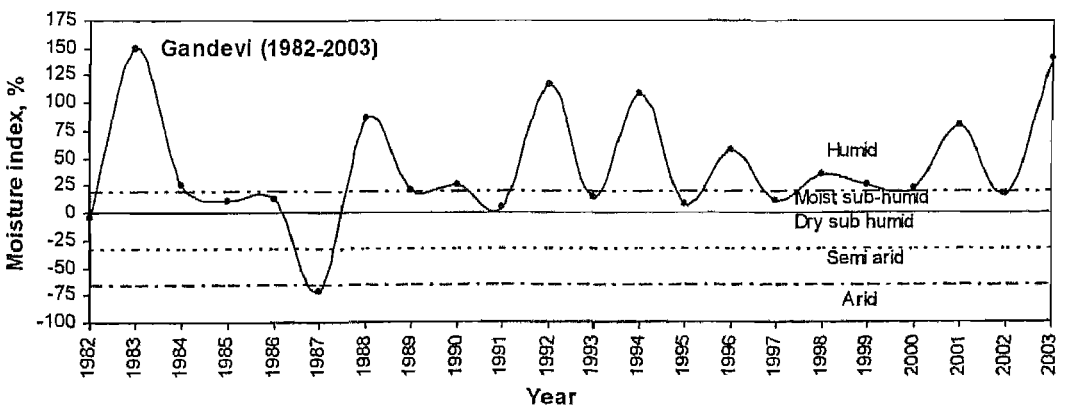
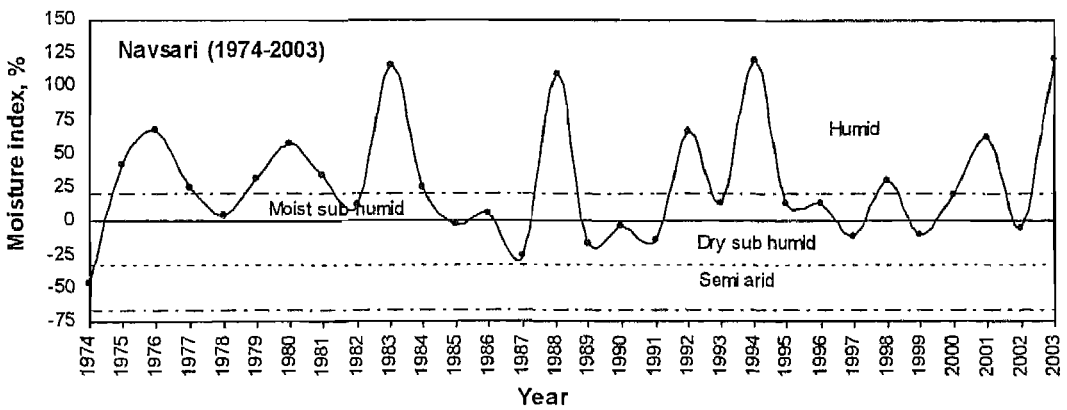
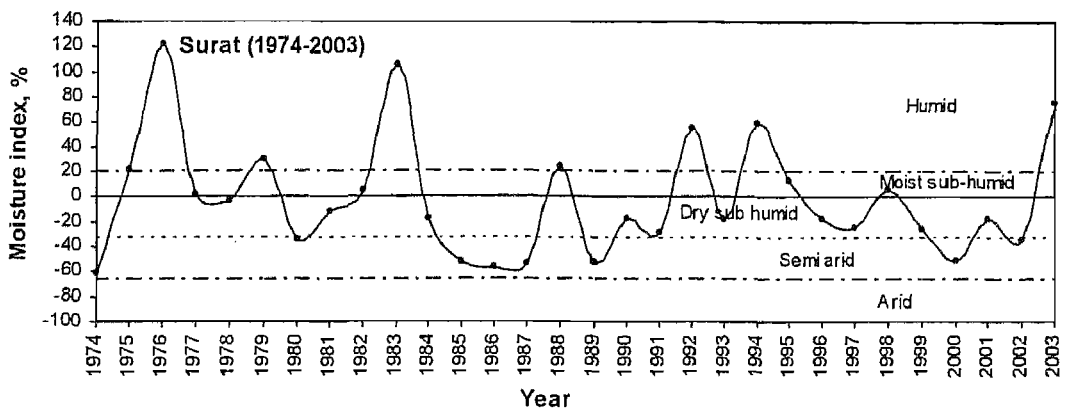
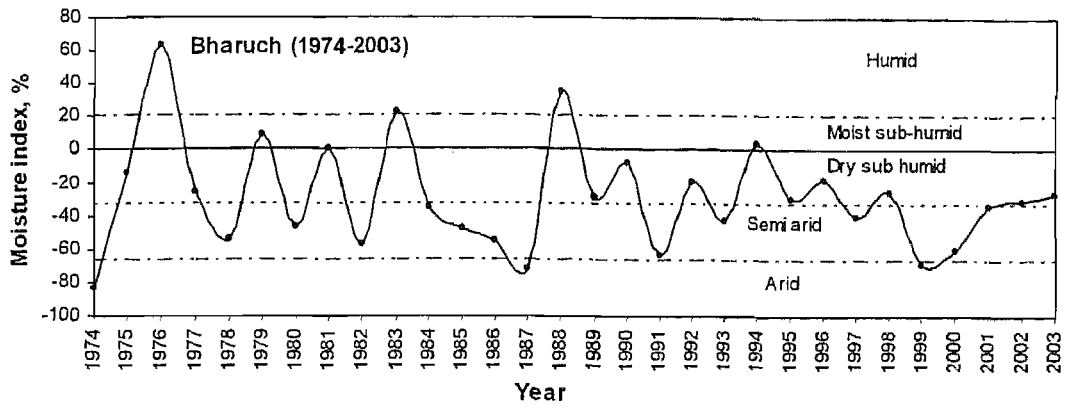


Fig. 4.5d Climatic shift at Bharuch, Surat, Navsari and Gandevi

23.33, 30.0, 23.07 and 33.33 % years; moist sub-humid 6.67, 6.67, 7.69 and 10.0 % years and humid 13.33, 3.33, 7.69 and 10.0 % years, respectively.

The dry sub-humid condition of Surat (33.33 % years) was shifted to semi-arid, moist sub-humid and humid for 26.67, 13.33 and 26.67 % years, respectively. Similarly, the humid condition of Navsari (50.0 %) and Gandevi (59.09 %) were found to swing to moist sub-humid for 20.0 and 31.82 and dry sub-humid for 26.67 and 4.45 % years, respectively. Navsari also experienced semi-arid condition for 3.33 % years, whereas Gandevi experienced arid condition for 4.54 % years.

Thus, Kothara and Radhanpur (north-west Gujarat) were found to be predominantly in arid climate, Bharuch, Surat, Navsari and Gandevi (South Gujarat) in humid (dry sub-humid to humid) climate and rest of the stations in semi-arid climatic condition.

4.3.5 Surplus Water

The quantity of surplus water generated during different weeks was estimated in climatic water balance study (Section 3.5) at different agro-climatic zones and the normal values are presented in Appendices C1 to C 16. The probabilities of occurrence of surplus water of 20, 40, 60, 80 and 100 mm during different weeks of the rainy season in different agro-climatic zones are presented in Tables 4.13a to 4.13p.

Tables 4.13a to 4.13p show that during the rainy season, probability of 20 mm surplus water ranges between 0.0 to 16.67 percent in arid areas (Kothara and Radhanpur); 0.0 to 72.72 percent in humid areas (Bharuch, Surat, Navsari and Gandevi) and 0.0 to 57.69 percent at rest of the stations located in semi arid areas. Similarly, the probability of 60 mm surplus water varies between 0.0 to 13.33, 0.00 to 30.77 and 0.0 to 63.63 percent, respectively in arid, semi arid and humid areas. The results also revealed that chances of 100 mm surplus water are very low (probability < 10 percent) in arid areas followed by semi arid areas (probability up to 26.92 percent). However, in humid areas the chances of 100 mm surplus water in the mid season are high (probability up to 59.09 percent).

Thus, the results of surplus water availability in different agro-climatic zones (Tables 4.13a to 4.13p) indicate that there are chances of getting excess water in rainy season in all the zones, which can be effectively harvested and used in water deficit periods.

4.4 DROUGHT CHARACTERIZATION

The nature of drought depends upon the amount and distribution of rainfall and its matching with the crop-water need. Drought occurs due to deficit of water, which happens when precipitation fails to meet the water need or the evaporative demand. For characterization of drought in different zones, intensity and duration of drought has been determined by the use of aridity index (I_a) anomalies estimated on weekly and annual basis.

Table 4.13a Probability (%) of surplus water during rainy season at Kothara

Std. met. week	Surplus water				
	20 mm	40 mm	60 mm	80 mm	100 mm
23	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00
25	3.33	3.33	3.33	3.33	3.33
26	3.33	3.33	3.33	3.33	3.33
27	3.33	3.33	3.33	3.33	3.33
28	15.38	11.54	11.54	11.54	7.69
29	10.00	10.00	6.67	6.67	6.67
30	16.67	13.33	13.33	10.00	10.00
31	6.67	6.67	6.67	6.67	6.67
32	10.00	10.00	10.00	3.33	3.33
33	6.67	3.33	0.00	0.00	0.00
34	0.00	0.00	0.00	0.00	0.00
35	10.00	6.67	6.67	0.00	0.00
36	10.00	10.00	6.67	6.67	6.67
37	10.00	3.33	3.33	3.33	3.33
38	10.00	6.67	0.00	0.00	0.00
39	0.00	0.00	0.00	0.00	0.00
40	6.67	6.67	0.00	0.00	0.00

Table 4.13b Probability (%) of surplus water during rainy season at Radhanpur

Std. met. Week	Surplus water				
	20 mm	40 mm	60 mm	80 mm	100 mm
23	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00
25	9.09	9.09	4.54	0.00	0.00
26	0.00	0.00	0.00	0.00	0.00
27	0.00	0.00	0.00	0.00	0.00
28	4.54	4.54	4.54	4.54	4.54
29	9.09	9.09	9.09	9.09	9.09
30	9.09	9.09	9.09	4.54	4.54
31	9.09	4.54	0.00	0.00	0.00
32	4.54	4.54	0.00	0.00	0.00
33	0.00	0.00	0.00	0.00	0.00
34	9.09	9.09	9.09	9.09	4.54
35	9.09	9.09	9.09	4.54	4.54
36	0.00	0.00	0.00	0.00	0.00
37	9.09	9.09	4.54	4.54	4.54
38	0.00	0.00	0.00	0.00	0.00
39	0.00	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00	0.00

Table 4.13c Probability (%) of surplus water during rainy season at Rajkot

Std. met. week	Surplus water				
	20 mm	40 mm	60 mm	80 mm	100 mm
23	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00
25	3.85	3.85	3.85	3.85	3.85
26	11.54	11.54	7.69	7.69	0.00
27	3.85	3.85	3.85	0.00	0.00
28	7.69	7.69	7.69	7.69	7.69
29	19.23	11.54	11.54	3.85	3.85
30	23.07	15.38	15.38	7.69	3.85
31	19.23	11.54	3.85	3.85	0.00
32	23.07	15.38	7.69	7.69	7.69
33	7.69	7.69	0.00	0.00	0.00
34	7.69	7.69	3.85	0.00	0.00
35	3.85	3.85	3.85	3.85	3.85
36	3.85	3.85	3.85	3.85	0.00
37	3.85	3.85	3.85	3.85	3.85
38	0.00	0.00	0.00	0.00	0.00
39	0.00	0.00	0.00	0.00	0.00
40	3.85	0.00	0.00	0.00	0.00

Table 4.13d Probability (%) of surplus water during rainy season at Amreli

Std. met. Week	Surplus water				
	20 mm	40 mm	60 mm	80 mm	100 mm
23	0.00	0.00	0.00	0.00	0.00
24	6.67	0.00	0.00	0.00	0.00
25	10.00	6.67	6.67	6.67	3.33
26	10.00	6.67	6.67	6.67	6.67
27	6.67	3.33	3.33	3.33	3.33
28	16.67	13.33	13.33	6.67	6.67
29	13.33	10.00	6.67	3.33	3.33
30	20.00	13.33	13.33	10.00	6.66
31	10.00	10.00	6.67	3.33	3.33
32	10.00	6.67	6.67	6.67	6.67
33	13.33	6.67	0.00	0.00	0.00
34	6.67	6.67	3.33	3.33	0.00
35	16.67	16.67	6.67	6.67	3.33
36	13.33	13.33	6.67	6.67	3.33
37	6.67	3.33	3.33	0.00	0.00
38	6.67	6.66	3.33	0.00	0.00
39	13.33	6.66	3.33	3.33	0.00
40	3.33	0.00	0.00	0.00	0.00

Table 4.13e Probability (%) of surplus water during rainy season at SK Nagar

Std. met. week	Surplus water				
	20 mm	40 mm	60 mm	80 mm	100 mm
23	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00
26	10.00	10.00	10.00	3.33	3.33
27	6.67	6.67	6.67	6.67	6.67
28	23.33	20.00	20.00	20.00	16.67
29	10.00	6.67	6.67	6.67	3.33
30	23.33	13.33	13.33	13.33	13.33
31	16.67	13.33	10.00	6.67	6.67
32	26.67	16.67	13.33	6.67	3.33
33	23.33	20.00	16.67	13.33	6.67
34	10.00	10.00	10.00	10.00	10.00
35	20.00	16.67	13.33	3.33	0.00
36	16.67	10.00	6.67	6.67	6.67
37	10.00	10.00	6.67	0.00	0.00
38	6.67	6.67	3.33	3.33	3.33
39	0.00	0.00	0.00	0.00	0.00
40	3.33	3.33	3.33	3.33	3.33

Table 4.13f Probability (%) of surplus water during rainy season at Khedbrahma

Std. met. Week	Surplus water				
	20 mm	40 mm	60 mm	80 mm	100 mm
23	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00
26	11.54	7.69	7.69	7.69	7.69
27	15.38	15.38	11.54	11.54	3.85
28	26.92	26.92	19.23	11.54	7.69
29	11.54	11.54	7.69	7.69	3.85
30	42.30	30.77	23.07	7.69	3.85
31	57.69	46.15	38.46	23.07	23.07
32	30.77	23.07	23.07	11.54	3.85
33	30.77	23.07	19.23	11.54	3.85
34	34.61	23.07	19.23	11.54	11.54
35	23.07	23.07	23.07	23.07	15.38
36	11.54	7.69	7.69	7.69	7.69
37	11.54	11.54	7.69	7.69	3.85
38	3.85	3.85	3.85	3.85	3.85
39	7.69	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00	0.00

Table 4.13g Probability (%) of surplus water during rainy season at Arnej

Std. met. week	Surplus water				
	20 mm	40 mm	60 mm	80 mm	100 mm
23	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00
25	4.54	0.00	0.00	0.00	0.00
26	4.54	4.54	4.54	4.54	4.54
27	4.54	4.54	4.54	4.54	4.54
28	9.09	9.09	9.09	4.54	4.54
29	18.18	18.18	13.63	13.63	13.63
30	13.63	9.09	9.09	4.54	0.00
31	13.63	13.63	9.09	9.09	0.00
32	18.18	13.63	9.09	0.00	0.00
33	13.63	9.09	9.09	4.54	4.54
34	13.63	13.63	9.09	9.09	9.09
35	13.63	13.63	0.00	0.00	0.00
36	13.63	9.09	9.09	9.09	4.54
37	4.54	0.00	0.00	0.00	0.00
38	0.00	0.00	0.00	0.00	0.00
39	0.00	0.00	0.00	0.00	0.00
40	4.54	0.00	0.00	0.00	0.00

Table 4.13h Probability (%) of surplus water during rainy season at Dhandhuka

Std. met. Week	Surplus water				
	20 mm	40 mm	60 mm	80 mm	100 mm
23	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00
25	4.54	4.54	4.54	0.00	0.00
26	4.54	4.54	4.54	4.54	4.54
27	0.00	0.00	0.00	0.00	0.00
28	0.00	0.00	0.00	0.00	0.00
29	0.00	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00
31	10.00	6.67	6.67	0.00	0.00
32	3.33	3.33	0.00	0.00	0.00
33	6.67	6.67	3.33	3.33	3.33
34	10.00	3.33	0.00	0.00	0.00
35	3.33	0.00	0.00	0.00	0.00
36	10.00	3.33	3.33	3.33	3.33
37	3.33	0.00	0.00	0.00	0.00
38	10.00	6.67	6.67	3.33	3.33
39	3.33	3.33	3.33	0.00	0.00
40	3.33	3.33	3.33	3.33	3.33

Table 4.13i Probability (%) of surplus water during rainy season at Junagadh

Std. met. Week	Surplus water				
	20 mm	40 mm	60 mm	80 mm	100 mm
23	0.00	0.00	0.00	0.00	0.00
24	13.33	10.00	10.00	0.00	0.00
25	10.00	6.67	6.67	6.67	6.67
26	16.67	16.67	13.33	6.67	6.67
27	23.33	16.67	16.67	16.67	16.67
28	26.67	23.33	16.67	16.67	16.67
29	33.33	33.33	30.00	23.33	20.00
30	50.00	30.00	23.33	20.00	10.00
31	33.33	30.00	20.00	16.67	10.00
32	30.00	23.33	20.00	13.33	10.00
33	20.00	16.67	13.33	13.33	6.67
34	6.67	0.00	0.00	0.00	0.00
35	20.00	16.67	13.33	3.33	3.33
36	20.00	13.33	6.67	3.33	3.33
37	10.00	6.67	6.67	6.67	3.33
38	3.33	3.33	3.33	3.33	3.33
39	3.33	0.00	0.00	0.00	0.00
40	6.67	6.67	6.67	3.33	3.33

Table 4.13j Probability (%) of surplus water during rainy season at Mahuva

Std. met. Week	Surplus water				
	20 mm	40 mm	60 mm	80 mm	100 mm
23	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00
25	4.54	4.54	4.54	0.00	0.00
26	0.00	0.00	0.00	0.00	0.00
27	4.54	0.00	0.00	0.00	0.00
28	13.63	13.63	9.09	9.09	9.09
29	13.63	9.09	4.54	4.54	4.54
30	18.18	9.09	9.09	4.54	4.54
31	13.63	4.54	4.54	4.54	4.54
32	18.18	4.54	4.54	4.54	4.54
33	4.54	0.00	0.00	0.00	0.00
34	9.09	9.09	4.54	4.54	0.00
35	9.09	4.54	4.54	4.54	4.54
36	13.63	4.54	4.54	4.54	4.54
37	9.09	4.54	0.00	0.00	0.00
38	13.63	4.54	4.54	4.54	4.54
39	18.18	9.09	9.09	9.09	9.09
40	0.00	0.00	0.00	0.00	0.00

Table 4.13k Probability (%) of surplus water during rainy season at Anand

Std. met. week	Surplus water				
	20 mm	40 mm	60 mm	80 mm	100 mm
23	0.00	0.00	0.00	0.00	0.00
24	3.33	3.33	3.33	3.33	3.33
25	0.00	0.00	0.00	0.00	0.00
26	0.00	0.00	0.00	0.00	0.00
27	6.67	6.67	6.67	6.67	6.67
28	6.67	6.67	3.33	3.33	3.33
29	10.00	10.00	10.00	10.00	6.67
30	23.33	20.00	20.00	20.00	10.00
31	33.33	30.00	26.67	20.00	20.00
32	36.67	23.33	23.33	20.00	16.67
33	36.67	33.33	30.00	23.33	20.00
34	30.00	26.67	20.00	13.33	13.33
35	30.00	26.67	23.33	20.00	20.00
36	33.33	13.33	6.67	6.67	6.67
37	33.33	23.33	16.67	10.00	10.00
38	13.33	13.33	10.00	10.00	6.67
39	10.00	6.66	3.33	0.00	0.00
40	6.67	3.33	0.00	0.00	0.00

Table 4.13l Probability (%) of surplus water during rainy season at Nawagam

Std. met. week	Surplus water				
	20 mm	40 mm	60 mm	80 mm	100 mm
23	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00
25	7.69	3.85	3.85	3.85	3.85
26	3.85	3.85	3.85	3.85	3.85
27	3.85	3.85	3.85	0.00	0.00
28	19.23	19.23	15.38	15.38	15.38
29	23.07	23.07	23.07	19.23	19.23
30	30.77	30.77	19.23	15.38	15.38
31	34.61	30.77	30.77	30.77	26.92
32	15.38	15.38	15.38	11.54	3.85
33	26.92	19.23	19.23	15.38	15.38
34	23.07	23.07	23.07	15.38	15.38
35	23.07	11.54	11.54	11.54	7.69
36	30.77	23.07	3.85	3.85	3.85
37	15.38	11.54	11.54	7.69	3.85
38	7.69	3.85	3.85	3.85	3.85
39	7.69	3.85	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00	0.00

Table 4.13m Probability (%) of surplus water during rainy season at Bharuch

Std. met. week	Surplus water				
	20 mm	40 mm	60 mm	80 mm	100 mm
23	3.33	3.33	3.33	3.33	3.33
24	3.33	3.33	3.33	0.00	0.00
25	3.33	3.33	3.33	0.00	0.00
26	23.33	20.00	20.00	13.33	13.33
27	10.00	6.67	3.33	3.33	0.00
28	23.33	23.33	20.00	13.33	13.33
29	30.00	30.00	26.67	20.00	10.00
30	26.67	20.00	16.67	13.33	10.00
31	23.33	23.33	13.33	13.33	13.33
32	33.33	23.33	16.67	10.00	10.00
33	23.33	23.33	16.67	6.67	3.33
34	30.00	13.33	13.33	3.33	3.33
35	33.33	20.00	13.33	10.00	10.00
36	26.67	23.33	23.33	20.00	16.67
37	16.67	16.67	10.00	10.00	10.00
38	16.67	13.33	10.00	10.00	6.67
39	13.33	10.00	10.00	3.33	3.33
40	3.33	3.33	3.33	0.00	0.00

Table 4.13n Probability (%) of surplus water during rainy season at Surat

Std. met. week	Surplus water				
	20 mm	40 mm	60 mm	80 mm	100 mm
23	3.33	3.33	3.33	3.33	3.33
24	10.00	6.67	3.33	3.33	3.33
25	26.67	26.67	26.67	26.67	20.00
26	26.67	26.67	20.00	20.00	16.67
27	43.33	36.67	26.67	20.00	16.67
28	43.33	36.67	33.33	26.67	26.67
29	46.67	43.33	40.00	36.67	36.67
30	46.67	30.00	20.00	16.67	16.67
31	33.33	23.33	20.00	16.67	16.67
32	36.67	30.00	23.33	20.00	20.00
33	26.67	20.00	20.00	13.33	3.33
34	26.67	20.00	13.33	10.00	10.00
35	30.00	20.00	13.33	10.00	0.00
36	20.00	16.67	13.33	13.33	10.00
37	10.00	10.00	10.00	10.00	6.67
38	13.33	6.67	0.00	0.00	0.00
39	10.00	6.67	6.67	6.67	6.67
40	3.33	3.33	3.33	3.33	3.33

Table 4.13o Probability (%) of surplus water during rainy season at Navsari

Std. met. week	Surplus water				
	20 mm	40 mm	60 mm	80 mm	100 mm
23	3.33	3.33	3.33	3.33	3.33
24	16.67	16.67	10.00	10.00	10.00
25	33.33	26.67	23.33	23.33	20.00
26	36.67	33.33	26.67	23.33	16.67
27	46.67	46.67	40.00	30.00	30.00
28	46.67	43.33	33.33	30.00	26.67
29	60.00	56.67	50.00	46.67	46.67
30	60.00	50.00	43.33	40.00	36.67
31	46.67	33.33	33.33	26.67	20.00
32	60.00	40.00	30.00	23.33	23.33
33	43.33	30.00	26.67	20.00	20.00
34	33.33	30.00	10.00	10.00	6.67
35	43.33	36.67	26.67	20.00	10.00
36	43.33	40.00	33.33	26.67	23.33
37	20.00	16.67	13.33	10.00	6.67
38	20.00	10.00	10.00	6.67	3.33
39	20.00	16.67	16.67	13.33	13.33
40	3.33	3.33	3.33	3.33	3.33

Table 4.13p Probability (%) of surplus water during rainy season at Gandevi

Std. met. Week	Surplus water				
	20 mm	40 mm	60 mm	80 mm	100 mm
23	0.00	0.00	0.00	0.00	0.00
24	9.09	9.09	9.09	9.09	9.09
25	27.27	27.27	22.72	18.18	13.63
26	31.82	22.72	22.72	22.72	22.72
27	40.90	22.72	18.18	18.18	18.18
28	50.00	40.90	40.90	40.90	36.36
29	72.72	68.18	63.63	63.63	59.09
30	54.54	45.45	40.90	36.36	36.36
31	63.63	45.45	31.82	22.72	18.18
32	68.18	54.54	45.45	45.45	22.72
33	68.18	36.36	27.27	27.27	22.72
34	45.45	40.90	27.27	22.72	9.09
35	54.54	36.36	22.72	13.63	4.54
36	40.90	31.82	22.72	13.63	9.09
37	45.45	36.36	22.72	13.63	9.09
38	31.82	22.72	18.18	9.09	9.09
39	27.27	27.27	22.72	22.72	18.18
40	0.00	0.00	0.00	0.00	0.00

4.4.1 Evaluation of Drought

Drought characterization in different agro-climatic zones was done by selecting two stations from each zone. Drought years were identified and their intensities assessed from departure of annual aridity indices from the normal value. Taxonomy of droughts, on the basis of their intensity, using standard deviation technique as explained in Section 3.6 has been made for different zones of Gujarat and the results are depicted in Figure 4.6a to 4.6d.

Drought years and their severities for different zones are given in Table 4.14. It is seen from Table 4.14 that disastrous droughts were observed at all the stations except Mahuva and Navsari. Droughts of other severities were observed in all the zones in random manner. The percentage of drought years of various categories in different zones varies from 38.46 to 50.00 per cent with an overall average of 43.09 per cent. Total drought years vary from 9 to 15 during the study period in different zones, indicating the frequency of one drought year in every two to three years.

Table 4.14 also reveals that total number of droughts of moderate, large, severe and disastrous severity in the state as a whole during 1974-2003, comes out to be 69 (36.32%), 57 (30.00%), 49 (25.79%) and 15 (7.89%), respectively, indicating clearly a decreasing frequency of drought years with increasing severity. All the stations, except Mahuva and Navsari, experienced at least 1 disastrous drought during the study period. The frequency of occurrence of severe drought year varies from 1 at Junagadh and Dhandhuka to 6 at Amreli, while that of large drought year varies from 1 at Amreli and Mahuva to 6 at Surat. The frequency of occurrence of moderate drought year varies from 2 at Rajkot and Arnej to 6 at Amreli, Junagadh, Bharuch and Navsari. This indicates that the drought incidences are not affecting all zones simultaneously but some parts of the region have experienced localised drought. However, in some years all zones of the state experienced droughty conditions and even in such years the drought severity varied from zone to zone.

Diagrammatic presentation of drought years as shown in Figure 4.7 indicates a tendency of occurrence of droughts of varying intensities for 2 to 4 years in succession in different agro-climatic zones. Critical observation of Figure 4.7 indicates that droughts of different categories occurred in all the zones in 1986, 1987 and 1991, whereas no drought was experienced in 1975, 1976, 1983 and 1998 in any zone.

These results indicate that drought of same category does not prevail simultaneously in all the agro-climatic zones but usually it occurs sporadically all over the state in a number of times. However, during some years all the zones experienced droughty conditions with varying severities. The results also indicate that droughts are not common only in arid and semi-arid climate but equally occur sporadically in sub-humid climate (Surat, Navsari and Gandevi).

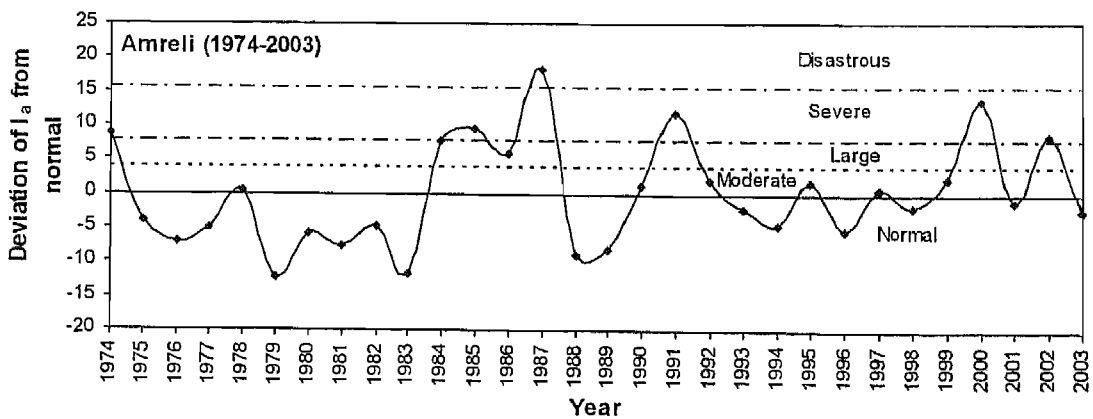
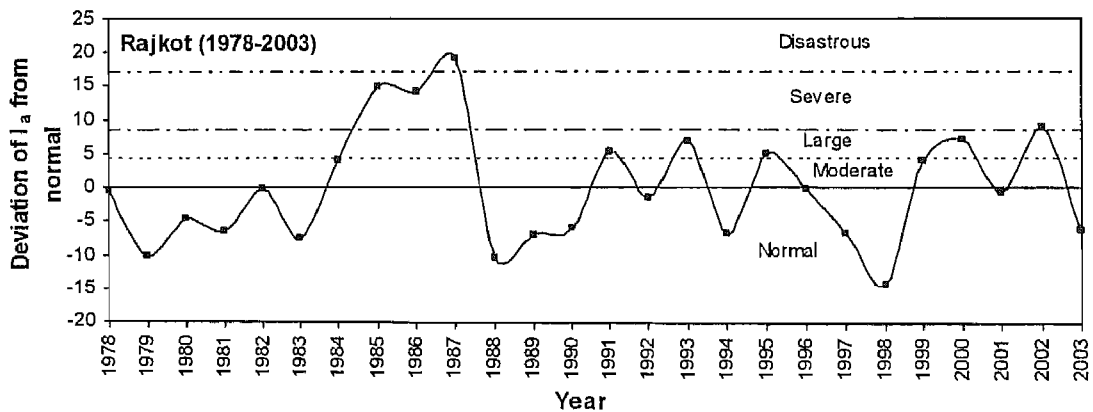
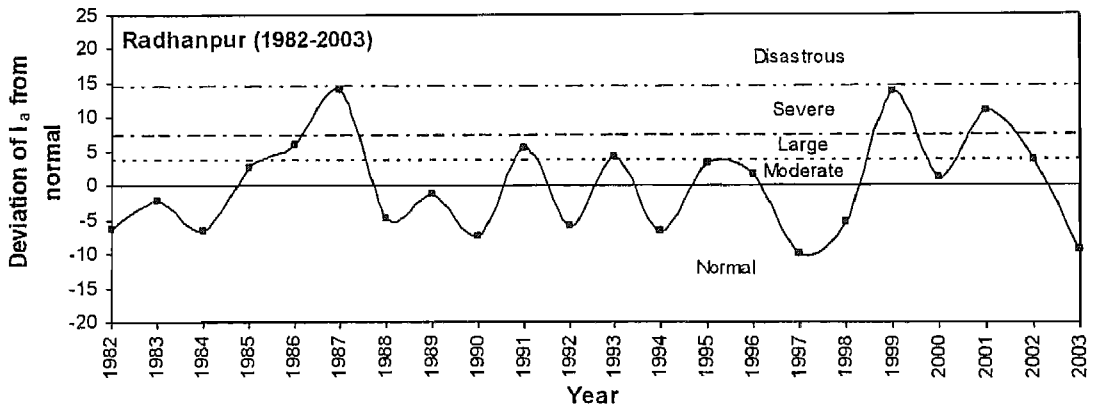
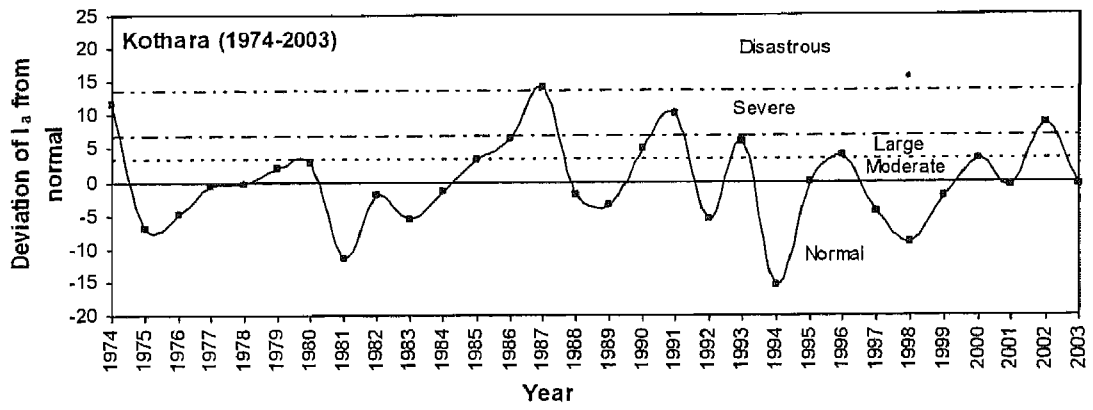


Fig. 4.6a March of aridity index for Kothara, Radhanpur, Rajkot and Amreli

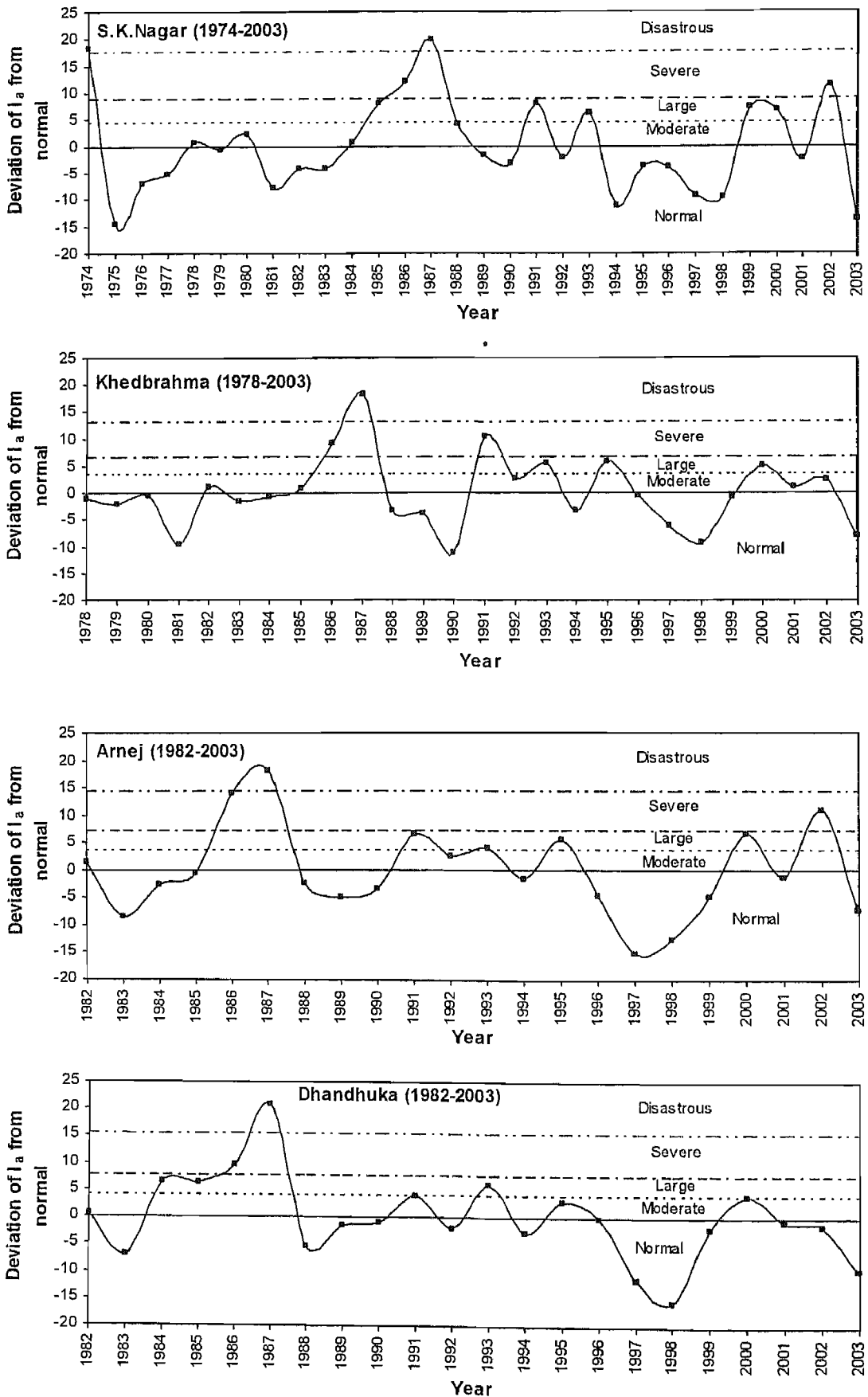


Fig. 4.6b March of aridity index for S.K. Nagar, Khedbrahma, Arnej and Dhandhuka

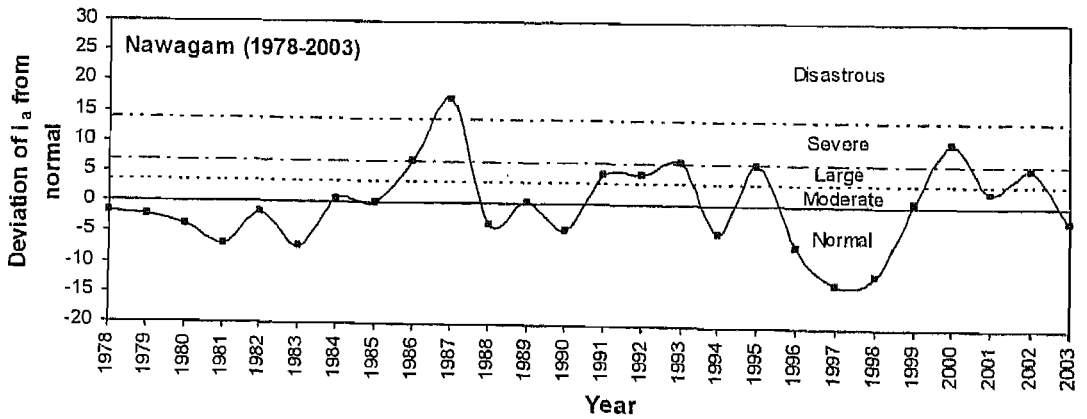
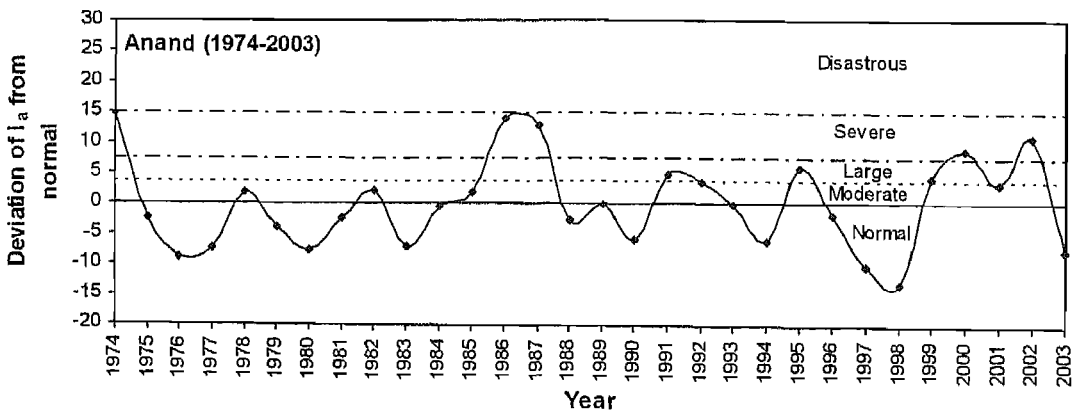
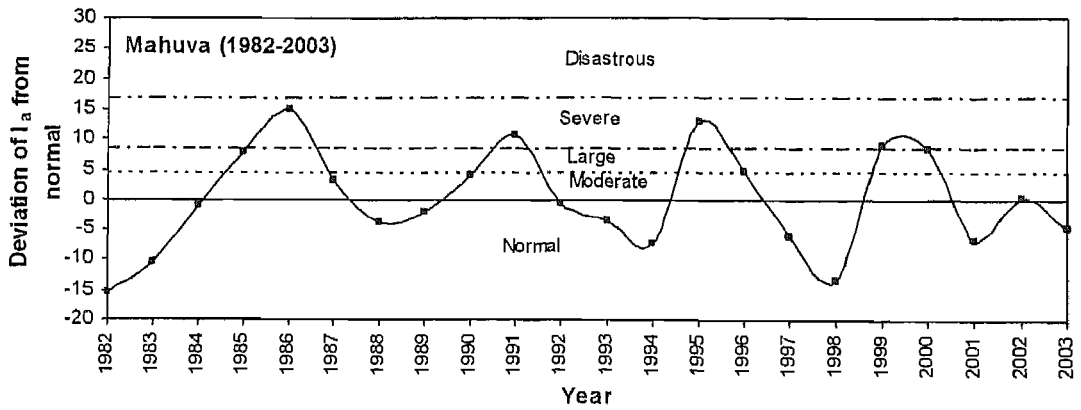
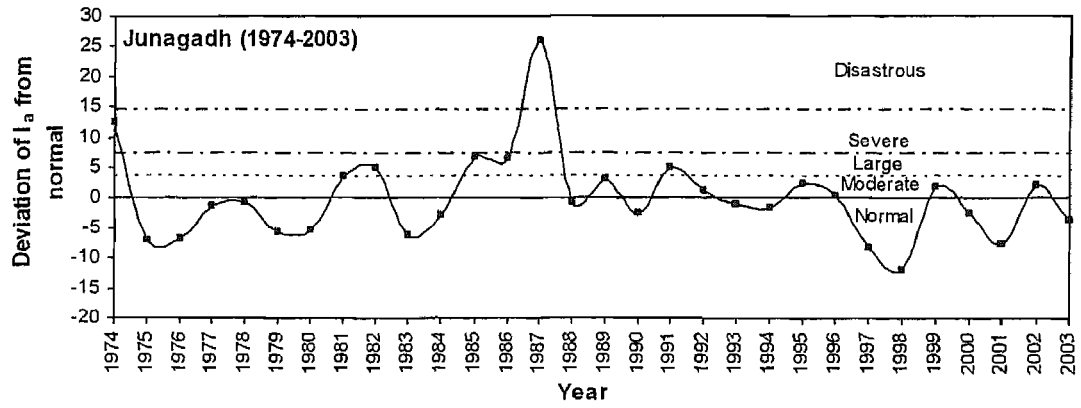


Fig. 4.6c March of aridity index for Junagadh, Mahuva, Anand and Nawagam

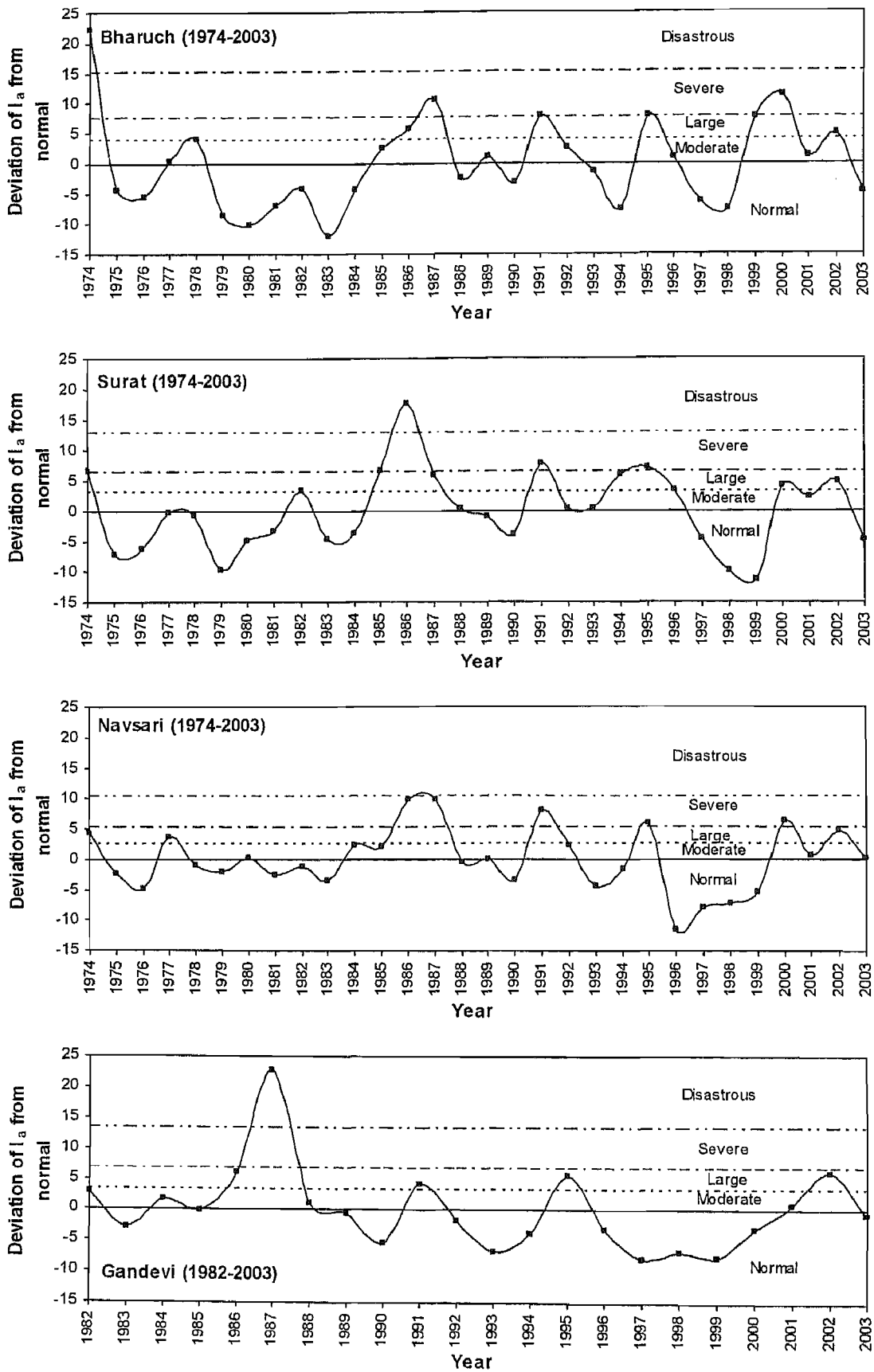


Fig. 4.6d March of aridity index for Bharuch, Surat, Navsari and Gandevi

Table 4.14 Drought years and their severities under different agro-climatic zones of Gujarat

Station	Severity of drought				Disastrous	Total drought years
	Moderate	Large	Severe			
Kothara (1974-2003)	1979,80,85	1986,90,93,96,2000	1974,91,2002		1987	12(40.00)
Radhanpur (1982-2003)	1985,95,96,2000,02	1986,91,93	1999,2001		1987	11(50.00)
Rajkot (1978-2003)	1984,99	1991,93,95,2000	1985,86,02		1987	10(38.46)
Amreli (1974-2003)	1978,90,92,95,97,99	1986	1974,84,85,91,2000,02		1987	14(43.33)
SK Nagar (1974-2003)	1978,80,84,88	1985,91,93,99,2000	1986,2002		1974,87	13(46.67)
Khedbrahma (1978-2003)	1982,85,92,2001,02	1993,95,2000	1986,91		1987	11(42.31)
Arnej (1982-2003)	1982,92	1991,93,95,2000	1986,2002		1987	9(40.90)
Dhandhuka (1982-2003)	1982,91,95	1984,85,93,2000	1986		1987	9(40.90)
Junagadh (1974-2003)	1989,92,95,96,99,2002	1981,82,85,86,91	1974		1987	13(43.33)
Mahuva (1982-2003)	1987,90,2002	1985	1986,91,95,99,2000		-	9(40.90)
Anand (1974-2003)	1978,82,85,92,2001	1991,95,99	1986,87,2000,02		1974	13(43.33)
Nawagam (1978-2003)	1984,85,89,99,2001	1991,92,2002	1986,93,95,2000		1987	13(50.00)
Bharuch (1974-2003)	1977,85,89,92,96,2001	1978,86,2002	1987,91,95,99,2000		1974	15(50.00)
Surat (1974-2003)	1988,92,93,2001	1982,87,94,96,2000,02	1974,85,91,95		1986	15(50.00)
Navsari (1974-2003)	1980,84,85,92,2001,03	1974,77,2002	1986,87,91,95,2000		-	14(46.67)
Gandevi (1982-2003)	1982,84,88,2001	1986,91,95,2002	-		1987	9(40.91)
Total years of different severity	69(36.32)	57(30.00)	49(25.79)		15(7.89)	190(43.09)

Figures in parenthesis indicate percentage of drought years.

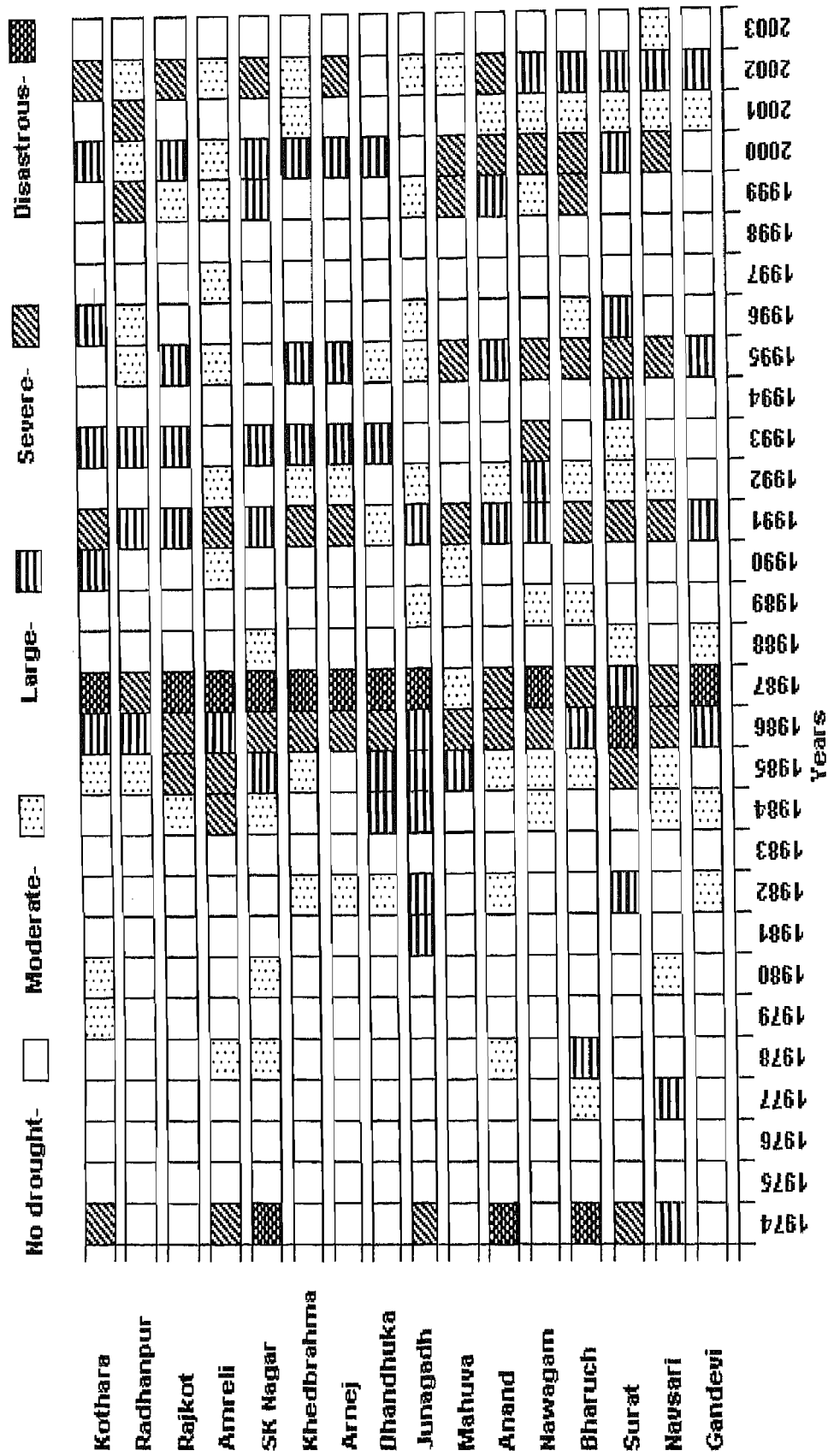


Fig. 4.7 Drought severity in different agro-climatic zones during the study period

4.4.2 Drought Severity and Duration

Droughts usually result from the cumulative effect of a set of weather sequences developing over an extended period of time. Thus, drought may be either prolonged or short-lived depending upon the nature and duration of water deficiency. Therefore, the year 1987 during which drought occurred in all the agro-climatic zones was selected for detailed study in terms of durations and severities on weekly basis, using cumulative deviation technique of Foley (1957) and categorized according to Malani (1981). Weekly cumulative deviation curves for different stations during 1987 are shown in Figures 4.8a and 4.8b. Duration and severity indices of drought spells in the kharif season during the year at different stations are given in Table 4.15.

Figures 4.8a and 4.8b reveal that drought during 1987 was of large to severe type in 24th to 26th smw in all the zones, except Surat and Navsari, which has delayed the sowing of crops. Table 4.15 clearly indicates that during the year all the stations have faced 2 to 3 drought spells varying from 2 to 10 weeks of large to severe intensity, intensified in disastrous drought, during the main crop growing period. Surat (37th smw onwards) and Navsari (35th smw onwards) have experienced moderate and large droughts, respectively.

The cumulative deviation curves of the drought year (Figures 4.8a and 4.8b) in different agro-climatic zones in general indicate that different category droughts of varying durations prevail simultaneously all over the state. The devastating drought of 1987 was considered for the study of spatial and temporal variability of water deficit and is discussed in Section 4.8.5.

4.5 FREQUENCY ANALYSIS OF EXTREME WATER DEFICIT DATA

Peak values of any hydrological variables are important from design and planning point of view, as it is the extreme, which plays a deciding role in success or failure of any design. In agriculture, the high severity plays a crucial role because of its devastating effects on the crop growth. With this in view, using three distributions such as log Pearson type-III, Gumbel and Weibull (maxima) the extreme weekly water deficit data during crop growing season were analysed. Chi-square test (χ^2) for goodness of fit of the observed data to the theoretical distribution was also performed. The distribution that gave the lowest Chi-square value has been selected as the best distribution for that location.

4.5.1 Test of Adequacy of Record

The test of adequacy of length of records was carried out using Mockus (1960) model (Equation 3.18). The results of adequacy of length of record (Table 4.16) indicate that water deficit data considered for extreme value analysis is adequate, as required length of record for each station is within the range of data considered for the respective station.

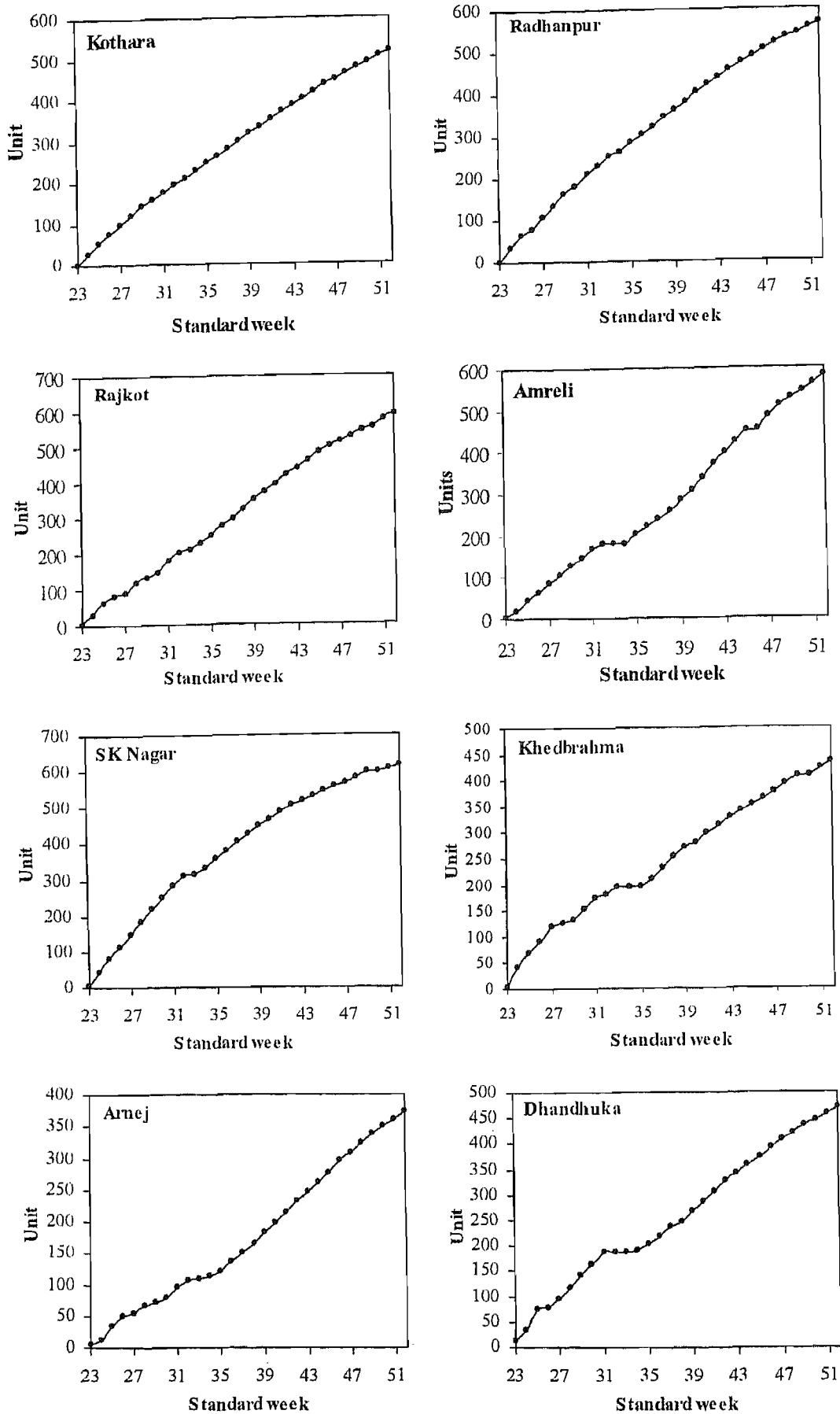


Fig. 4.8a Cumulative deviation curve for 1987 drought in North-West Gujarat, North Gujarat, North Saurashtra and Bhal and Coastal zones

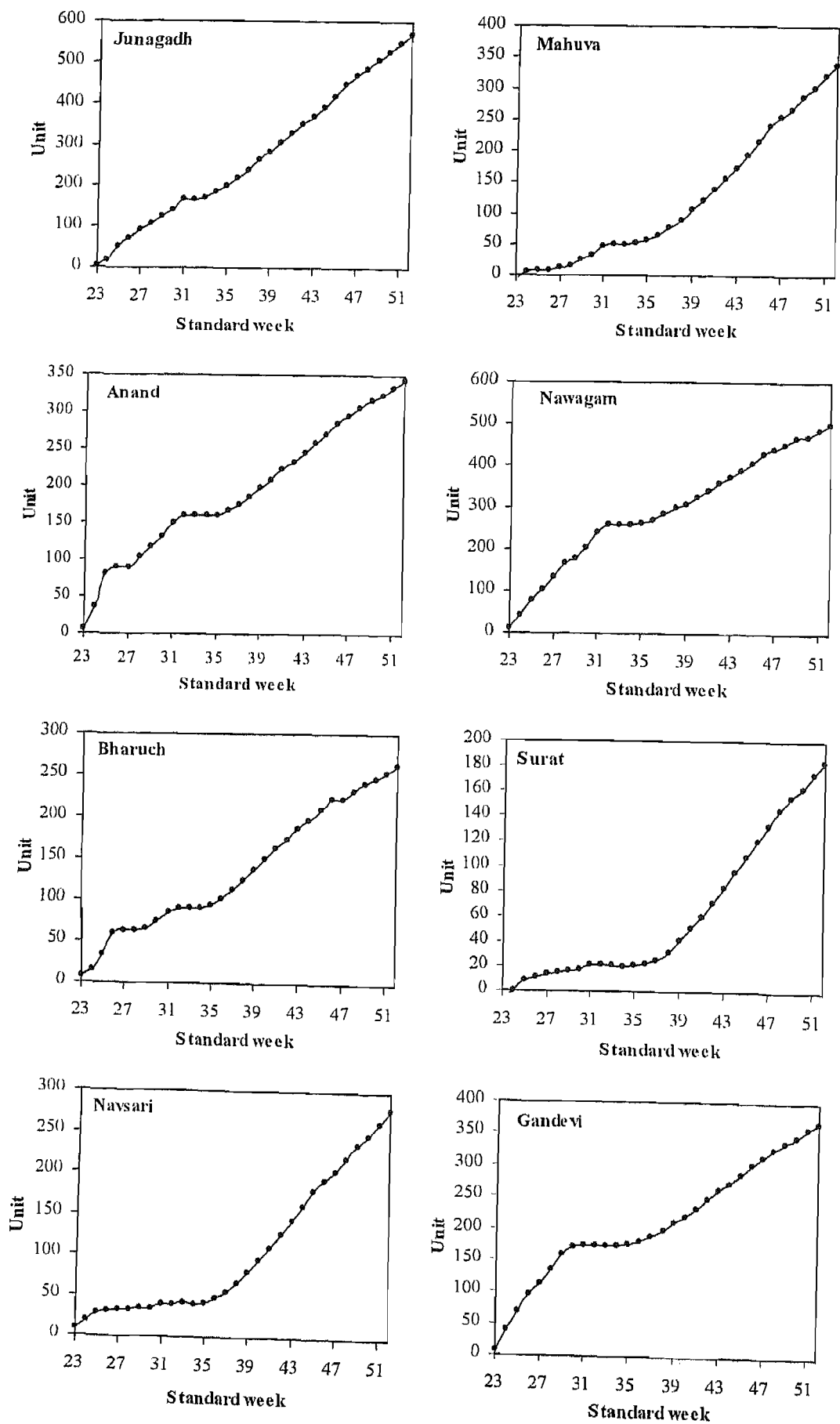


Fig. 4.8b Cumulative deviation curve for 1987 drought in South Saurashtra, Middle Gujarat and South Gujarat zones

Table 4.15 Duration and severity indices of drought spell during the kharif season of 1987 in different agro-climatic zones of Gujarat

Station	Drought spell period	Drought duration, weeks	Severity index	Drought category
	Std. met. week			
Kothara	24-40	17	19.71	Large
Radhanpur	24-40	17	21.30	Severe
Rajkot	24-40	17	21.91	Severe
Amreli	24-32	9	19.62	Large
	35-40	6	21.50	Severe
SKNagar	24-32	9	33.90	Severe
	34-40	7	22.00	Severe
Khedbrahma	24-27	4	29.40	Severe
	30-33	4	15.70	Large
	36-40	5	16.80	Large
Arnej	24-26	3	15.18	Large
	28-32	5	10.65	Large
	35-40	6	14.30	Large
Dhandhuka	23-25	3	24.35	Severe
	27-31	5	22.10	Severe
	35-40	6	15.90	Large
Junagadh	23-31	9	18.50	Large
	33-40	8	17.20	Large
Mahuva	29-31	3	10.40	Large
	35-40	6	13.00	Large
Anand	24-25	2	37.80	Severe
	28-32	5	14.40	Large
	36-40	5	9.58	Moderate
Nawagam	23-32	10	25.90	Severe
	35-40	6	12.23	Large
Bharuch	24-26	3	19.60	Large
	30-32	3	8.77	Moderate
	36-40	5	11.10	Large
Surat	37-45	9	9.49	Moderate
Navsari	23-25	3	9.36	Moderate
	35-40	6	10.40	Large
Gandevi	23-30	8	21.57	Severe
	36-40	5	9.12	Moderate

Table 4.16 Adequacy of length of records for frequency analysis of water deficit data at different stations

Station	Water deficit _{100 yr} , mm	Water deficit _{2yr} , mm	$R=WD_{100yr}/WD_{2yr}$	Student's t value	Required length of record, years
Kothara	62.28	26.49	2.35	1.86	14.62
Radhanpur	53.98	25.14	2.15	1.895	13.11
Rajkot	65.13	28.89	2.25	1.86	14.06
Amreli	50.52	15.32	3.30	1.753	21.24
SK Nagar	55.46	18.42	3.01	1.771	19.26
Khedbrahma	39.04	12.95	3.01	1.771	19.29
Arnej	53.79	19.49	2.76	1.796	17.55
Dhandhuka	50.56	18.49	2.73	1.796	17.34
Junagadh	52.60	17.94	2.93	1.782	18.78
Mahuva	56.57	22.56	2.51	1.833	15.72
Anand	48.05	12.98	3.70	1.734	23.98
Nawagam	49.69	12.79	3.89	1.729	25.1
Bharuch	50.82	21.64	2.35	1.86	14.73
Surat	38.33	10.06	3.81	1.734	24.75
Navsari	37.70	9.95	3.79	1.734	24.62

4.5.2 Frequency Distribution of Water Deficit

A computer based routine, called VTFIT was used for fitting the weekly extreme water deficit data to the selected distributions. The best fit probability distribution with corresponding Chi-square values for maximum weekly water deficit at different stations are presented in Table 4.17.

Results from Table 4.17 reveal that all the selected probability distributions fit the extreme weekly water deficit data well, since their Chi-square values are within the critical limits at 0.05 level of significance.

To arrive at best probability model for determining seasonal maximum weekly water deficit in different agro-climatic zones, the distributions with lowest Chi-square value were sorted out (highlighted in Table 4.17). Results of best-fit frequency distribution revealed that at Radhanpur, Amreli, Khedbrahma, Arnej, Anand, Bharuch and Navsari only log Pearson type-III distribution; at Dhandhuka, Junagadh, Mahuva, Nawagam and Surat only Weibull (maxima) distribution and at Kothara only Gumbel distribution fitted closest to the observed data. Log Pearson type-III and Gumbel distribution gave closest fit to the observed data at SK Nagar. All the three distributions fitted closest to the observed data at Rajkot. The comparison of Chi-square test of best fit distributions clearly indicates that log Pearson type-III distribution is the best probability model for predicting weekly maximum water deficit at Radhanpur, Rajkot, Amreli, SK Nagar, Khedbrahma, Arnej, Anand, Bharuch and Navsari. Weibull (maxima) fitted best at Dhandhuka, Junagadh, Mahuva, Nawagam and Surat while Gumbel at Kothara.

Table 4.17 Best fit frequency distribution for observed weekly maximum water deficit

Station	Log Pearson Type III	Gumbel(maxima)	Weibull(maxima)
	Chi-square (χ^2) value		
Kothara	2.0	1.2	1.6
Radhanpur	1.2	1.6	4.4
Rajkot	1.2	1.2	1.2
Amreli	6.8	10.8	13.2
SK Nagar	2.8	2.8	6.4
Khedbrahma	4.8	9.6	24.0
Arnej	6.8	10.8	13.2
Dhandhuka	8.0	8.0	4.8
Junagadh	2.8	3.2	1.6
Mahuva	6.0	6.8	4.0
Anand	6.8	8.0	7.6
Nawagam	8.2	8.4	7.2
Bharuch	4.0	9.2	7.6
Surat	5.2	4.4	3.2
Navsari	2.0	4.0	2.1

Chi-square (χ^2) value for DF=5 Tabulated value at 5% =11.1 and at 1% = 15.1

Table 4.18 Predicted weekly maximum water deficit for different return periods using best-fit distribution for different agro-climatic zones of Gujarat

Station	Return period, years	2	10	20	30	40	50	100
	Probability, %	50.00	10.00	5.00	3.33	2.50	2.00	1.00
		Maximum water deficit, mm week ⁻¹						
Kothara		26.49	31.39	34.29	36.44	38.29	42.04	62.28
Radhanpur		25.14	30.00	33.35	36.05	38.57	41.14	53.98
Rajkot		28.89	34.21	38.31	41.51	44.42	47.30	65.13
Amreli		15.32	22.14	26.38	29.49	32.29	34.99	50.52
SK Nagar		18.42	24.15	28.19	31.53	34.71	37.97	55.46
Khedbrahma		12.95	16.52	19.12	21.31	23.43	25.66	39.04
Arnej		19.49	22.77	25.27	27.45	29.60	31.91	53.79
Dhandhuka		18.49	23.54	26.96	29.72	32.32	34.98	50.56
Junagadh		17.94	25.60	30.23	33.69	36.72	39.61	52.60
Mahuva		22.56	26.93	29.76	31.97	33.97	35.96	56.57
Anand		12.98	18.24	21.64	24.30	26.75	29.15	48.05
Nawagam		12.79	19.15	23.26	26.47	29.40	32.30	49.69
Bharuch		21.64	24.94	27.44	29.56	31.71	33.96	50.82
Surat		10.06	14.80	18.00	20.59	23.03	25.52	38.33
Navsari		9.95	16.03	20.57	24.09	27.18	30.09	37.70

Frequency distributions of weekly maximum water deficit at different return periods obtained by using the best probability model selected above are shown in Figure 4.9. Predicted weekly maximum water deficit for different return periods for different agro-climatic zones of Gujarat are given in Table 4.18. Weekly maximum water deficit obtained from the long term historical data can be used for designing of protective/life saving irrigation systems and water resource structures in drought prone areas of Gujarat.

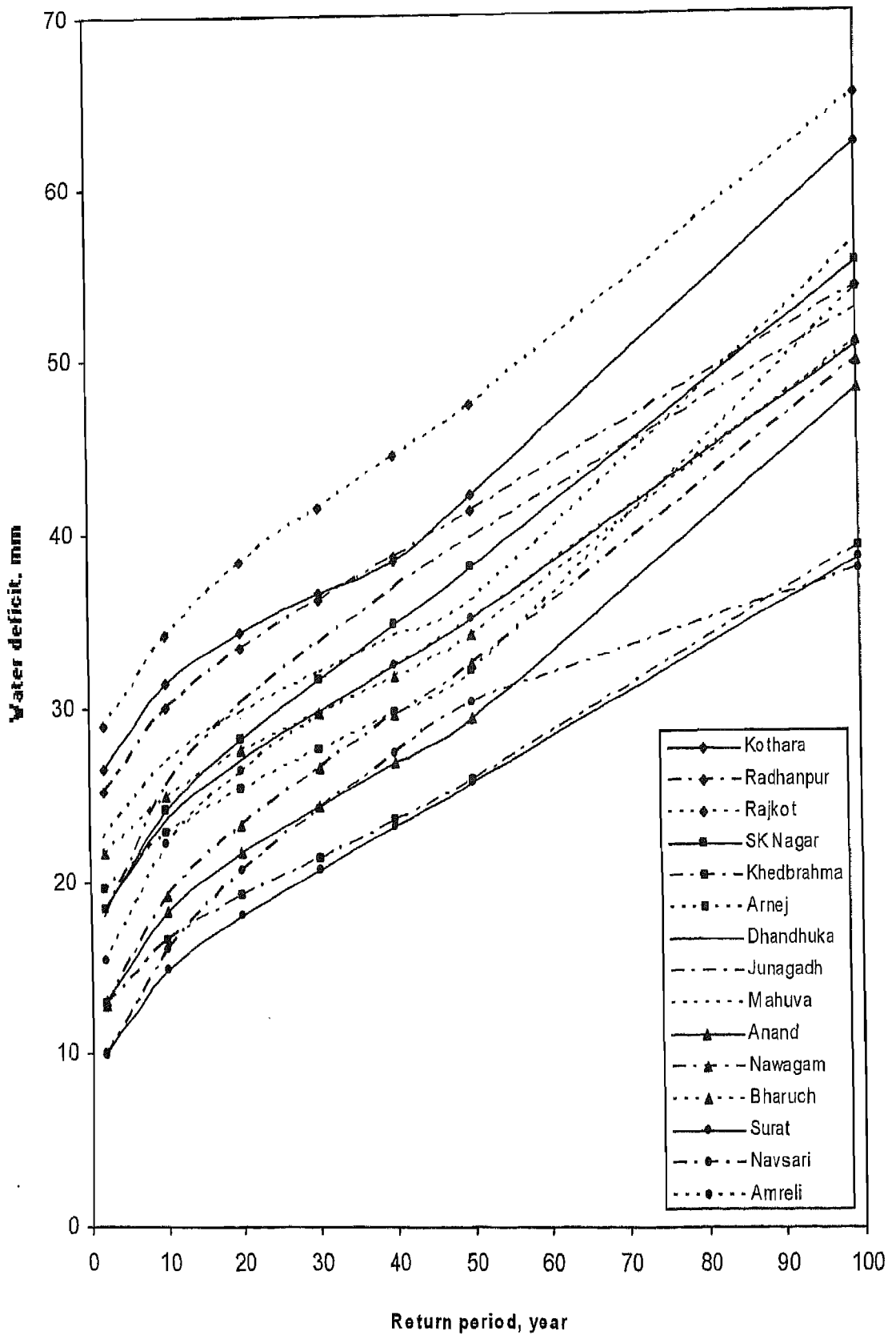


Fig. 4.9 Frequency distribution of maximum weekly water deficit during rainy season under different agro-climatic zones of Gujarat

4.6 ESTIMATION OF WATER DEFICIT USING ARTIFICIAL NEURAL NETWORKS

The mean weekly meteorological data for 22 to 30 years was used for this analysis. The data up to the year 2002 was used for training the network and the data for the year 2003 was used for validation. The input vector included maximum and minimum temperature, maximum and minimum relative humidity, wind speed, bright sunshine hours and rainfall. The output vector consisted of water deficit data. The methodology given in Section 3.10 was adopted for the analysis. A developed software program was run with the help of MATLAB 6.0 software. The results obtained are described in the following sub sections:

4.6.1 Training of Artificial Neural Networks

The principal component analysis has not reduced the size of the input vector, which shows that there is no redundancy in the data set. The data in respect of number of neurons in a hidden layer, number of epochs and the mean square error (MSE) for training data set are given in Table 4.19.

Table 4.19 Artificial Neural Network architecture with epoch and mean square error for training data set

S. No.	Station	Architecture	No. of epoch	Training data set mean square error
1	Kothara	7 - 4 - 1	22	0.0029
2	Radhanpur	7 - 4 - 1	39	0.0032
3	Rajkot	7 - 4 - 1	46	0.0006
4	Amreli	7 - 4 - 1	74	0.0011
5	SK Nagar	7 - 4 - 1	47	0.0046
6	Khedbrahma	7 - 4 - 1	28	0.0046
7	Arnej	7 - 4 - 1	45	0.0047
8	Dhandhuka	7 - 4 - 1	28	0.0045
9	Junagadh	7 - 4 - 1	28	0.0063
10	Mahuva	7 - 4 - 1	29	0.0069
11	Anand	7 - 4 - 1	29	0.0036
12	Nawagam	7 - 4 - 1	51	0.0045
13	Bharuch	7 - 4 - 1	31	0.0015
14	Surat	7 - 4 - 1	42	0.0029
15	Navsari	7 - 4 - 1	25	0.0059
16	Gandevi	7 - 4 - 1	38	0.0046

It is observed from the Table 4.19 that 7 - 4 - 1 architecture is enough for training the network for all the stations. The numbers of epochs were found to vary between 22 at Kothara to 74 at Amreli. The training data set mean square error also varied from 0.0011 to 0.0069, which indicated proper training of the network. The error variation with each epoch of

training, validation and test set, variation of weekly observed water deficit (DEF) and ANN predicted water deficit (DEF_{ANN}) and relationship between weekly observed water deficit (DEF) and ANN predicted water deficit (DEF_{ANN}) are graphically presented in Figures 4.10a to 4.10d, 4.11a to 4.11d and 4.12a to 4.12d, respectively. It is seen from the Figures 4.10a to 4.10d that the test set error and validation set error have similar characteristics and do not show occurrence of any significant over fitting for any station. This also represents that the network is properly generalized and it can estimate the water deficit for new input data.

It is also observed that the ANN predicted water deficit (DEF_{ANN}) and observed water deficit (DEF) shows similar trend for all the weeks for different stations. The results of the regression analysis show that the correlation coefficients vary between 0.973 for Mahuva to 0.9961 for Radhanpur, which indicate that the network has accurately estimated the water deficit and the provided architecture is adequate for the network.

4.6.2 Validation of Artificial Neural Networks

The weekly water deficit data for the year 2003 were used for validation of the trained network. For this purpose maximum and minimum temperature, maximum and minimum relative humidity, wind speed, bright sunshine hours and rainfall data were given as input to the network to obtain predicted water deficit. The predicted water deficit results were compared with the observed water deficit for the year 2003. The variation and relationship between weekly observed water deficit and generated water deficit by ANN for the year 2003 for different stations are given in Figures 4.13a to 4.13d and 4.14a to 4.14d, respectively. It is seen from the Figures 4.13a to 4.13d and 4.14a to 4.14d that the ANN has predicted water deficit reasonably accurate for all the stations. The correlation coefficients vary between 0.7228 at Radhanpur to 0.9392 at Junagadh which were found to be significant at 5% level of significance. The regression line in general is closer to 1:1 line in all the cases.

4.7 STOCHASTIC MODELLING OF WATER DEFICIT

Weekly water deficit values for the selected sixteen stations vary from twenty (1982-2001) to twenty eight years (1974 - 2001) were estimated using Thornthwaite and Mather (1955,1957) procedure as described in Section 3.5. Water deficit data were analysed using time series analysis techniques and a stochastic weekly water deficit generator was developed. The time series of weekly water deficit was assumed to be composed of deterministic component and stochastic component.

The mathematical procedure of stochastic modelling as described in Section 3.11 has been used in investigating the structure of time series of weekly water deficit for the different agro-climatic zones of Gujarat. The weekly water deficit series were tested for its stochastic behavior. The presence of trend component in series was examined using turning point test

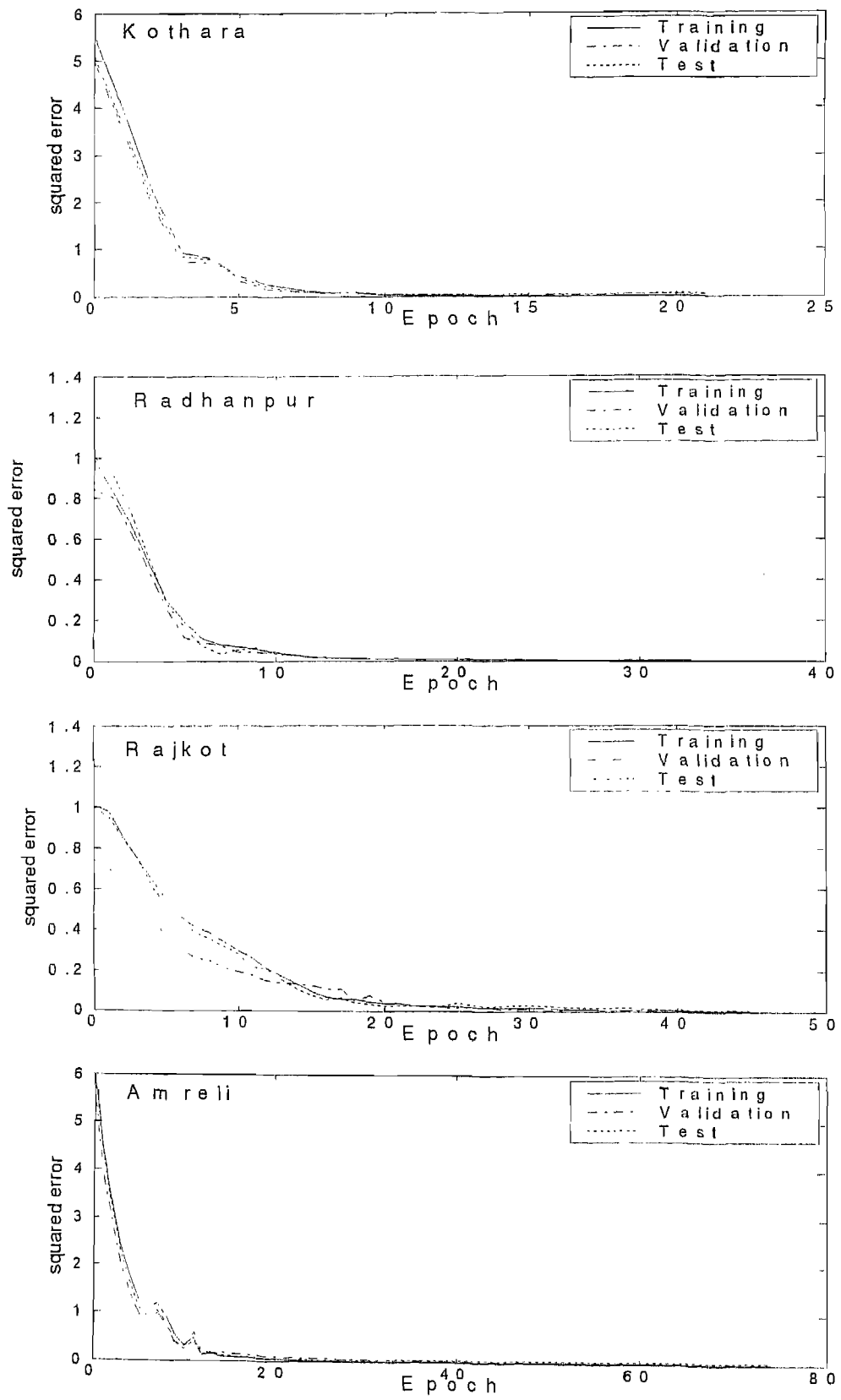


Fig. 4.10a Error variation with epoch for water deficit at Kothara, Radhanpur, Rajkot and Amreli

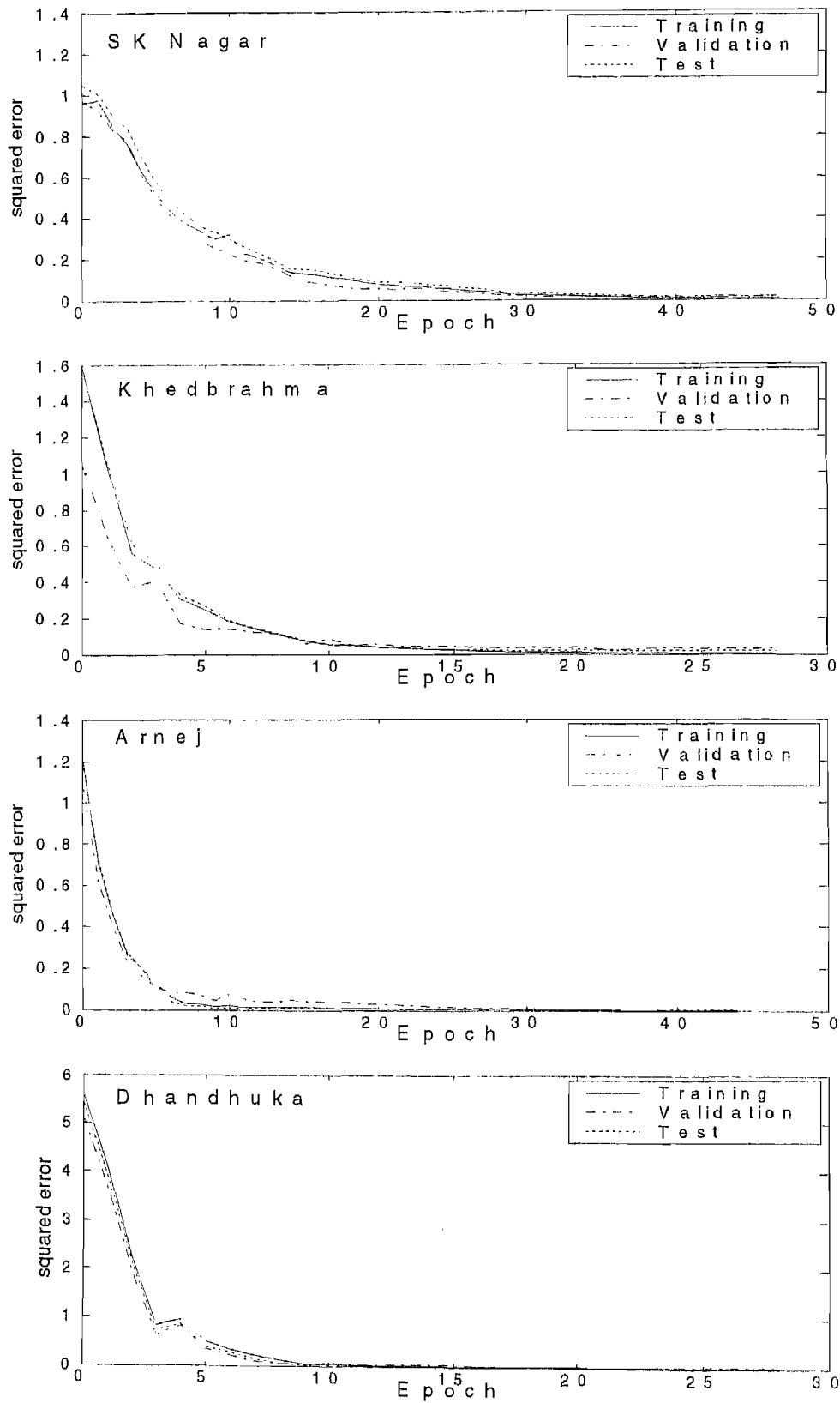


Fig. 4.10b Error variation with epoch for water deficit at SK Nagar, Khedbrahama, Arnej and Dhandhuka

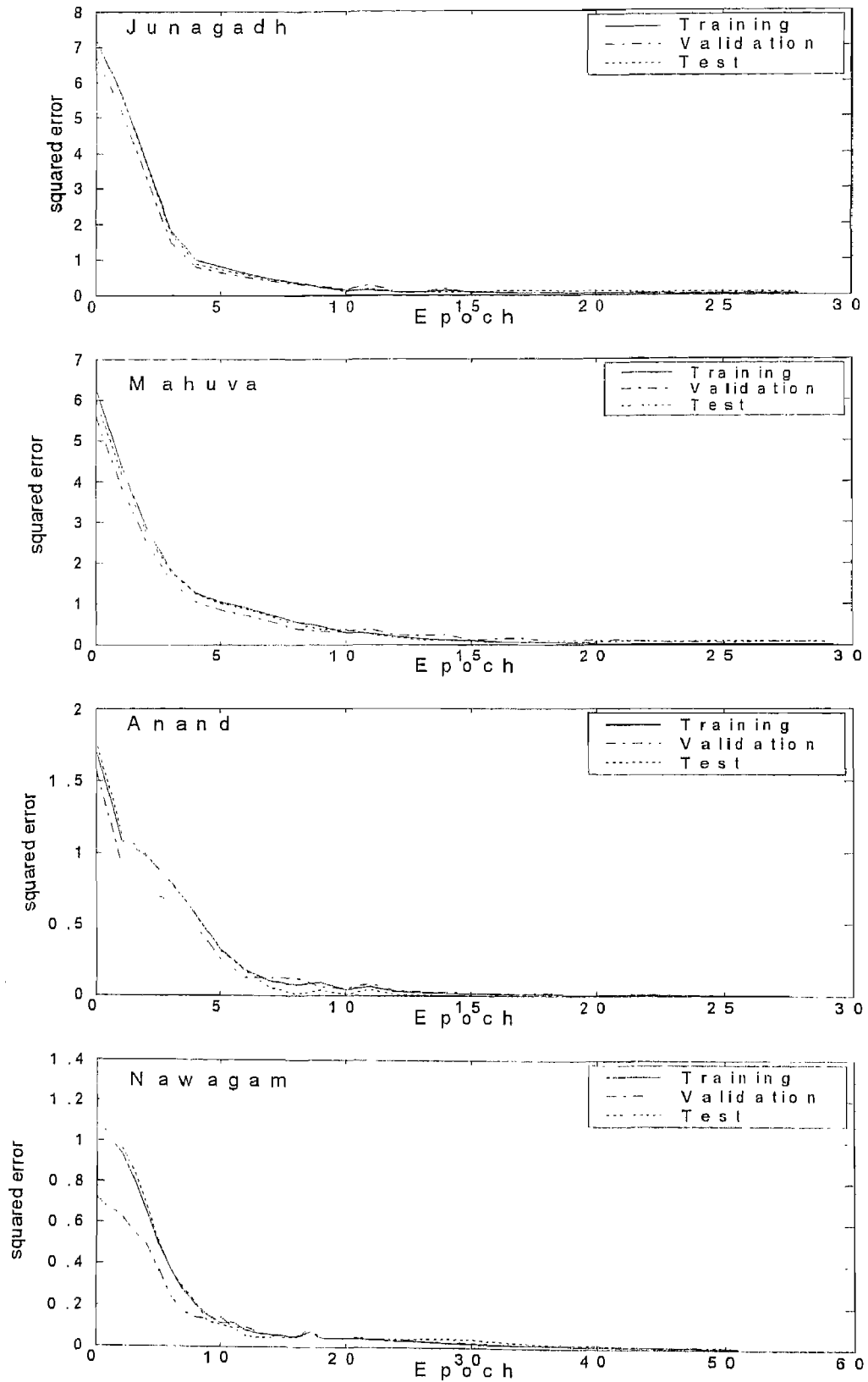


Fig. 4.10c Error variation with epoch for water deficit at Junagadh, Mahuva, Anand and Nawagam

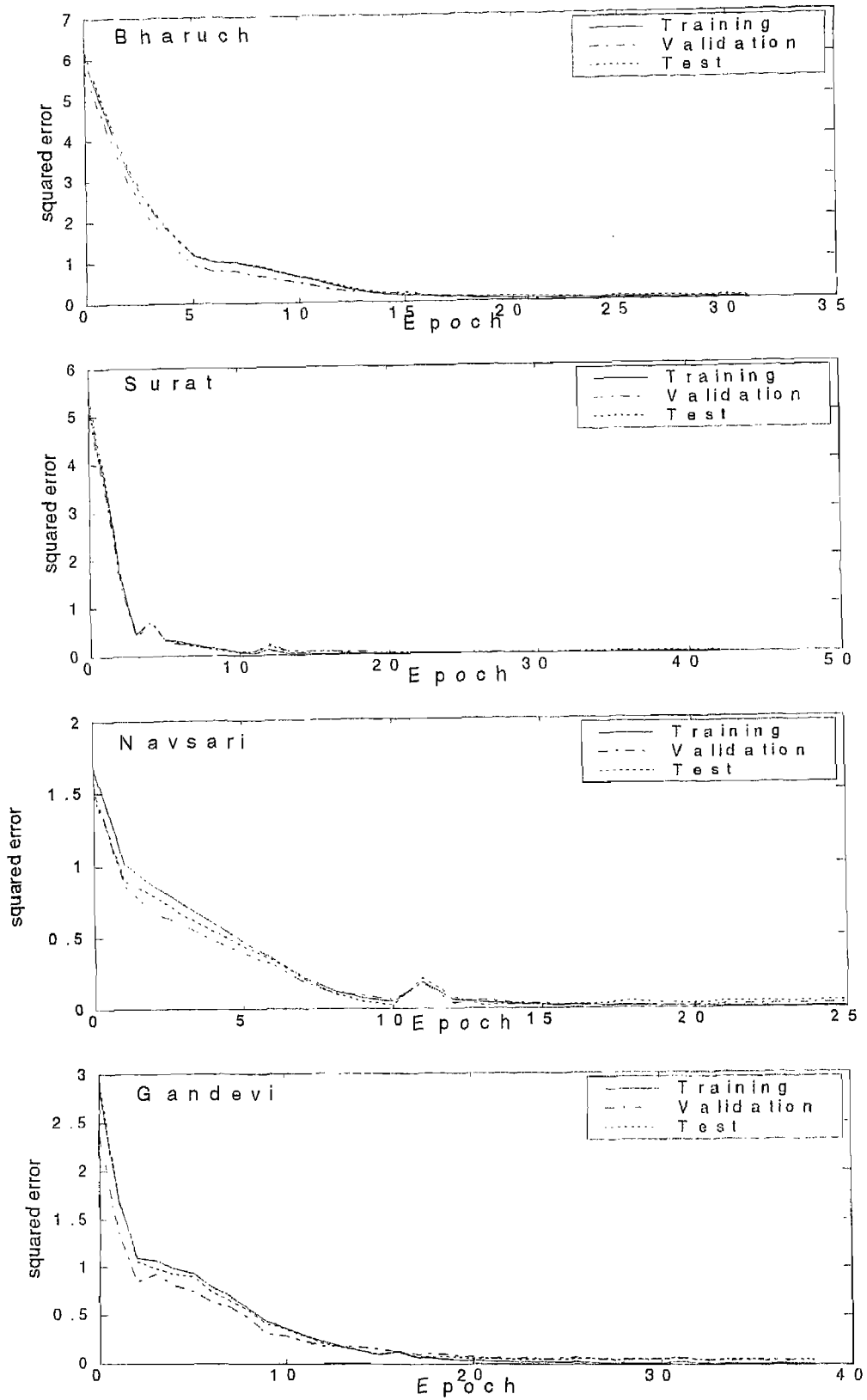


Fig. 4.10d Error variation with epoch for water deficit at Bharuch, Surat, Navsari and Gandevi

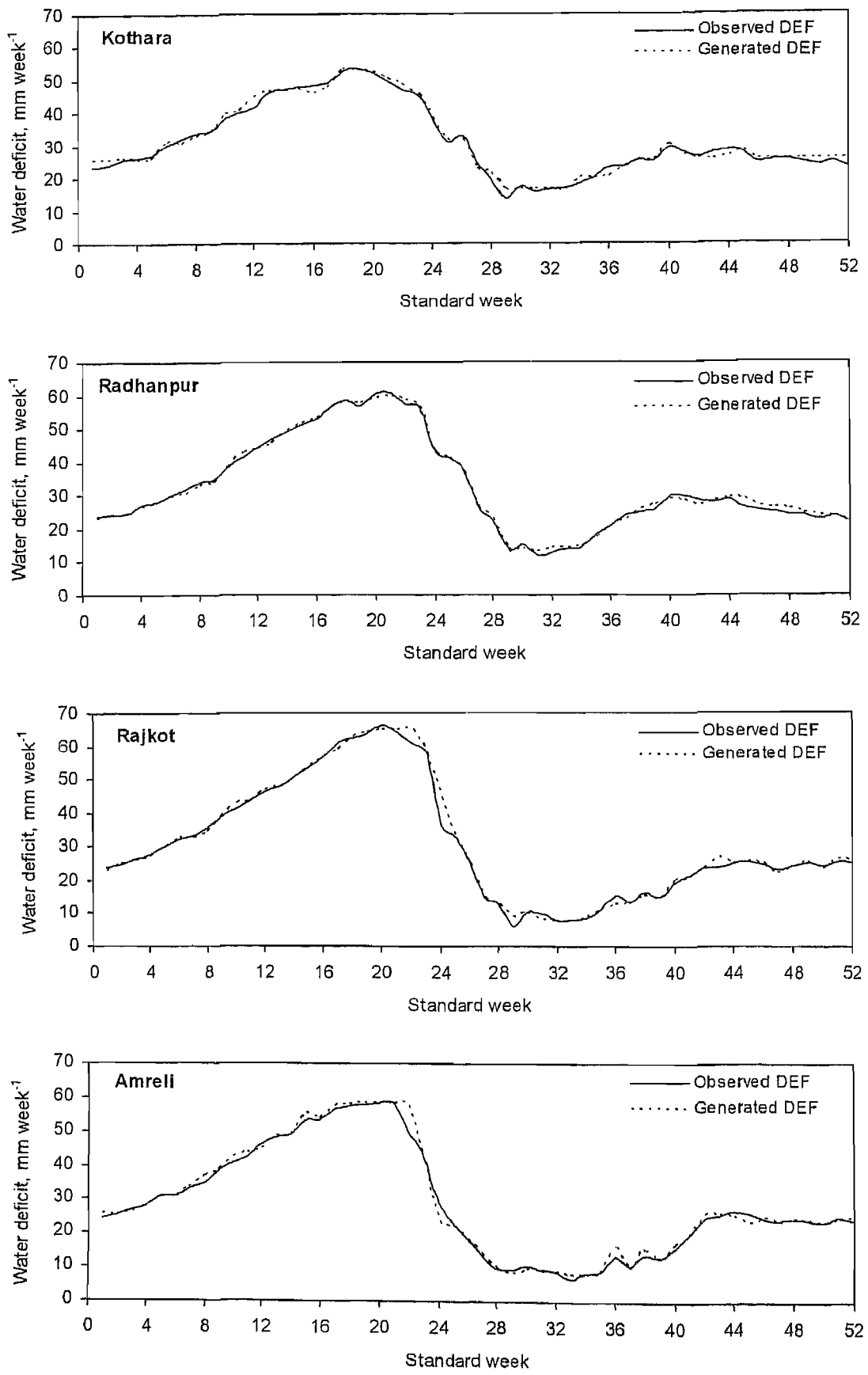


Fig. 4.11a Variation between weekly observed and generated water deficit by ANN for Kothara, Radhanpur, Rajkot and Amreli

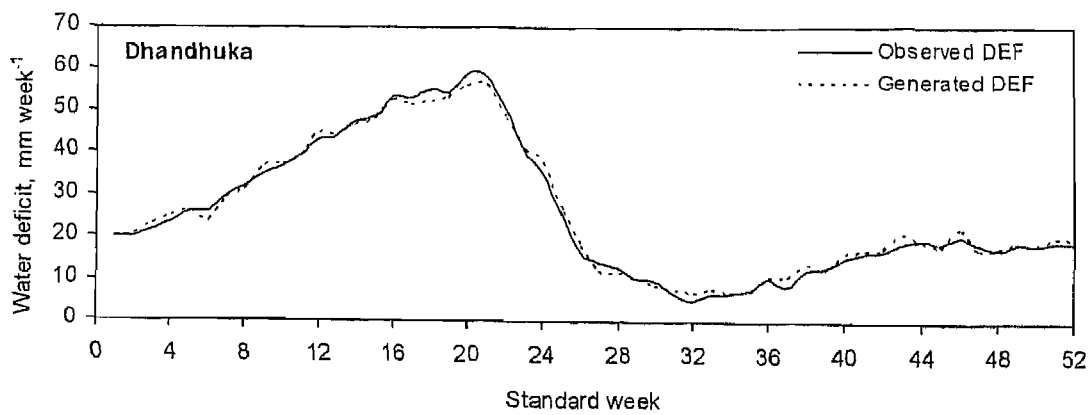
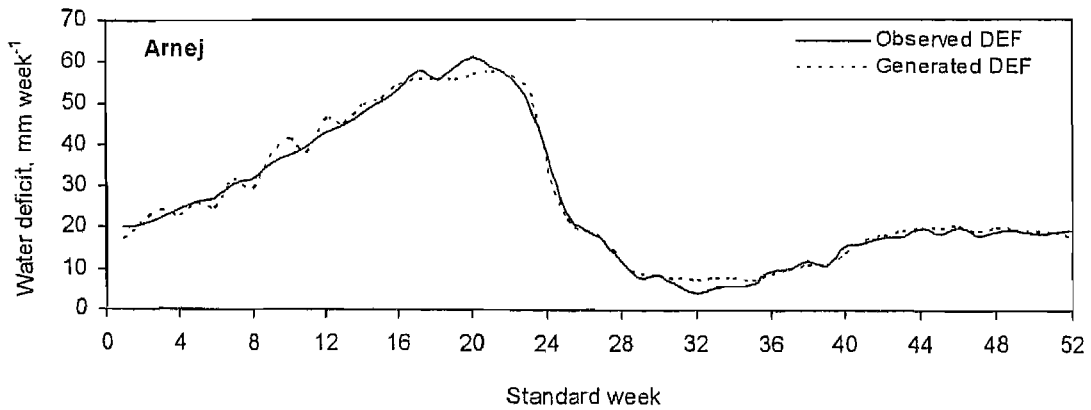
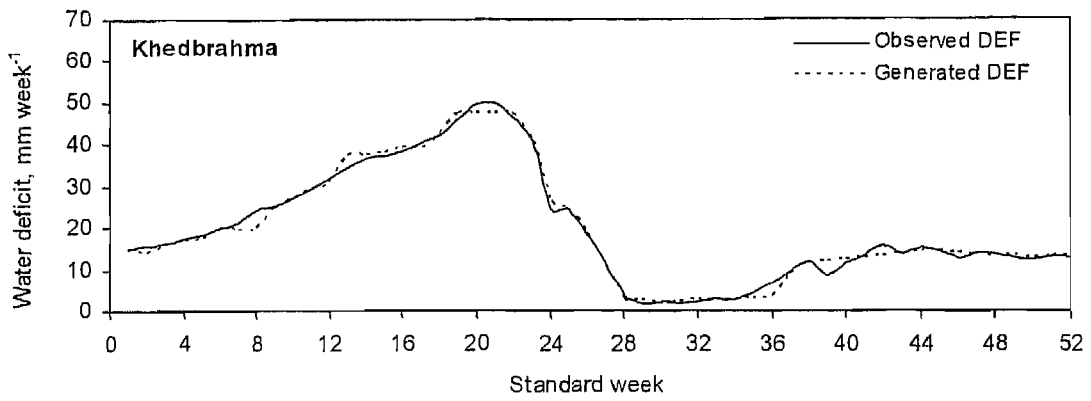
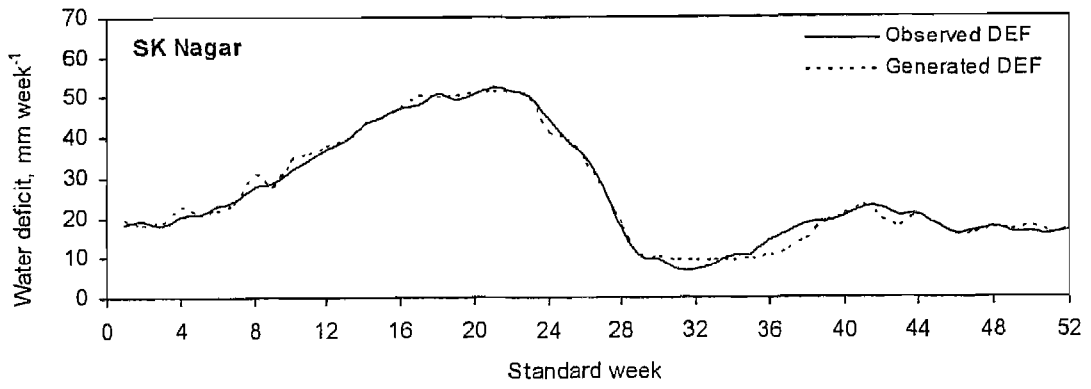


Fig. 4.11b Variation between weekly observed and generated water deficit by ANN for SK Nagar, Khedbrahma, Arnej and Dhandhuka

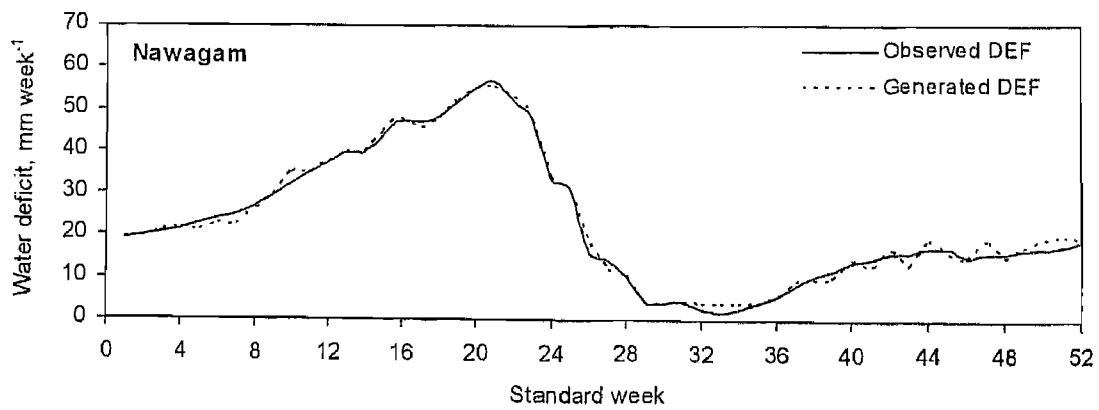
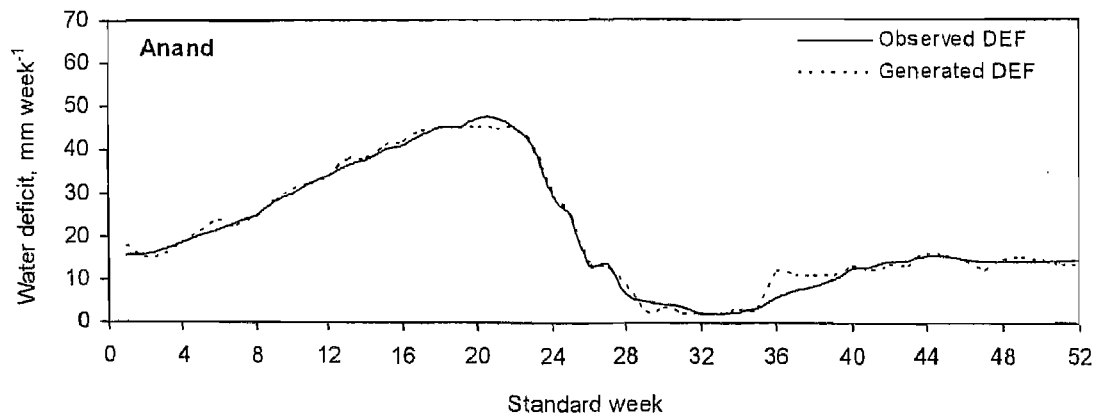
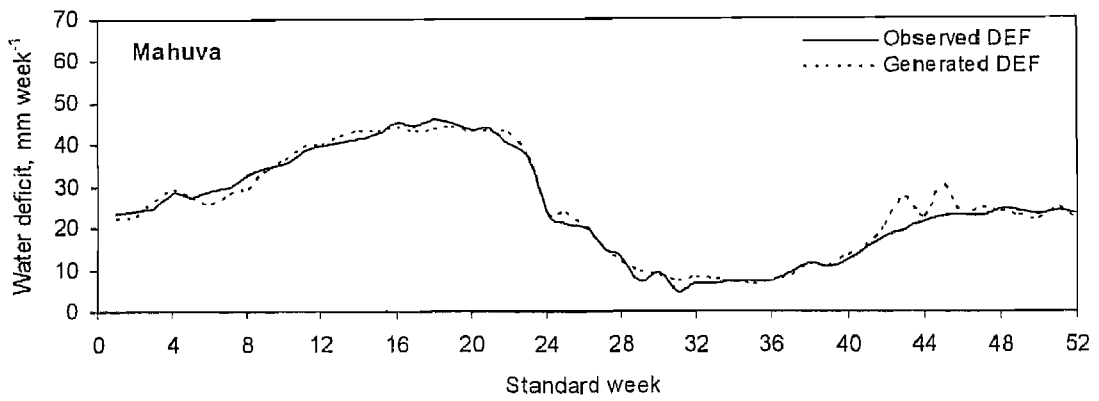
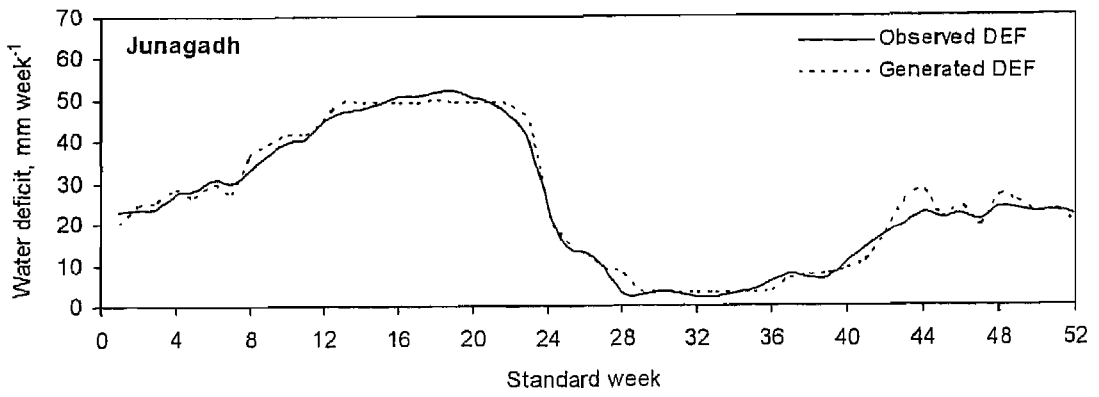


Fig. 4.11c Variation between weekly observed and generated water deficit by ANN for Junagadh, Mahuva, Anand and Nawagam

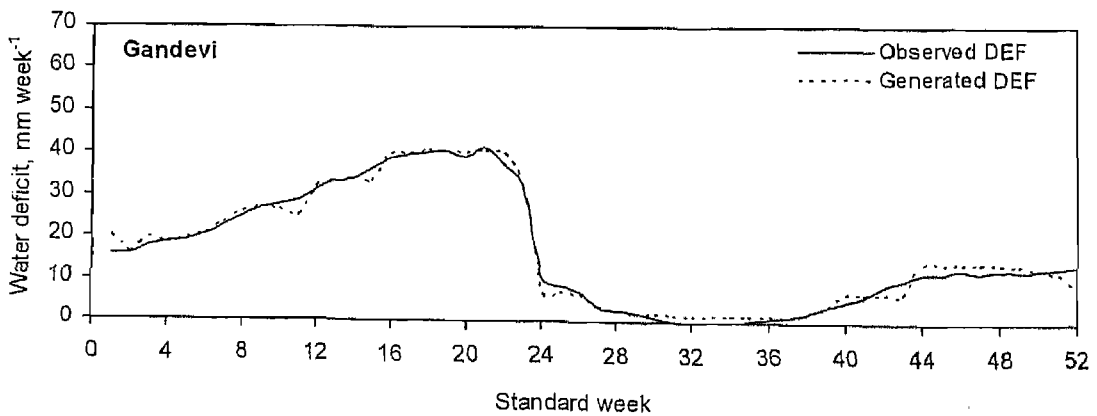
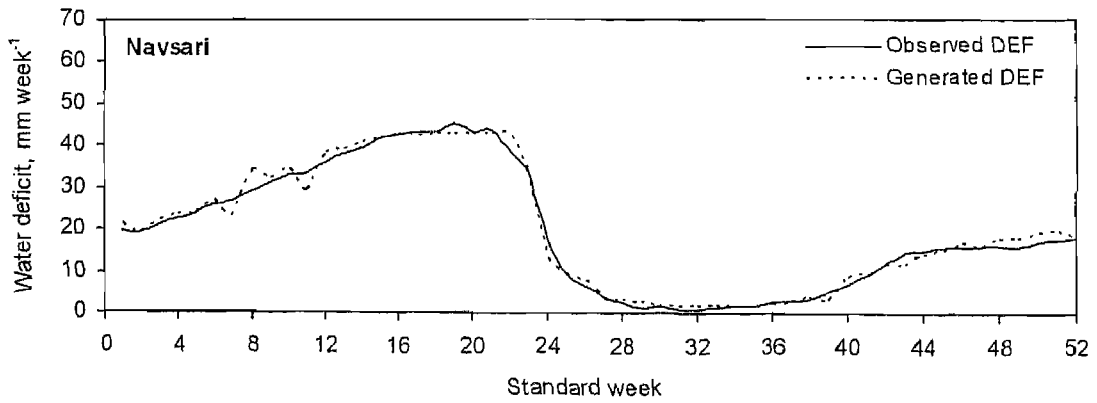
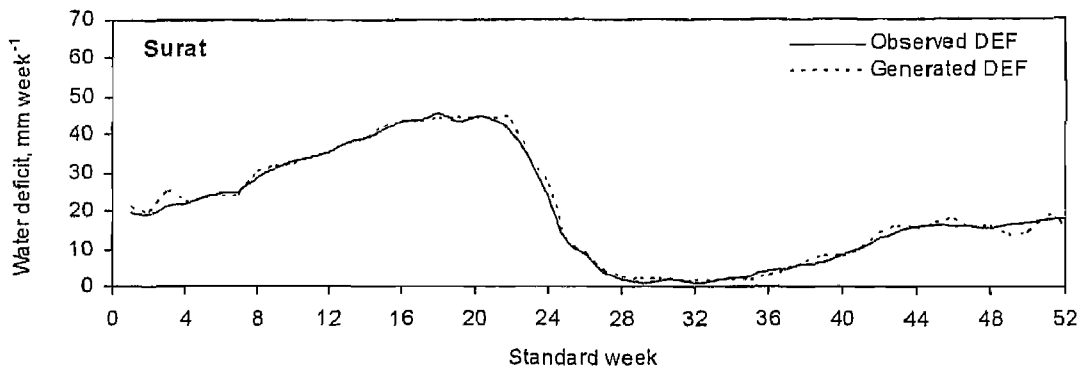
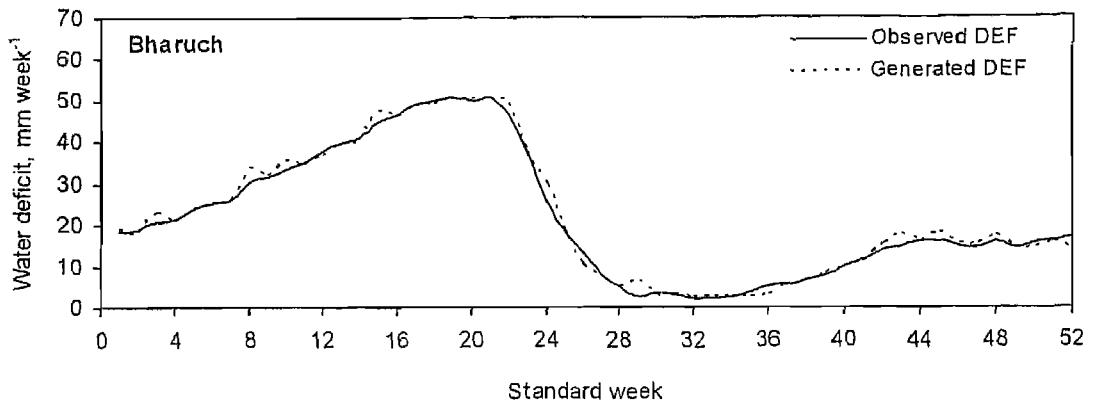


Fig. 4.11d Variation between weekly observed and generated water deficit by ANN for Bharuch, Surat, Navsari and Gandevi

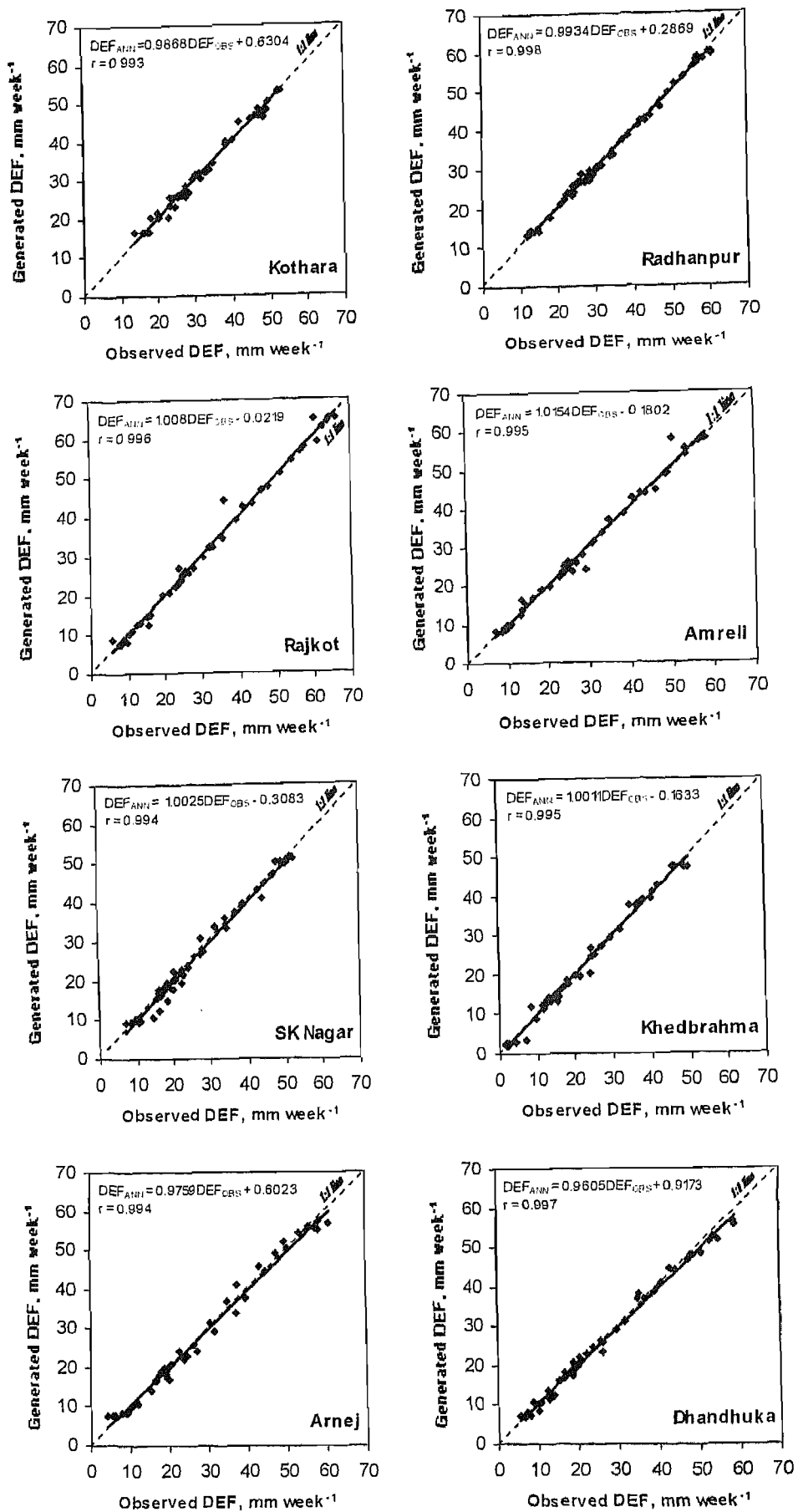


Fig. 4.12a Relationship between weekly observed and generated water deficit by ANN for Kothara, Radhanpur, Rajkot, Amreli, SK Nagar, Khedbrahma, Arnej and Dhandhuka

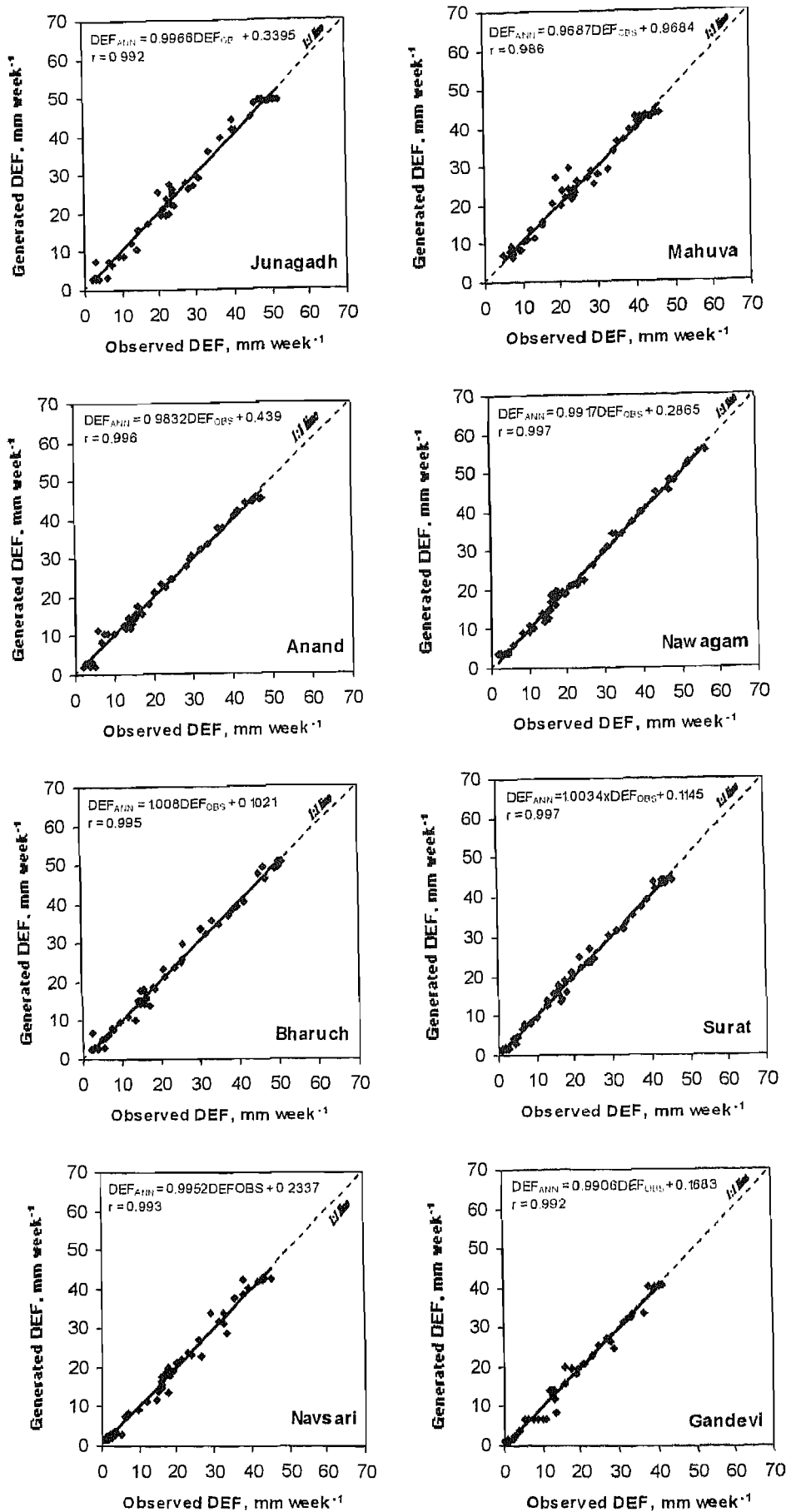


Fig. 4.12b Relationship between weekly observed and generated water deficit by ANN for Junagadh, Mahuva, Anand, Nawagam, Bharuch, Surat, Navsari and Gandevi

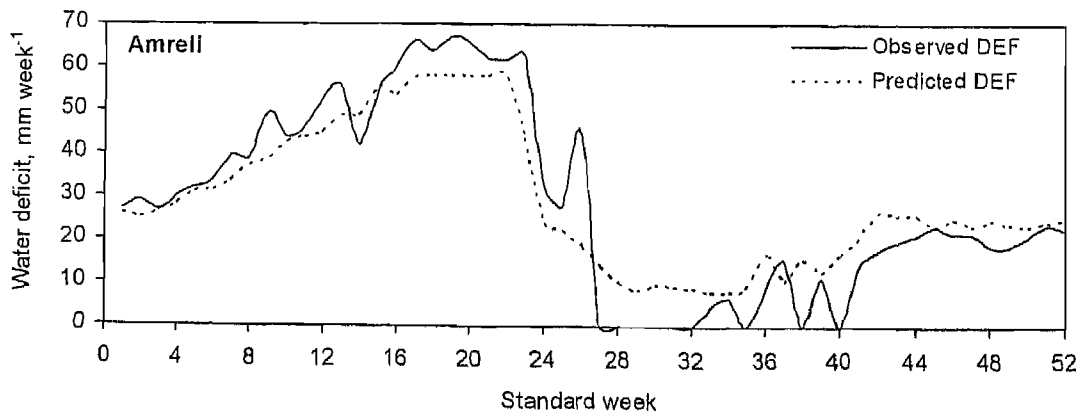
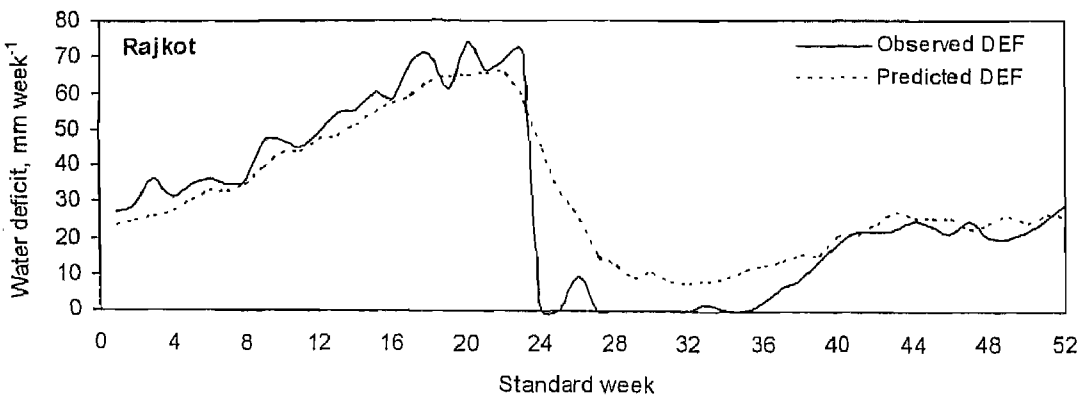
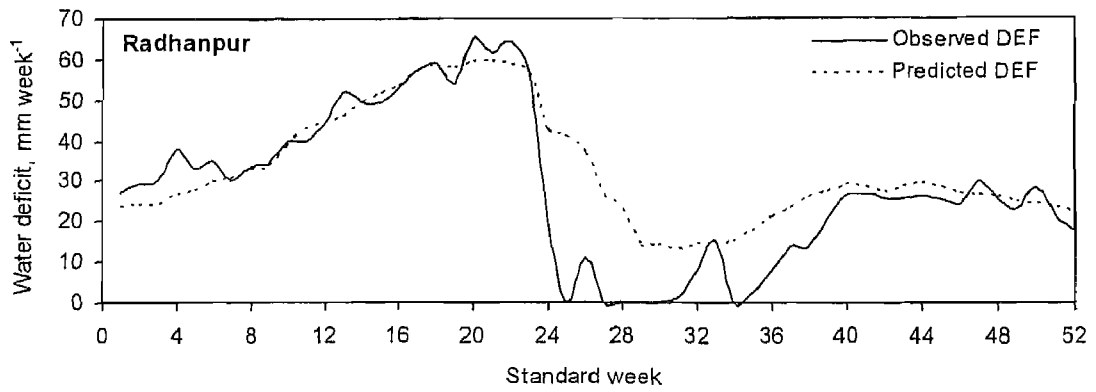
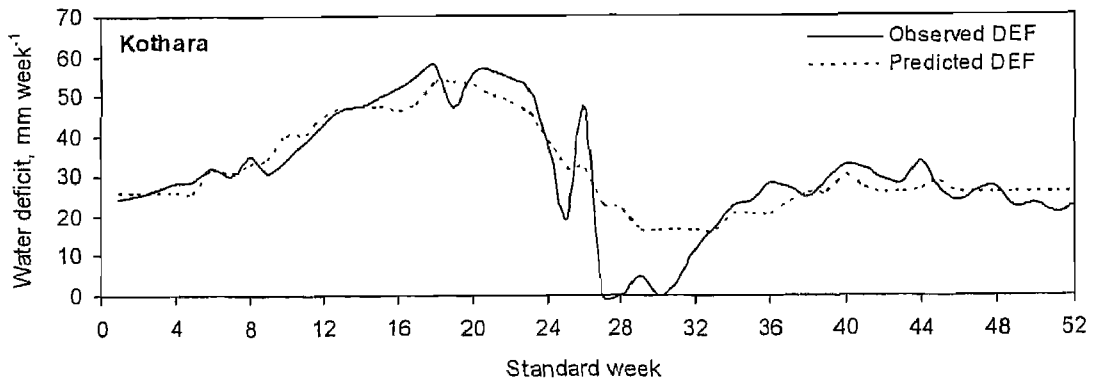


Fig. 4.13a Variation between weekly observed and predicted water deficit by ANN for the year 2003 for Kothara, Radhanpur, Rajkot and Amreli

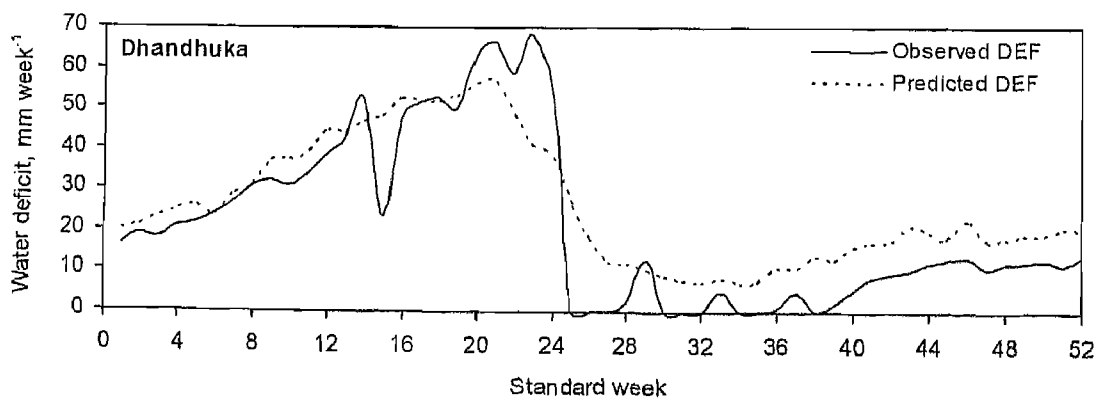
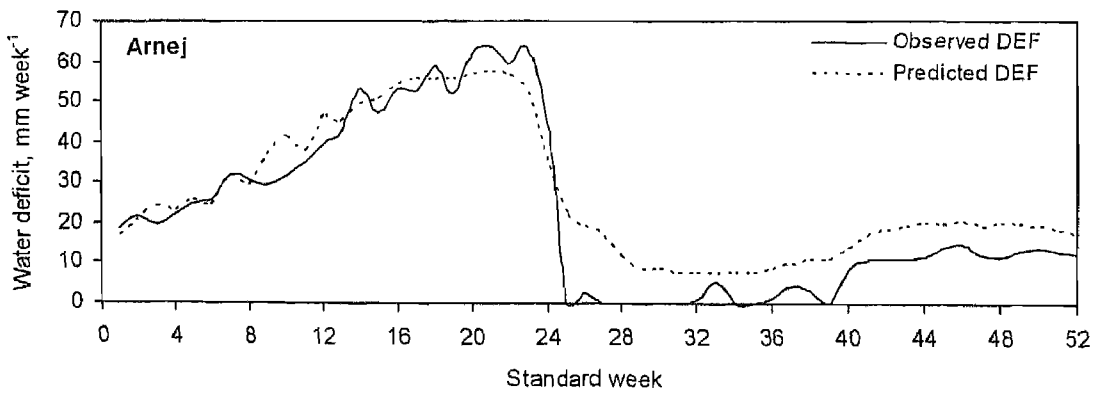
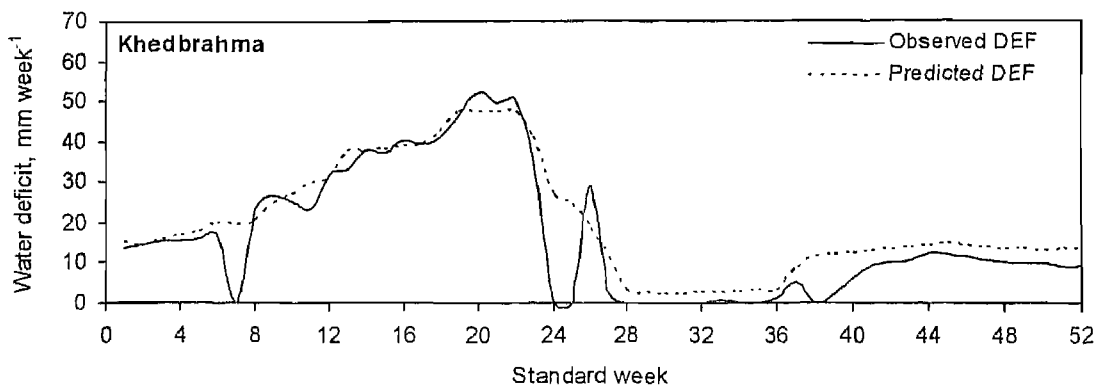
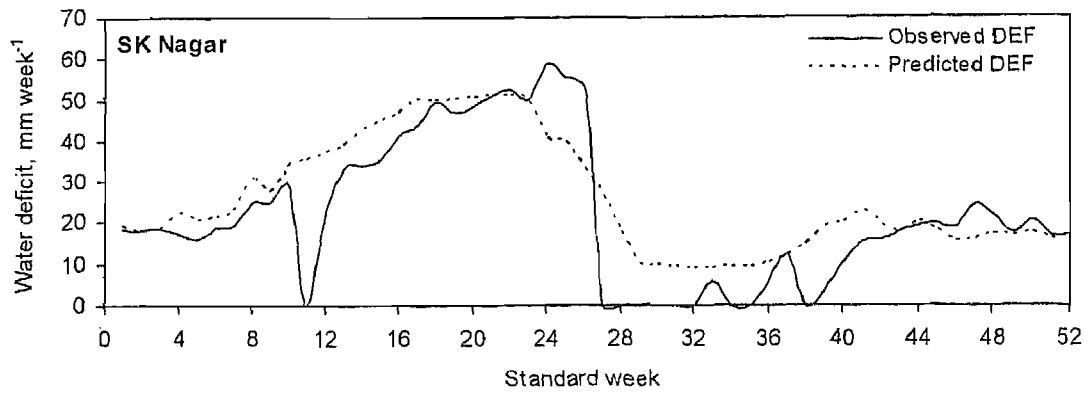


Fig. 4.13b Variation between weekly observed and predicted water deficit by ANN for the year 2003 for SK Nagar, Khedbrahma, Arnej and Dhandhuka

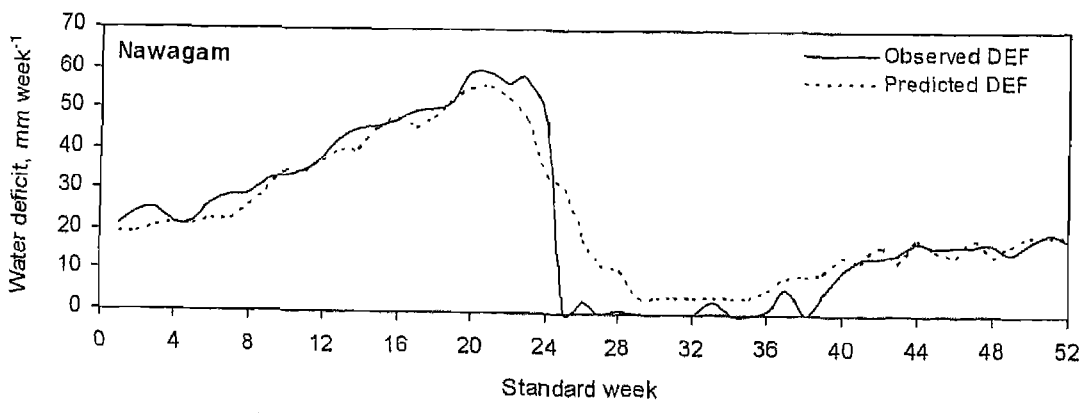
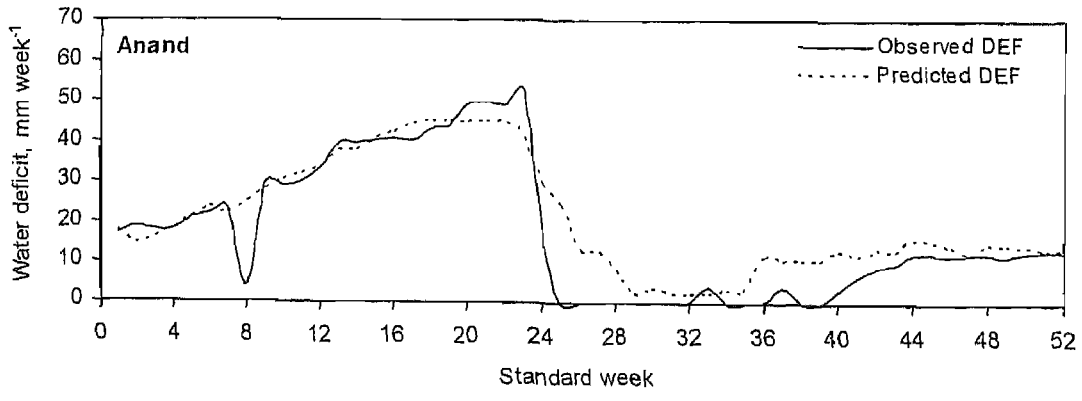
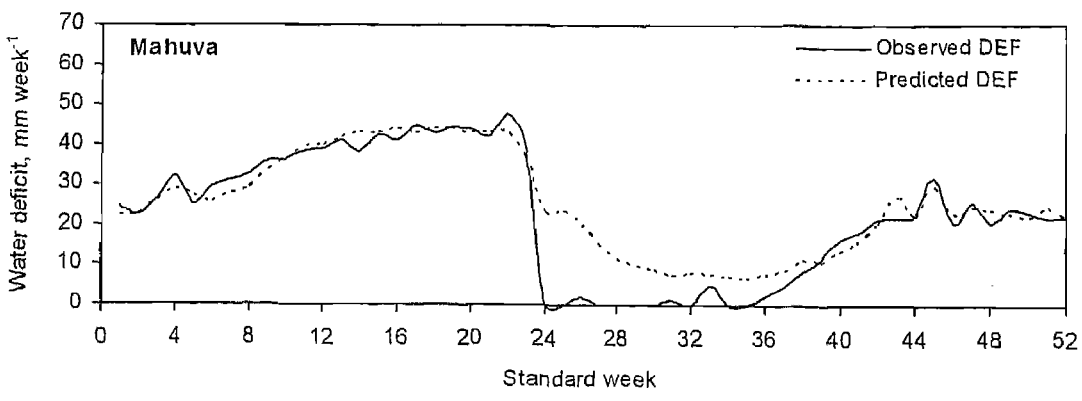
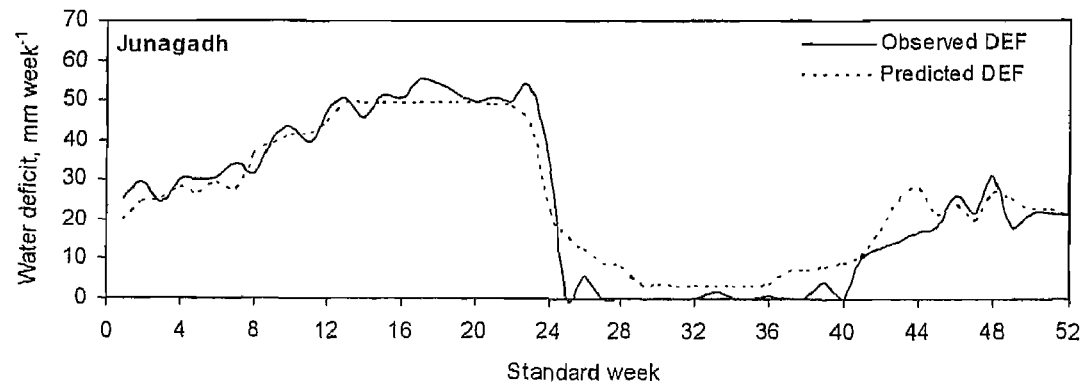


Fig. 4.13c Variation between weekly observed and predicted water deficit by ANN for the year 2003 for Junagadh, Mahuva, Anand and Nawagam

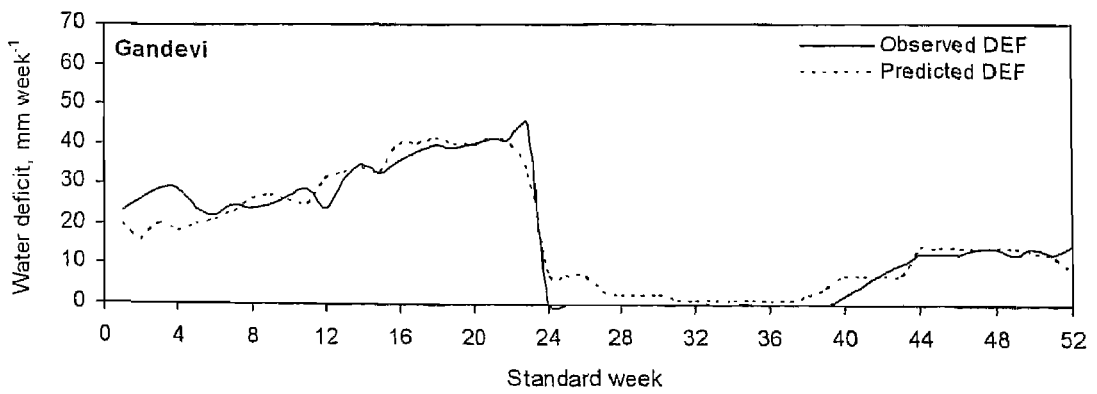
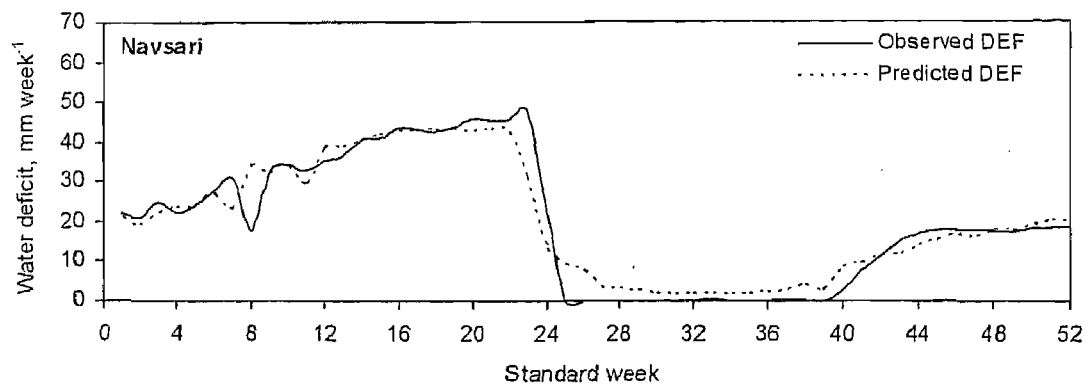
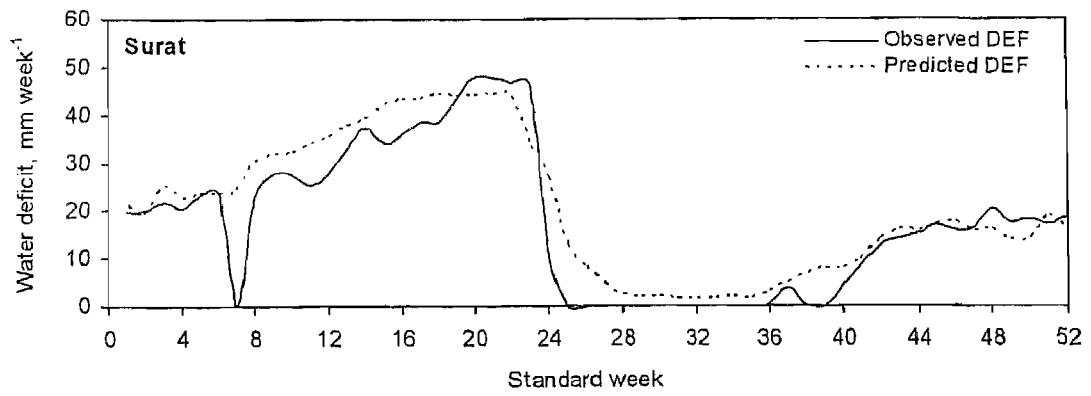
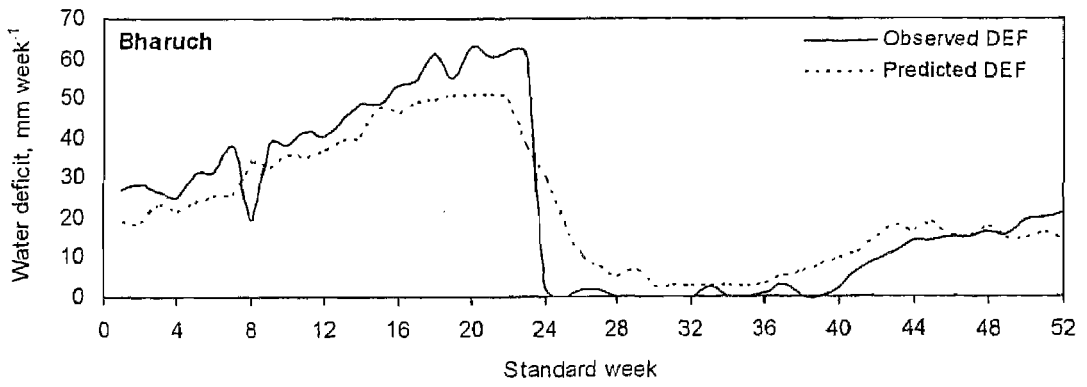


Fig. 4.13d Variation between weekly observed and predicted water deficit by ANN for the year 2003 for Bharuch, Surat, Navsari and Gandevi

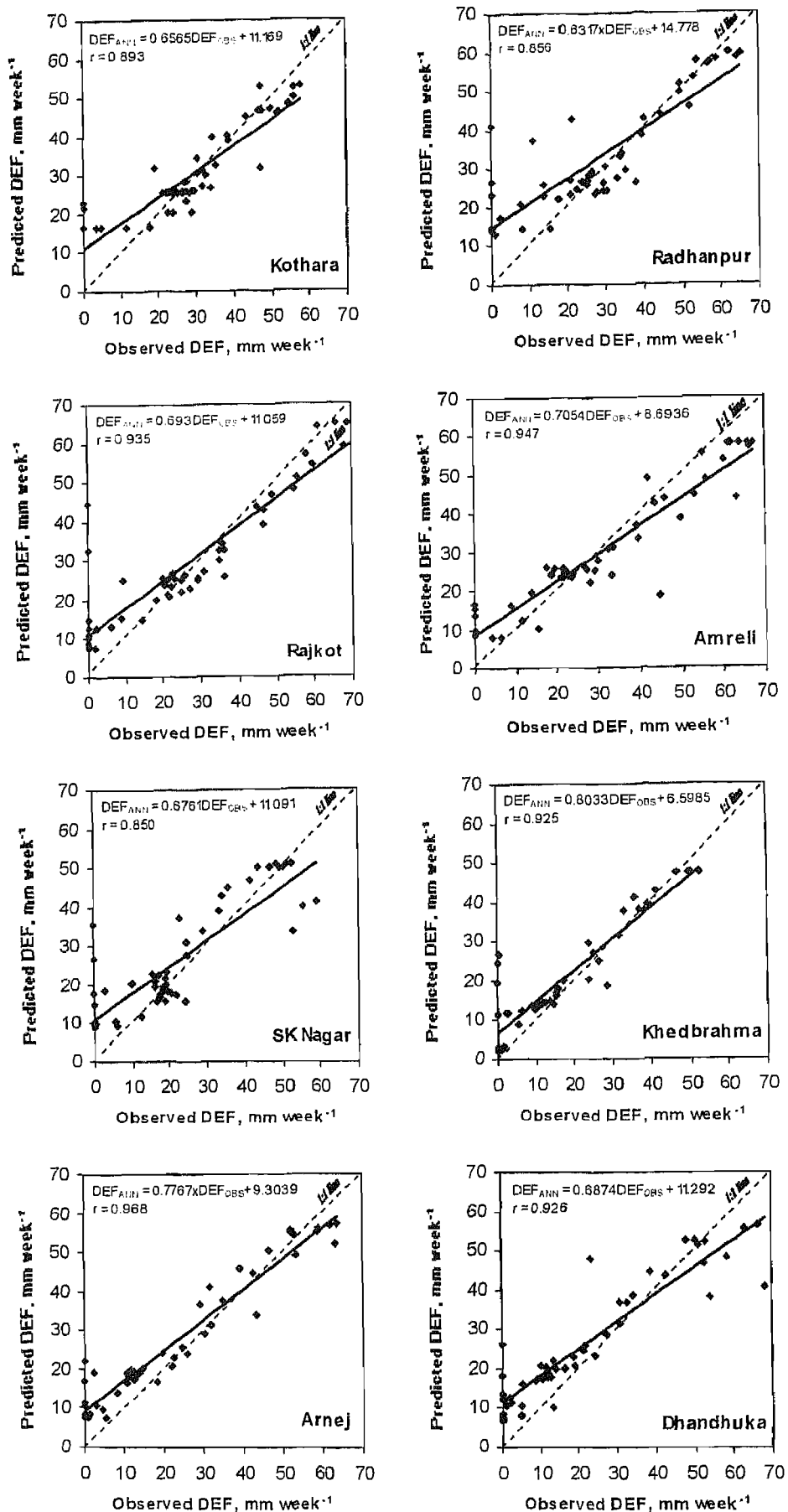


Fig. 4.14a Relationship between weekly observed and predicted water deficit by ANN for the year 2003 for Kothara, Radhanpur, Rajkot, Amreli, SK Nagar, Khedbrahma, Arnej and Dhandhuka

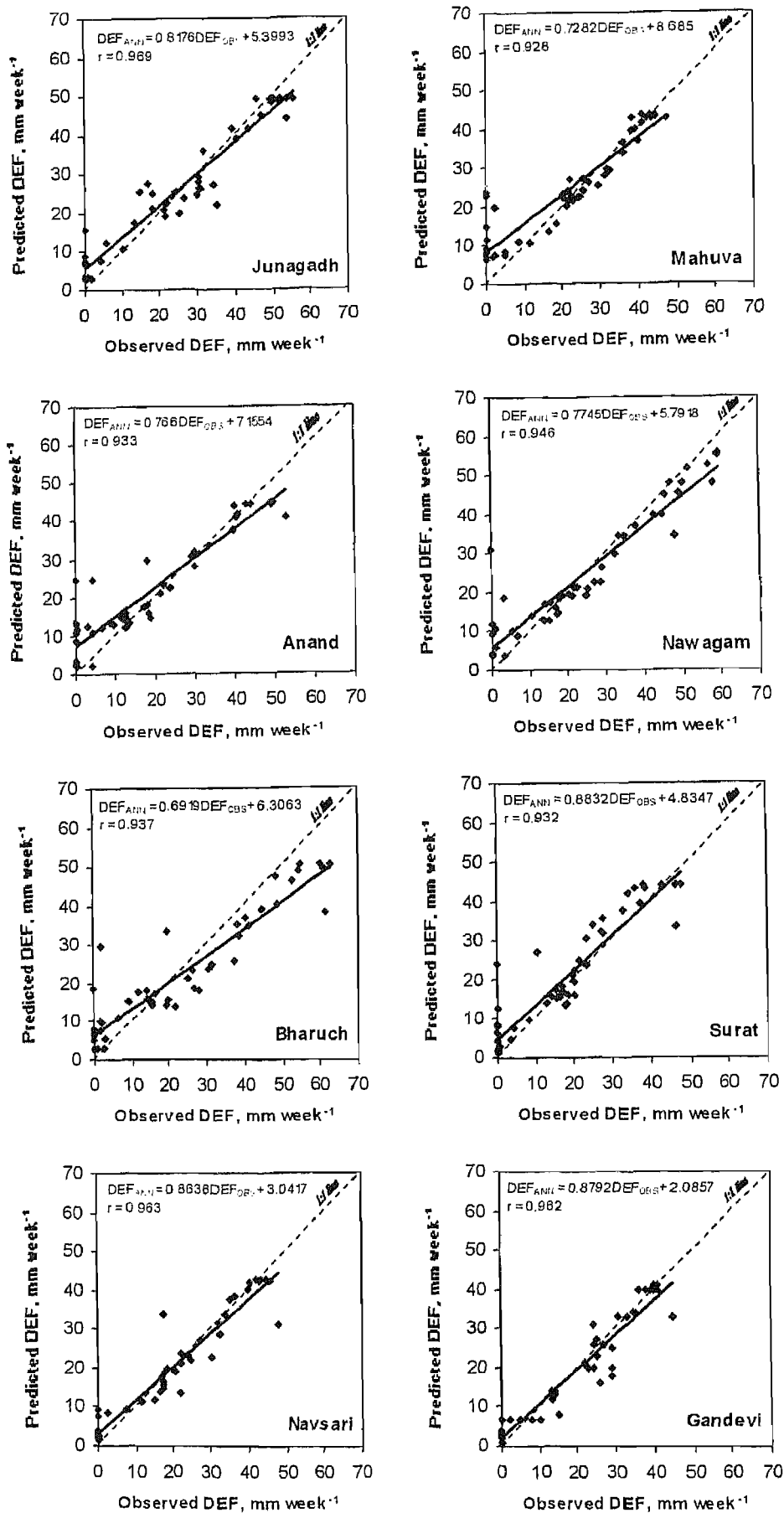


Fig. 4.14b Relationship between weekly observed and predicted water deficit by ANN for the year 2003 for Junagadh, Mahuva, Anand, Nawagam, Bharuch, Surat, Navsari and Gandevi

and Kendall's rank correlation test. The periodic component in the series was modelled by Fourier series analysis and the residuals from the Fourier series were modelled using an autoregressive model. The results are presented as under:

4.7.1 Statistical Characteristics of Water Deficit Series

Some of the statistical characteristics of weekly water deficit series used for stochastic modelling for the eight agro-climatic zones of Gujarat are computed and presented in Tables 4.20a to 4.20p. The mean weekly water deficit series, as shown in Tables 4.20a to 4.20p, in different agro-climatic zones varied from 13.45 mm in 29th standard meteorological week (smw) to 53.68 mm (19th smw) at Kothara, 11.60 mm (31st smw) to 60.61 mm (21st smw) at Radhanpur, 5.62 mm (29th smw) to 65.48 mm (20th smw) at Rajkot, 6.39 mm (33rd smw) to 58.13 mm (21st smw) at Amreli, 6.97 mm (31st smw) to 51.96 mm (21st smw) at SK Nagar, 1.70 mm (29th smw) to 50.20 mm (21st smw) at Khedbrahma, 2.85 mm (32nd smw) to 60.51 mm (20th smw) at Arnej, 5.38 mm (32nd smw) to 58.53 mm (20th smw) at Dhandhuka, 1.92 mm (33rd smw) to 51.88 mm (19th smw) at Junagadh, 5.03 mm (31st smw) to 46.23 mm (18th smw) at Mahuva, 1.95 mm (33rd smw) to 47.22 mm (21st smw) at Anand, 1.56 mm (33rd smw) to 56.38 mm (21st smw) at Nawagam, 2.23 mm (32nd smw) to 50.34 mm (19th smw) at Bharuch, 0.86 mm (32nd smw) to 46.10 mm (18th smw) at Surat, 0.51 mm (31st smw) to 45.40 mm (19th smw) at Navsari and 0.02 mm (32nd smw) to 41.40 mm (21st smw) at Gandevi, respectively. No Large variability among the weekly values of water deficit of different years was observed. This is further confirmed by the lower value of estimated standard deviations (SD).

The standard deviation of weekly water deficit ranged from 2.02 mm (6th smw) to 17.99 mm (25th smw) at Kothara, 1.93 mm (5th smw) to 19.78 mm (25th smw) at Radhanpur, 4.33 mm (2nd smw) to 28.25 mm (25th smw) at Rajkot, 4.93 mm (8th smw) to 22.42 mm (25th smw) at Amreli, 2.48 mm (6th smw) to 23.91 mm (24th smw) at SK Nagar, 2.40 mm (6th and 52nd smw) to 17.8 mm (25th and 26th smw) at Khedbrahma, 2.94 mm (1st smw) to 24.22 mm (25th smw) at Arnej, 3.07 mm (51st smw) to 23.58 mm (23rd smw) at Dhandhuka, 3.80 mm (2nd smw) to 20.51 mm (23rd smw) at Junagadh, 3.74 mm (13th smw) to 18.05 mm (25th smw) at Mahuva, 2.31 mm (6th smw) to 22.30 mm (25th smw) at Anand, 3.07 mm (1st smw) to 24.02 mm (25th smw) at Nawagam, 4.00 mm (33rd smw) to 21.67 mm (24th smw) at Bharuch, 2.25 mm (32nd smw) to 19.46 mm (24th smw) at Surat, 2.85 mm (35th smw) to 17.25 mm (23rd smw) at Navsari and 0.06 mm (32nd smw) to 13.61 mm (25th smw) at Gandevi, respectively, during the entire year.

Values of coefficient of variation (CV) as presented in Tables 4.20a to 4.20p indicate that they are greater than zero at all the stations, which shows the importance of time variability of weekly water deficit series. Further, the values of coefficient of variation

Table 4.20a Statistical characteristics of weekly water deficit series at Kothara (1974-01)

Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis	Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis
1	23.55	4.96	21.06	-2.23	5.28	27	25.30	14.16	55.99	-1.01	-0.64
2	23.93	2.25	9.39	-0.51	1.74	28	19.93	14.73	73.88	-0.22	-1.49
3	25.66	2.51	9.77	-0.56	0.24	29	13.45	14.55	108.14	0.54	-1.46
4	26.15	2.39	9.15	-0.03	0.34	30	17.88	14.62	81.79	-0.10	-1.71
5	26.79	6.30	23.51	-3.23	12.36	31	15.60	14.11	90.44	0.21	-1.72
6	30.27	2.02	6.67	0.14	0.68	32	16.15	15.00	92.94	0.25	-1.54
7	31.80	2.45	7.70	0.72	2.07	33	16.49	14.15	85.85	0.26	-1.28
8	33.85	3.51	10.38	-0.87	0.35	34	17.59	12.92	73.46	0.07	-1.38
9	34.87	3.28	9.42	-0.98	1.13	35	20.75	12.56	60.55	0.00	-0.75
10	38.41	4.45	11.60	1.33	4.52	36	22.76	12.92	56.76	-0.63	-0.63
11	40.02	2.49	6.22	-0.57	2.38	37	23.06	13.57	58.85	-0.54	-0.84
12	41.50	2.70	6.51	-0.20	-0.03	38	25.34	11.72	46.24	-0.77	-0.29
13	46.21	3.14	6.81	0.77	1.08	39	25.06	9.60	38.31	-0.85	0.01
14	46.82	2.54	5.43	-0.35	1.50	40	29.36	7.97	27.13	-2.03	5.99
15	47.83	3.21	6.71	-0.11	0.71	41	27.47	8.63	31.43	-2.48	6.28
16	48.25	3.22	6.67	0.11	0.79	42	26.14	10.03	38.38	-1.76	2.63
17	49.31	3.60	7.30	-0.89	1.01	43	27.88	6.76	24.25	-2.76	10.72
18	52.44	11.87	22.64	-2.28	13.00	44	28.39	8.08	28.48	-2.79	8.18
19	53.68	5.12	9.53	-1.94	5.19	45	28.09	6.57	23.38	-2.94	8.68
20	52.28	4.74	9.06	-0.54	-0.02	46	24.74	6.93	28.03	-2.26	5.71
21	49.61	10.24	20.64	-4.49	22.17	47	25.38	3.92	15.44	-2.11	5.15
22	47.22	9.57	20.27	-3.03	11.01	48	25.53	4.28	16.75	-0.68	2.00
23	44.89	10.44	23.25	-2.52	6.68	49	24.82	3.34	13.47	-0.63	0.99
24	38.25	13.70	35.81	-2.04	3.38	50	24.17	2.63	10.88	-0.82	0.43
25	31.43	17.99	57.24	-0.83	-0.98	51	24.79	3.15	12.70	-0.63	1.60
26	33.45	14.38	43.00	-1.40	1.12	52	23.42	2.83	12.07	0.01	-0.56

Table 4.20b Statistical characteristics of weekly water deficit series at Radhanpur (1982-01)

Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis	Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis
1	23.04	2.07	8.99	0.11	-0.24	27	28.68	19.22	67.02	-0.33	-1.62
2	23.69	2.12	8.95	0.31	0.36	28	24.11	17.74	73.61	-0.11	-1.22
3	24.24	1.99	8.23	0.92	2.01	29	13.89	16.64	119.74	0.65	-1.34
4	26.46	2.58	9.74	-0.28	2.15	30	15.27	17.22	112.78	0.77	-0.96
5	27.78	1.93	6.97	-0.67	-0.57	31	11.60	16.00	137.99	1.51	1.41
6	30.06	2.50	8.33	-0.13	0.65	32	13.43	13.67	101.80	0.87	-0.35
7	31.99	2.97	9.29	1.39	1.47	33	13.59	14.40	105.97	1.26	0.57
8	33.88	2.57	7.59	-0.09	-0.35	34	15.60	13.70	87.81	0.58	-0.58
9	34.71	5.19	14.94	-2.65	9.31	35	18.71	13.82	73.88	0.31	-0.54
10	38.93	3.25	8.35	2.19	6.84	36	21.75	12.22	56.22	-0.43	-0.91
11	41.91	2.19	5.23	0.46	-0.24	37	24.47	14.01	57.24	-0.66	-0.82
12	44.47	3.21	7.22	0.34	0.36	38	25.34	15.11	59.61	-0.55	-1.21
13	46.49	4.05	8.71	1.09	0.75	39	25.44	12.98	51.02	-0.31	-1.15
14	49.15	3.20	6.52	-0.07	0.23	40	29.36	10.05	34.22	-1.15	0.90
15	51.43	4.24	8.25	-1.24	5.19	41	29.44	9.48	32.19	-1.56	3.76
16	52.93	3.21	6.06	0.20	-1.26	42	28.62	8.86	30.96	-1.99	5.10
17	56.50	5.25	9.28	2.20	6.87	43	28.22	6.54	23.16	-3.21	12.27
18	57.89	4.72	8.15	-0.09	-0.47	44	28.61	5.58	19.49	-2.95	10.99
19	56.86	14.53	25.56	-3.41	13.49	45	26.40	7.70	29.16	-2.65	7.60
20	60.37	7.44	12.32	-2.75	9.97	46	25.48	6.22	24.43	-1.44	3.11
21	60.61	5.97	9.85	-1.47	3.16	47	24.49	4.08	16.68	-2.05	4.09
22	56.47	10.62	18.80	-2.02	4.58	48	24.10	3.78	15.69	-1.06	0.87
23	55.63	11.01	19.79	-3.04	10.97	49	24.16	3.97	16.45	-0.21	-0.32
24	42.91	18.63	43.43	-1.20	0.93	50	22.55	3.11	13.77	-0.94	0.92
25	43.69	19.78	45.27	-1.66	1.56	51	23.64	2.85	12.04	-0.73	0.75
26	40.64	15.22	37.45	-1.05	0.29	52	22.39	2.71	12.11	-0.06	-1.13

Table 4.20c Statistical characteristics of weekly water deficit series at Rajkot (1978-01)

Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis	Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis
1	23.54	5.20	22.07	-0.19	0.63	27	15.85	21.76	137.28	1.10	-0.23
2	24.52	4.33	17.67	0.44	-0.27	28	12.99	16.60	127.82	1.45	1.72
3	26.23	5.01	19.08	0.72	1.15	29	5.62	7.93	141.05	1.73	3.44
4	27.66	4.43	16.02	0.28	1.24	30	10.19	14.35	140.76	1.08	-0.19
5	30.06	5.38	17.89	0.28	-0.70	31	9.54	15.25	159.74	2.38	6.89
6	32.02	4.78	14.94	0.81	0.82	32	8.00	11.94	149.37	1.81	2.93
7	32.73	4.86	14.84	0.51	0.15	33	7.50	9.65	128.70	1.58	1.87
8	35.71	4.51	12.62	0.28	-0.24	34	9.40	12.26	130.47	1.50	1.50
9	38.73	5.09	13.16	-0.33	-0.39	35	11.53	13.14	114.04	1.38	1.10
10	40.82	5.74	14.06	0.07	0.41	36	15.80	14.01	88.67	1.04	0.36
11	43.92	5.05	11.49	-0.68	1.09	37	12.79	11.85	92.72	1.21	1.80
12	45.76	6.62	14.47	-0.21	-0.65	38	15.95	15.00	94.04	0.82	0.22
13	47.77	6.35	13.30	0.37	0.57	39	14.30	14.21	99.41	0.90	0.28
14	50.69	5.74	11.32	-0.27	-0.39	40	18.59	13.14	70.66	0.35	-0.31
15	53.49	5.29	9.89	-0.45	0.46	41	20.54	13.97	68.00	0.80	0.81
16	56.70	7.14	12.59	0.41	0.12	42	23.42	11.57	49.40	0.54	0.58
17	60.41	9.05	14.98	-0.02	-0.23	43	23.68	9.15	38.63	-0.13	0.13
18	61.73	8.51	13.79	-0.15	-0.69	44	24.67	9.83	39.86	-0.88	1.96
19	63.46	12.14	19.13	-2.09	6.27	45	25.04	9.38	37.47	-0.45	2.11
20	65.48	7.51	11.47	0.79	0.39	46	24.45	8.92	36.46	-0.78	1.56
21	63.85	9.84	15.42	-0.04	0.68	47	22.86	7.00	30.62	-1.69	4.11
22	59.85	20.84	34.83	-2.02	4.52	48	24.27	5.54	22.81	-0.94	1.49
23	56.78	17.45	30.74	-1.16	0.83	49	24.87	6.29	25.28	0.16	0.72
24	37.41	21.87	58.47	-0.78	-0.81	50	24.25	4.47	18.43	0.05	1.12
25	34.22	28.25	82.54	-0.28	-1.71	51	25.63	6.69	26.09	0.52	1.44
26	26.83	23.83	88.81	0.39	-1.06	52	24.79	4.47	18.04	0.13	-0.08

Table 4.20d Statistical characteristics of weekly water deficit series at Amreli (1974-01)

Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis	Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis
1	24.23	5.37	22.15	0.45	-0.07	27	14.19	16.88	118.96	0.96	-0.33
2	24.82	5.48	22.10	0.66	0.51	28	9.71	13.49	138.90	1.37	0.98
3	26.75	7.08	26.46	0.90	0.51	29	9.12	11.39	124.91	1.16	0.97
4	27.99	5.67	20.24	0.82	0.34	30	10.81	12.96	119.80	0.73	-1.15
5	30.70	5.95	19.38	0.24	-0.41	31	8.92	11.57	129.69	1.35	1.08
6	30.80	5.27	17.09	0.91	0.45	32	9.47	11.25	118.71	0.93	-0.72
7	32.91	5.49	16.67	0.51	-0.36	33	6.39	7.16	112.14	1.43	1.65
8	34.66	4.93	14.23	0.53	-0.51	34	8.69	10.28	118.25	1.02	0.05
9	37.87	6.13	16.19	0.23	-0.70	35	9.10	11.86	130.33	1.15	0.39
10	40.25	6.18	15.36	0.78	-0.01	36	13.65	12.78	93.67	0.74	-0.72
11	42.39	6.91	16.30	0.97	1.63	37	9.69	9.94	102.50	1.02	0.15
12	45.44	7.47	16.44	0.28	-0.99	38	15.00	11.93	79.52	0.47	-0.49
13	47.93	7.03	14.67	-0.01	-0.79	39	12.50	14.05	112.43	0.92	0.15
14	49.06	7.50	15.30	-0.01	-1.08	40	15.99	14.43	90.27	0.41	-0.96
15	53.06	6.40	12.07	-0.30	-0.06	41	20.14	13.65	67.77	0.68	1.15
16	52.83	7.55	14.28	0.60	0.74	42	24.85	15.72	63.27	1.20	1.93
17	55.98	8.61	15.37	0.01	0.22	43	25.61	11.52	44.99	-0.27	1.07
18	56.86	11.30	19.88	-0.73	0.24	44	26.98	9.65	35.75	-0.30	2.29
19	57.42	10.15	17.67	-0.87	0.95	45	25.90	10.19	39.33	-0.07	2.33
20	57.97	13.19	22.75	-1.71	4.55	46	24.49	10.29	42.01	-0.87	0.60
21	58.13	11.46	19.72	-0.42	0.53	47	24.01	10.20	42.47	-0.19	3.02
22	49.28	15.66	31.77	-1.26	2.14	48	24.54	10.13	41.29	-0.12	2.12
23	43.24	19.43	44.93	-1.17	0.57	49	23.84	7.57	31.74	0.03	0.76
24	28.74	21.21	73.81	-0.2	-1.73	50	23.37	6.04	25.83	-0.05	1.54
25	21.78	22.42	102.94	0.26	-1.82	51	24.82	6.57	26.46	0.52	0.65
26	18.09	18.6	102.83	0.45	-1.54	52	23.74	5.35	22.54	0.39	-0.17

Table 4.20e Statistical characteristics of weekly water deficit series at SK Nagar (1974-01)

Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis	Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis
1	17.68	2.76	15.60	0.29	0.89	27	29.00	22.62	78.01	-0.21	-1.68
2	18.59	3.65	19.64	-0.48	-0.39	28	17.78	15.96	89.73	0.80	0.25
3	18.83	3.35	17.76	-0.38	1.41	29	9.87	16.07	162.79	1.52	1.06
4	20.31	2.66	13.12	1.01	2.46	30	9.49	13.74	144.73	1.43	1.37
5	20.54	4.70	22.89	-1.51	5.24	31	6.97	12.63	181.19	2.73	9.04
6	22.75	2.48	10.88	0.82	-0.21	32	7.67	11.13	145.08	1.68	2.44
7	24.51	4.12	16.82	-1.52	6.76	33	7.70	9.79	127.16	1.18	0.07
8	27.60	4.00	14.49	0.60	0.77	34	10.47	11.22	107.19	0.92	-0.33
9	28.48	4.51	15.84	-2.02	8.57	35	11.14	13.25	118.92	1.02	0.10
10	31.61	3.66	11.56	0.81	1.34	36	15.19	13.06	85.97	0.37	-1.28
11	35.69	3.86	10.81	0.57	0.21	37	15.72	13.91	88.46	0.48	-1.12
12	37.60	3.75	9.96	-0.39	-1.10	38	18.91	13.39	70.79	-0.05	-1.44
13	39.18	3.98	10.15	-0.41	-0.84	39	18.75	11.48	61.26	0.08	-1.06
14	43.41	6.25	14.41	-0.17	0.49	40	20.01	10.99	54.94	-0.58	-0.82
15	45.31	7.31	16.14	1.72	5.26	41	22.55	8.90	39.47	-0.89	0.75
16	47.22	5.92	12.54	0.15	-0.29	42	22.40	9.21	41.10	-1.23	0.93
17	47.83	11.67	24.40	-2.21	5.65	43	20.10	7.84	39.02	-1.57	2.21
18	50.55	6.71	13.27	-0.01	1.68	44	20.33	6.92	34.04	-1.44	2.17
19	49.16	15.04	30.59	-2.66	7.34	45	17.60	6.28	35.69	-1.83	2.97
20	50.73	10.80	21.30	-2.55	9.12	46	15.54	7.52	48.42	-1.12	0.48
21	51.96	7.18	13.81	-1.07	0.42	47	16.41	4.67	28.48	-1.80	4.62
22	51.70	10.10	19.54	-1.85	4.11	48	17.36	4.68	26.94	-1.00	2.39
23	49.82	14.15	28.41	-2.16	4.97	49	15.86	3.52	22.19	-0.04	2.90
24	43.80	23.91	54.60	-0.05	1.42	50	16.10	4.42	27.45	-1.92	5.34
25	38.12	21.65	56.79	-0.78	-0.85	51	15.65	4.15	26.49	-1.96	6.77
26	35.34	21.40	60.55	-0.73	-0.79	52	16.81	2.61	15.55	0.77	0.79

Table 4.20f Statistical characteristics of weekly water deficit series at Khedbrahma (1978-01)

Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis	Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis
1	15.00	4.50	29.80	1.80	4.70	27	12.60	16.20	128.70	0.80	-1.00
2	15.80	4.30	27.50	1.90	2.80	28	4.30	8.30	192.50	2.30	4.90
3	16.30	3.20	19.60	1.70	2.80	29	1.70	5.90	348.90	4.40	20.00
4	17.60	4.10	23.50	1.40	1.60	30	1.90	6.20	319.40	4.40	20.50
5	18.50	2.90	15.70	1.70	2.60	31	2.00	6.50	329.40	4.20	18.70
6	20.30	2.40	11.90	1.00	0.20	32	2.20	3.50	158.40	1.60	1.40
7	22.50	3.20	14.30	2.90	10.90	33	2.70	5.60	204.90	2.80	7.60
8	24.30	4.00	16.30	1.80	4.20	34	2.80	4.20	152.00	2.30	6.50
9	25.30	5.40	21.50	-0.40	6.10	35	4.70	5.00	107.40	1.10	0.80
10	27.40	4.70	17.20	1.60	3.60	36	7.40	7.50	101.40	0.80	-0.50
11	30.00	3.80	12.80	0.80	1.00	37	10.00	8.00	80.80	0.50	0.20
12	32.00	3.80	11.90	0.90	1.20	38	12.40	8.80	71.00	0.20	-0.40
13	34.90	4.30	12.30	0.40	0.30	39	8.60	8.20	95.50	0.50	-1.10
14	36.80	3.40	9.20	1.30	2.30	40	11.70	7.60	65.30	-0.10	-1.60
15	37.20	3.30	8.80	-0.30	0.90	41	13.30	7.00	52.60	0.00	-0.90
16	38.30	9.10	23.90	-3.30	14.30	42	15.70	4.90	31.00	-0.20	-0.80
17	40.50	6.00	14.90	-2.50	9.80	43	14.00	6.10	43.70	-1.10	0.60
18	42.10	5.50	13.10	-1.30	1.40	44	15.80	3.80	24.00	-1.00	0.70
19	46.10	8.80	19.00	1.80	6.40	45	14.60	4.30	29.80	-1.90	4.60
20	49.70	8.00	16.20	2.90	12.70	46	13.10	4.70	36.00	-1.10	1.40
21	50.20	5.50	11.00	0.70	2.10	47	14.50	4.20	28.90	-1.70	5.60
22	46.50	15.40	33.20	-1.70	3.70	48	13.70	2.50	18.60	0.30	0.10
23	40.80	12.50	30.60	-1.40	1.50	49	13.10	3.40	26.10	0.10	2.10
24	26.90	16.80	62.30	-0.40	-1.00	50	12.30	3.30	26.60	-1.10	6.90
25	25.40	17.80	70.10	-0.40	-1.50	51	13.30	5.00	37.30	0.90	6.20
26	18.60	17.80	95.80	0.30	-1.60	52	13.10	2.40	18.40	1.60	2.40

Table 4.20g Statistical characteristics of weekly water deficit series at Arnej (1982-01)

Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis	Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis
1	20.03	2.94	14.61	-0.97	2.10	27	16.75	20.10	118.98	0.85	-0.88
2	20.25	5.55	27.28	-2.78	9.08	28	9.82	14.22	131.90	1.26	0.42
3	22.55	3.15	13.89	-0.58	1.24	29	6.38	8.88	133.69	1.02	-0.64
4	24.41	3.73	15.23	-0.55	-0.34	30	7.19	9.83	122.17	0.89	-0.70
5	26.05	4.11	15.73	-0.47	0.34	31	3.62	8.05	155.53	2.02	4.73
6	26.92	3.04	11.27	-0.96	1.19	32	2.85	4.36	120.99	1.36	1.68
7	30.46	3.14	10.30	-1.27	2.67	33	4.28	5.03	115.34	1.00	0.05
8	31.84	3.48	10.91	0.71	1.12	34	6.23	7.48	114.02	1.05	0.08
9	35.49	3.98	11.19	0.56	2.40	35	5.52	6.72	105.59	0.64	-1.05
10	37.87	3.82	10.08	-0.53	1.33	36	8.81	10.53	103.98	0.77	-0.79
11	40.06	3.09	7.71	-1.01	2.70	37	8.53	10.52	106.76	0.81	-0.55
12	43.20	6.19	14.31	-2.24	7.53	38	11.05	10.86	88.29	0.25	-1.40
13	44.65	3.13	7.00	-0.38	0.73	39	9.78	9.74	86.19	0.52	-0.88
14	47.14	7.26	15.40	-2.23	5.93	40	14.35	10.73	69.59	0.14	-0.86
15	50.36	4.37	8.68	-0.59	0.33	41	15.44	10.46	64.24	-0.23	-0.96
16	52.78	5.77	10.93	-0.87	2.23	42	16.80	8.54	48.80	-0.27	0.16
17	57.97	13.46	23.22	0.86	0.73	43	17.54	9.31	51.43	-0.27	-0.71
18	54.33	12.50	22.99	-1.75	3.78	44	19.49	6.40	32.06	-0.59	-0.32
19	58.06	8.95	15.42	-0.79	1.99	45	18.16	6.97	37.62	-0.99	1.23
20	60.51	9.31	15.43	-1.32	1.81	46	20.10	6.67	32.55	0.29	-0.46
21	57.97	17.90	30.87	-2.52	6.37	47	18.45	5.19	27.73	0.17	-0.49
22	55.53	15.87	28.57	-2.42	7.59	48	19.19	4.45	22.92	-0.39	-0.48
23	48.29	19.76	40.91	-1.66	2.07	49	19.43	4.85	24.71	0.01	-0.68
24	37.63	21.22	59.19	-0.58	-1.07	50	18.77	3.36	17.77	0.26	0.04
25	24.65	24.22	92.65	0.01	-1.90	51	19.31	3.24	16.66	-0.69	0.16
26	19.77	19.21	91.79	0.18	-1.47	52	19.81	3.23	16.21	-0.48	0.56

Table 4.20h Statistical characteristics of weekly water deficit series at Dhandhuka (1982-01)

Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis	Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis
1	20.37	3.57	17.55	-0.45	1.02	27	15.35	16.55	107.79	0.96	0.22
2	20.20	4.42	21.90	-1.34	3.00	28	13.51	14.47	107.05	0.74	-0.80
3	22.33	3.34	14.96	-0.56	0.24	29	9.90	12.79	129.28	1.54	1.86
4	23.81	3.35	14.06	-0.34	1.01	30	10.05	12.27	122.15	0.95	-0.37
5	26.49	4.63	17.47	-0.38	-0.16	31	7.12	10.99	154.47	2.37	6.47
6	26.40	3.10	11.74	-0.59	0.46	32	5.38	7.81	145.10	1.38	0.64
7	29.98	3.64	12.15	-1.29	2.96	33	6.68	8.03	120.29	1.34	1.11
8	31.90	3.12	9.80	-0.51	0.32	34	7.51	9.28	123.61	1.04	-0.12
9	35.19	4.20	11.93	-0.03	-0.30	35	8.56	9.91	115.68	0.96	-0.41
10	36.96	3.43	9.29	-0.22	1.76	36	11.67	11.25	96.45	0.60	-0.94
11	39.74	3.16	7.96	-0.39	1.93	37	9.05	10.76	118.95	1.21	0.45
12	43.26	3.56	8.22	-0.90	1.28	38	13.71	9.87	72.04	0.17	-0.83
13	44.26	5.65	12.77	-1.89	4.00	39	14.40	12.32	85.56	0.53	-0.51
14	47.27	5.02	10.62	-1.92	6.04	40	16.23	11.28	69.49	0.04	-0.94
15	49.96	4.81	9.63	-0.78	1.47	41	17.03	11.54	67.76	-0.21	-0.94
16	53.79	6.90	12.82	-0.37	1.23	42	17.50	10.11	57.79	-0.21	-0.51
17	52.77	9.68	18.35	-0.63	0.23	43	19.47	9.10	46.74	-0.75	0.12
18	54.08	11.18	20.67	-2.51	7.68	44	20.10	6.82	33.91	-0.52	-0.04
19	54.36	14.22	26.17	-3.15	12.09	45	19.04	6.92	36.34	-1.35	2.00
20	58.53	9.78	16.70	-0.65	1.60	46	21.27	7.31	34.34	-0.20	-0.19
21	58.06	12.57	21.65	-0.90	1.94	47	19.43	5.05	25.99	-0.98	0.89
22	49.80	18.21	36.56	-2.24	4.69	48	17.85	5.43	30.44	-1.97	5.52
23	38.43	23.58	61.36	-0.64	-1.28	49	19.44	3.95	20.29	0.00	0.30
24	33.34	20.08	60.22	-0.41	-1.00	50	18.76	3.24	17.28	-0.75	0.57
25	28.35	22.90	80.80	-0.13	-1.68	51	19.83	3.07	15.49	-1.27	2.50
26	18.44	18.12	98.28	0.40	-1.09	52	19.74	3.30	16.73	-0.63	0.88

Table 4.20i Statistical characteristics of weekly water deficit series at Junagadh (1974-01)

Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis	Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis
1	22.95	4.01	17.46	0.29	0.30	27	9.86	13.14	133.24	1.22	0.07
2	23.50	3.80	16.17	0.43	0.02	28	3.07	6.99	227.41	3.18	11.21
3	23.71	4.73	19.94	-0.27	-0.42	29	2.81	7.16	255.42	3.76	15.81
4	27.29	4.37	16.02	-0.27	0.03	30	3.38	6.41	189.80	2.12	4.08
5	28.12	5.37	19.10	0.67	0.63	31	2.82	8.61	305.79	4.56	22.27
6	30.78	5.08	16.52	-0.07	-0.94	32	2.37	4.92	207.75	2.44	5.66
7	29.38	7.52	25.61	-2.16	7.97	33	1.92	4.36	227.64	2.67	6.33
8	33.20	5.54	16.69	0.38	-0.29	34	3.08	6.19	200.89	2.65	6.98
9	36.26	4.90	13.52	-0.76	-0.41	35	4.07	7.05	173.00	2.20	3.89
10	39.25	7.86	20.03	0.79	2.06	36	6.18	8.81	142.64	1.70	2.48
11	40.68	6.84	16.81	-0.52	0.30	37	7.50	9.75	129.99	1.52	1.48
12	44.58	8.21	18.42	1.90	6.46	38	7.38	9.98	135.23	2.34	6.01
13	46.80	6.65	14.20	0.08	-0.79	39	6.86	8.31	121.14	1.74	3.99
14	48.01	8.43	17.56	0.76	0.71	40	10.93	11.36	103.90	1.37	1.72
15	48.82	7.98	16.34	-0.15	0.03	41	14.14	11.36	80.32	1.14	1.67
16	50.57	7.12	14.07	0.41	-0.41	42	17.45	12.14	69.54	1.24	2.22
17	50.54	8.11	16.05	0.14	0.74	43	19.95	10.53	52.81	-0.15	-0.11
18	51.55	6.07	11.78	-0.17	-0.42	44	23.02	11.59	50.37	0.87	2.48
19	51.88	7.90	15.23	-0.10	-0.59	45	21.28	10.58	49.72	0.67	1.69
20	50.19	11.30	22.51	-2.20	8.35	46	21.85	9.87	45.18	0.88	2.83
21	48.90	7.09	14.51	-0.34	-0.83	47	20.92	9.07	43.36	-0.45	1.22
22	45.25	12.61	27.87	-1.51	1.95	48	23.44	6.17	26.33	-0.16	0.52
23	38.44	20.51	53.36	-0.73	-0.81	49	23.96	6.56	27.36	0.52	0.80
24	22.92	19.67	85.80	-0.11	-1.77	50	22.68	5.04	22.20	0.14	-0.63
25	15.23	17.79	116.79	0.73	-1.13	51	23.17	5.78	24.95	0.50	0.41
26	13.57	14.90	109.87	0.85	-0.51	52	22.07	5.42	24.56	0.62	0.80

Table 4.20j Statistical characteristics of weekly water deficit series at Mahuva (1982-01)

Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis	Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis
1	23.76	4.91	20.67	-0.11	-1.15	27	14.92	15.33	102.76	0.38	-1.80
2	23.78	4.27	17.96	0.34	-0.55	28	12.48	12.37	99.09	0.42	-1.44
3	24.56	4.31	17.54	-0.40	-0.63	29	6.53	9.29	142.35	1.53	1.90
4	28.29	4.42	15.61	-0.72	0.12	30	10.42	11.01	105.66	0.45	-1.55
5	27.23	4.60	16.90	-0.15	-0.62	31	5.03	8.47	168.42	1.38	0.23
6	29.04	5.12	17.63	0.62	-0.29	32	7.16	8.82	123.12	1.16	0.13
7	30.00	5.05	16.85	0.22	-0.66	33	7.44	8.95	120.27	1.30	0.50
8	32.67	6.43	19.69	0.49	-0.65	34	7.78	9.83	126.42	1.06	-0.34
9	34.31	5.23	15.24	-0.62	-0.71	35	7.64	9.42	123.31	1.06	-0.42
10	35.28	4.70	13.32	0.02	-0.55	36	8.05	9.80	121.71	0.91	-0.35
11	38.19	5.01	13.12	0.42	0.19	37	9.98	10.19	102.15	0.60	-0.89
12	39.82	4.85	12.17	0.69	-0.16	38	12.06	11.23	93.14	0.49	-1.12
13	40.52	3.74	9.24	0.24	-0.68	39	11.11	10.88	97.93	0.67	-0.70
14	41.36	4.93	11.91	-0.06	-1.01	40	12.69	10.27	80.93	0.61	-0.81
15	42.51	4.66	10.96	-0.06	-0.99	41	15.84	9.73	61.42	0.13	-0.78
16	45.29	5.10	11.26	0.38	-0.33	42	18.27	11.02	60.31	-0.18	-0.58
17	44.48	4.21	9.46	0.03	-1.26	43	19.25	10.88	56.55	-0.48	0.01
18	46.23	4.35	9.40	-0.57	-0.91	44	21.59	10.53	48.79	-0.49	0.07
19	44.91	8.15	18.15	-0.99	1.73	45	22.31	12.05	54.04	0.03	0.42
20	43.14	8.52	19.74	-1.58	4.85	46	23.58	10.61	44.98	0.29	1.24
21	43.47	5.63	12.95	0.55	-0.81	47	22.48	9.98	44.41	0.65	4.05
22	38.96	11.99	30.78	-2.31	5.91	48	24.74	9.85	39.81	1.07	2.73
23	36.40	14.92	41.00	-1.54	1.96	49	24.08	6.54	27.15	0.15	-0.26
24	23.67	16.04	67.77	-0.58	-1.34	50	23.22	5.67	24.42	-0.06	-0.82
25	20.85	18.05	86.58	-0.23	-2.00	51	23.83	6.03	25.30	0.37	0.09
26	19.93	15.02	75.34	-0.31	-1.46	52	23.21	5.14	22.16	0.60	0.49

Table 4.20k Statistical characteristics of weekly water deficit series at Anand (1974-01)

Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis	Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis
1	15.83	2.50	15.82	-0.88	1.15	27	13.47	15.27	113.35	0.98	0.06
2	15.44	4.10	26.57	-2.21	6.67	28	6.15	8.92	145.08	1.08	-0.43
3	16.85	3.00	17.81	0.29	1.48	29	4.54	7.45	164.23	1.42	0.54
4	18.70	2.56	13.69	0.16	1.97	30	3.25	6.53	200.87	2.01	3.10
5	20.06	2.71	13.49	-0.44	0.07	31	3.39	7.19	212.38	2.74	8.10
6	21.41	2.31	10.81	0.48	0.94	32	2.06	5.37	260.59	2.95	8.64
7	22.98	2.45	10.65	-1.60	5.58	33	1.95	4.90	251.69	3.99	17.69
8	25.42	3.64	14.31	0.56	5.14	34	2.61	4.85	185.84	2.61	6.57
9	28.15	3.50	12.43	0.76	0.86	35	3.58	6.55	183.16	2.56	6.93
10	29.74	3.16	10.63	0.09	1.75	36	6.02	7.98	132.62	1.84	3.59
11	32.38	3.11	9.60	0.27	1.07	37	7.60	8.98	118.15	1.36	1.69
12	33.78	4.02	11.89	-1.59	4.47	38	8.68	8.37	96.40	0.73	-0.44
13	36.25	3.60	9.94	-0.60	2.03	39	10.41	8.91	85.59	0.51	-0.73
14	37.42	4.81	12.85	-1.11	4.17	40	12.75	7.65	60.02	-0.05	-0.42
15	40.25	4.58	11.38	-0.32	1.26	41	13.04	7.76	59.50	0.08	-0.35
16	41.17	4.39	10.67	-0.60	-0.24	42	14.25	7.04	49.41	-0.27	0.10
17	43.36	4.20	9.69	-0.82	1.06	43	14.24	6.76	47.46	-0.65	0.25
18	45.16	4.55	10.06	-2.14	5.20	44	15.42	5.25	34.03	-1.18	1.99
19	44.80	9.50	21.21	-4.14	19.58	45	15.34	5.91	38.52	-0.29	2.21
20	46.99	10.30	21.92	-3.69	16.88	46	14.65	5.57	38.04	-1.26	1.80
21	47.22	9.20	19.48	-2.91	9.38	47	14.25	5.39	37.79	-1.24	1.91
22	45.05	13.12	29.13	-2.49	5.86	48	14.10	5.41	38.37	-1.06	1.55
23	40.05	18.26	45.59	-1.52	1.11	49	13.99	4.20	29.99	-1.17	1.78
24	28.77	19.18	66.69	-0.29	-1.33	50	13.97	2.94	21.05	-1.69	4.10
25	24.25	22.30	91.95	0.19	-1.50	51	14.04	3.74	26.66	-1.64	4.42
26	14.41	17.29	119.93	0.97	-0.32	52	14.44	2.51	17.42	-1.03	2.60

Table 4.20l Statistical characteristics of weekly water deficit series at Nawagam (1978-01)

Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis	Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis
1	19.03	3.07	16.12	-0.11	-0.40	27	14.86	20.20	135.90	1.03	-0.58
2	19.36	4.05	20.90	-0.75	1.45	28	10.21	14.27	139.74	1.62	2.25
3	20.35	3.69	18.15	1.42	3.82	29	3.79	6.91	182.35	2.07	4.23
4	21.54	3.57	16.58	0.08	-0.68	30	3.35	9.99	297.86	4.06	17.40
5	22.47	3.21	14.27	-0.66	1.61	31	4.24	12.08	284.77	4.32	19.94
6	23.61	3.88	16.44	-0.20	-0.40	32	2.75	6.78	246.72	3.72	15.08
7	24.46	3.89	15.88	-1.41	1.47	33	1.56	3.35	214.69	2.91	9.35
8	26.77	4.64	17.34	-0.27	0.45	34	2.55	4.60	180.59	2.61	7.25
9	29.34	5.82	19.85	0.03	0.61	35	4.03	6.16	152.95	1.88	3.61
10	31.88	4.33	13.56	-1.08	1.14	36	6.06	7.11	117.43	1.22	0.65
11	34.81	4.82	13.83	-0.80	1.45	37	8.47	8.55	101.05	0.59	-1.08
12	37.19	6.16	16.55	-0.82	2.80	38	10.55	8.57	81.21	0.43	-0.65
13	39.49	9.41	23.82	-0.31	1.67	39	11.51	8.49	73.73	0.02	-1.26
14	39.65	7.09	17.88	-1.09	0.23	40	13.75	8.50	61.81	-0.21	-1.05
15	43.60	7.96	18.25	-0.67	0.96	41	14.51	8.16	56.21	-0.31	-0.78
16	47.21	8.06	17.07	-0.59	2.37	42	15.90	7.81	49.11	-0.27	-0.13
17	46.45	8.61	18.54	-0.93	0.06	43	15.54	6.98	44.92	-0.69	0.25
18	48.12	8.84	18.37	-1.64	2.65	44	16.92	6.27	37.04	-1.08	1.27
19	51.34	9.87	19.23	-1.01	0.38	45	16.90	7.42	43.90	-0.26	1.11
20	54.42	9.84	18.08	-2.14	6.32	46	14.81	8.18	55.24	-0.25	0.09
21	56.38	9.44	16.74	-1.35	2.47	47	15.74	5.82	36.98	-0.76	0.79
22	51.65	18.27	35.38	-1.94	3.33	48	15.70	6.07	38.68	-0.51	0.79
23	46.90	20.42	43.53	-1.52	1.09	49	16.66	5.22	31.34	-0.40	0.32
24	32.00	21.40	66.89	-0.37	-1.34	50	16.98	4.25	25.01	-1.11	1.58
25	31.62	24.02	75.96	-0.31	-1.58	51	17.51	3.70	21.15	0.19	0.14
26	16.81	19.30	114.87	0.77	-0.90	52	18.87	4.24	22.46	0.54	0.47

Table 4.20m Statistical characteristics of weekly water deficit series at Bharuch (1974-01)

Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis	Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis
1	17.78	5.53	31.09	-0.01	-1.07	27	8.31	14.81	178.09	1.96	3.23
2	18.23	7.01	38.47	-0.65	0.61	28	5.16	9.84	190.74	2.32	5.46
3	20.51	4.68	22.85	-0.42	-0.46	29	2.61	6.60	253.10	2.86	7.54
4	21.03	5.37	25.54	-0.17	-0.99	30	3.39	6.39	188.51	2.38	5.72
5	23.36	5.94	25.42	-0.26	-0.91	31	2.96	5.36	181.02	2.04	3.73
6	24.85	5.79	23.30	-0.44	-1.12	32	2.23	4.57	204.86	2.47	5.70
7	25.18	6.32	25.12	-0.70	0.85	33	2.32	4.00	172.29	1.90	2.81
8	30.65	6.28	20.50	1.08	3.50	34	2.66	5.58	209.67	2.70	7.24
9	31.19	6.10	19.57	-0.69	0.18	35	4.07	7.46	183.28	2.73	8.27
10	33.10	5.29	15.99	-0.36	-0.84	36	5.56	8.02	144.18	2.53	7.42
11	35.05	5.52	15.75	0.22	-0.73	37	5.89	8.68	147.20	2.08	4.99
12	37.01	5.46	14.74	-0.46	-0.73	38	7.14	8.17	114.40	1.08	-0.01
13	39.33	5.65	14.36	-0.47	-0.55	39	7.78	7.64	98.14	0.59	-0.90
14	40.67	5.83	14.34	-0.26	-0.97	40	9.79	8.31	84.90	0.66	-0.63
15	44.70	6.18	13.82	-0.59	0.78	41	11.55	8.55	73.98	0.48	-0.69
16	46.17	6.89	14.91	-0.55	0.99	42	14.07	7.37	52.35	-0.03	-0.66
17	48.66	6.22	12.78	-0.15	-1.05	43	15.04	7.06	46.94	0.03	-0.39
18	49.09	8.77	17.87	-2.09	7.80	44	16.19	7.83	48.33	0.09	1.21
19	50.34	11.45	22.73	-2.22	7.31	45	15.94	6.86	43.02	-0.54	-0.10
20	49.20	12.30	25.00	-2.11	7.33	46	14.67	7.73	52.70	-0.57	-0.74
21	49.94	7.88	15.78	-0.01	-0.61	47	14.61	7.24	49.58	-0.34	-0.39
22	45.29	17.38	38.38	-1.88	3.12	48	15.98	6.22	38.94	-0.28	0.14
23	36.56	19.56	53.51	-0.84	-0.38	49	14.59	6.22	42.67	-0.38	0.13
24	25.77	21.67	84.08	-0.17	-1.72	50	15.43	5.69	36.91	-0.17	-0.74
25	19.74	17.46	88.48	0.27	-1.41	51	16.04	6.54	40.74	0.22	0.37
26	14.42	17.20	119.28	0.84	-0.58	52	16.85	6.32	37.50	1.32	3.94

Table 4.20n Statistical characteristics of weekly water deficit series at Surat (1974-01)

Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis	Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis
1	19.39	4.78	24.66	-0.05	-0.62	27	3.97	10.23	257.86	2.94	8.29
2	19.10	5.39	28.21	-0.44	1.71	28	1.61	3.61	224.45	2.25	3.74
3	21.30	4.68	21.96	-0.21	-0.37	29	1.07	2.70	252.36	2.76	6.94
4	21.78	3.92	18.01	-0.18	-0.55	30	1.51	3.09	204.31	2.78	8.39
5	23.67	3.82	16.14	-0.07	-0.10	31	1.53	3.64	237.88	3.32	12.34
6	25.02	5.00	20.00	0.89	3.04	32	0.86	2.25	261.57	3.97	17.41
7	26.28	3.87	14.74	-0.26	-0.38	33	1.24	2.42	195.12	2.90	10.37
8	29.35	4.81	16.38	0.03	-0.42	34	2.28	3.58	157.09	2.38	7.06
9	31.68	4.39	13.86	-0.03	-0.01	35	3.01	4.55	150.81	1.73	2.73
10	33.55	5.74	17.11	0.47	-0.33	36	4.38	5.30	120.99	1.31	0.81
11	34.74	5.22	15.01	0.12	-0.94	37	4.75	5.82	122.60	1.48	1.54
12	35.88	3.67	10.23	0.00	-0.75	38	6.28	6.35	101.12	0.95	0.68
13	38.04	3.75	9.85	0.07	-0.85	39	6.86	7.24	105.56	1.01	0.67
14	39.17	3.90	9.95	0.06	0.23	40	8.24	7.78	94.32	0.62	-0.56
15	41.76	4.13	9.89	0.63	0.47	41	10.13	7.04	69.53	0.14	-0.87
16	43.53	3.97	9.11	0.78	0.88	42	12.43	7.40	59.49	-0.22	-0.57
17	44.22	3.98	9.00	0.19	-1.06	43	14.35	6.68	46.53	-0.12	0.35
18	46.10	5.71	12.38	0.64	-0.62	44	15.59	7.02	45.00	-0.35	0.82
19	43.07	9.29	21.58	-2.84	11.59	45	16.27	6.54	40.17	-0.55	0.65
20	44.52	5.15	11.56	-0.43	0.40	46	15.97	6.40	40.09	-0.46	0.80
21	43.58	9.35	21.46	-3.94	18.55	47	15.81	7.49	47.38	-0.05	1.19
22	40.79	13.03	31.94	-2.39	5.79	48	15.18	7.25	47.77	-0.36	1.58
23	32.87	16.15	49.13	-0.82	-0.31	49	15.96	5.06	31.71	-0.02	2.55
24	24.35	19.46	79.92	-0.22	-1.73	50	16.39	4.72	28.79	-0.06	1.50
25	13.70	17.45	127.35	0.77	-1.08	51	17.59	4.87	27.71	-0.20	0.93
26	9.16	13.81	150.71	1.38	0.61	52	17.84	4.21	23.59	-0.80	0.69

Table 4.20o Statistical characteristics of weekly water deficit series at Navsari (1974-01)

Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis	Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis
1	19.55	4.56	23.31	-0.16	0.39	27	4.23	11.68	275.98	3.10	9.00
2	18.88	5.87	31.11	-0.87	3.82	28	2.27	7.82	344.16	4.52	21.67
3	21.12	6.98	33.05	-1.09	2.10	29	1.38	5.90	427.54	5.17	27.09
4	22.79	4.67	20.50	-0.49	1.20	30	1.59	5.81	366.56	5.10	26.56
5	23.62	3.27	13.84	0.31	-0.47	31	0.51	1.86	365.28	4.88	24.75
6	25.77	3.36	13.02	0.06	-0.81	32	0.93	4.10	442.10	5.00	25.60
7	25.92	4.38	16.91	-1.46	5.28	33	1.37	4.98	364.63	5.13	26.81
8	29.46	3.64	12.34	0.17	-0.63	34	1.97	4.65	235.97	4.29	20.33
9	31.26	6.04	19.31	-2.16	8.47	35	1.65	2.85	173.34	1.54	0.79
10	32.99	4.35	13.18	0.60	0.59	36	2.73	4.08	149.20	1.45	1.15
11	33.84	6.40	18.91	-0.51	1.83	37	3.08	5.13	166.56	1.89	2.46
12	35.93	4.90	13.63	0.06	-0.10	38	3.54	5.39	152.16	1.90	3.21
13	38.28	4.69	12.26	-0.10	0.49	39	5.59	6.74	120.54	1.25	0.76
14	39.26	4.42	11.26	0.14	0.26	40	7.14	7.49	104.99	0.82	-0.37
15	41.80	4.47	10.69	0.66	-0.18	41	9.55	8.04	84.10	0.76	-0.35
16	42.99	4.64	10.80	1.10	1.32	42	11.72	8.93	76.21	0.57	-0.60
17	43.06	4.23	9.82	0.28	-0.16	43	14.27	8.69	60.87	0.25	0.03
18	43.11	5.06	11.73	-0.33	1.50	44	14.97	8.95	59.78	-0.09	-0.14
19	45.40	7.64	16.83	1.08	4.55	45	15.70	8.40	53.53	-0.11	-0.77
20	43.09	6.05	14.04	-2.10	6.83	46	15.58	7.26	46.60	-0.14	-0.33
21	43.63	5.99	13.72	-1.11	3.65	47	15.83	8.75	55.25	0.37	0.82
22	37.53	14.11	37.59	-2.01	2.98	48	16.09	6.64	41.27	0.30	2.60
23	32.00	17.25	53.89	-0.97	-0.57	49	15.78	6.46	40.96	0.00	1.31
24	17.65	16.96	96.07	0.31	-1.45	50	17.17	3.86	22.47	0.62	1.47
25	10.23	14.31	139.92	1.02	-0.49	51	17.53	4.68	26.70	0.00	-0.11
26	6.69	13.31	199.02	2.04	2.83	52	18.17	3.92	21.55	0.71	0.05

Table 4.20p Statistical characteristics of weekly water deficit series at Gandevi (1982-01)

Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis	Week	Mean, mm week ⁻¹	SD, mm week ⁻¹	CV, %	Skewness	Kurtosis
1	15.46	4.29	27.76	0.15	-1.25	27	3.78	8.73	230.89	2.18	3.25
2	15.31	4.54	29.67	-1.23	3.14	28	2.64	8.11	307.37	3.11	9.05
3	17.24	4.13	23.98	0.56	-0.98	29	2.39	8.32	348.44	3.89	15.68
4	18.51	3.65	19.73	0.66	-0.61	30	1.15	3.80	330.46	4.24	18.45
5	19.07	2.84	14.91	0.65	-0.54	31	0.12	0.35	286.40	2.89	7.36
6	20.56	2.81	13.65	0.43	-1.03	32	0.02	0.06	330.19	3.53	12.69
7	22.47	2.45	10.92	0.22	-1.27	33	0.08	0.26	337.51	3.95	16.21
8	24.65	3.35	13.59	0.49	-1.26	34	0.25	0.53	207.58	2.37	5.39
9	26.81	4.35	16.22	1.36	1.02	35	0.35	0.74	212.28	2.40	5.45
10	28.00	4.32	15.42	0.52	1.29	36	1.06	1.98	186.21	2.63	7.75
11	28.73	5.35	18.62	-1.08	3.05	37	1.37	3.09	225.40	2.59	6.75
12	31.62	3.69	11.67	0.30	0.24	38	2.00	3.95	197.46	2.72	7.42
13	33.30	3.93	11.82	0.29	-0.43	39	3.90	5.13	131.68	1.53	2.01
14	33.47	5.89	17.61	-2.91	11.29	40	5.15	5.38	104.56	1.10	0.44
15	36.54	3.44	9.41	0.66	0.64	41	6.03	5.58	92.65	1.18	1.32
16	38.97	3.28	8.41	-0.16	-0.56	42	8.64	5.79	66.98	0.42	-0.23
17	39.75	3.51	8.83	-0.70	2.51	43	9.80	5.63	57.43	0.13	-0.34
18	40.21	3.79	9.42	-1.22	4.01	44	11.70	5.09	43.52	0.23	-0.09
19	40.56	4.33	10.67	-1.64	4.53	45	11.81	5.14	43.53	-0.17	0.61
20	39.00	10.43	26.75	-3.05	10.85	46	12.54	4.03	32.18	0.16	-0.09
21	41.40	4.08	9.86	-0.31	1.35	47	11.82	3.80	32.18	-1.53	4.07
22	37.24	11.34	30.45	-2.50	6.39	48	12.82	2.95	23.01	0.29	-0.26
23	32.26	13.22	40.98	-1.54	1.87	49	12.30	2.41	19.62	0.36	-0.30
24	10.86	13.16	121.19	0.69	-1.19	50	12.55	2.04	16.26	-0.49	0.52
25	9.45	13.61	143.96	1.14	-0.07	51	13.16	2.12	16.08	-0.38	-0.75
26	8.16	12.79	156.66	1.42	0.59	52	13.44	2.47	18.39	-0.33	-0.71

significantly different than zero at all the stations indicate that water deficit is mutually dependent.

The skewness coefficient of weekly water deficit, a characterization of the degree of asymmetry of distribution around its mean, ranged between -4.49 to 1.33 at Kothara, -3.41 to 2.20 at Radhanpur, -2.09 to 2.38 at Rajkot, -1.71 to 1.43 at Amreli, -2.66 to 2.73 at SK Nagar, -3.30 to 4.40 at Khedbrahma, -2.78 to 2.02 at Arnej, -3.15 to 2.37 at Dhandhuka, -2.20 to 4.56 at Junagadh, -2.31 to 1.53 at Mahuva, -4.14 to 3.99 at Anand, -2.14 to 4.32 at Nawagam, -2.22 to 2.86 at Bharuch, -3.94 to 3.97 at Surat, -2.16 to 5.17 at Navsari and -3.05 to 4.24 at Gandevi, respectively. The values indicated that water deficit at Kothara, Radhanpur, Amreli, Arnej, Dhandhuka and Mahuva were left skewed whereas at Anand was slightly left skewed. Similarly, water deficit at Rajkot, Khedbrahma, Junagadh, Nawagam, Bharuch, Navsari and Gandevi was rightly skewed and at SK Nagar slight rightly skewed. Surat observed equally skewed water deficit on both sides. The data revealed that no weekly water deficit series is normally distributed.

Kurtosis, which indicates flatness or peakedness of a distribution of the water deficit series compared with normal distribution ($C_K = 3$). Positive kurtosis ($C_K > 3$) indicates a relatively peaked distribution while less than 3 and negative kurtosis, a relatively flat distribution. Results (Tables 4.20a to 4.20p) indicate that kurtosis ranged between -1.72 to 22.17 at Kothara, -1.62 to 13.49 at Radhanpur, -1.71 to 6.89 at Rajkot, -1.82 to 4.55 at Amreli, -1.68 to 9.12 at SK Nagar, -1.60 to 20.50 at Khedbrahma, -1.90 to 9.08 at Arnej, -1.68 to 12.09 at Dhandhuka, -1.77 to 22.27 at Junagadh, -1.80 to 5.91 at Mahuva, -1.33 to 19.58 at Anand, -1.58 to 19.94 at Nawagam, -1.72 to 8.27 at Bharuch, -1.73 to 18.55 at Surat, -1.45 to 27.09 at Navsari and -1.27 to 18.45 at Gandevi, respectively. The results indicate that no series is normally distributed but showed a wide variation in weekly water deficit distribution during the study period at all the stations.

4.7.2 Trend Component

For identification of trend component, annual water deficit series was used to suppress periodic component (Kottegoda 1980). The annual water deficit series shown in Table 4.21 was obtained from 20 to 28 (1982/1974 - 2001) year's water deficit data and used for identification and detection of trend component in the series. The hypothesis of no trend in the series was made and checked using the test statistic (Z) procedure as described in Section 3.11.2.1 for turning point and Kendall's rank correlation test.

The results for turning point and Kendall's rank correlation test are shown in Table 4.22. The estimated values of test statistics (Z) for both the tests were within the acceptable range at 0.01 level of significance for all agro-climatic zones. Hence, the hypothesis of no trend was not rejected. From this analysis it is confirmed that the trend component in water

Table 4.21 Annual water deficit series under different agro-climatic zones of Gujarat

Year	Kothara	Radhanpur	Rajkot	Anreli	SKNagar	Khedbrafama	Arnej	Dbandhuka	Junagadh	Mahuva	Anand	Nawagam	Bharuch	Surat	Navsari	Gandevi
1974	1919.21	-	-	1799.51	1741.38	-	-	-	1719.17	-	1353.06	-	1568.35	1212.85	1197.31	-
1975	1514.39	-	-	1487.93	1292.92	-	-	-	1334.58	-	1106.68	-	1158.7	1013.15	1013.76	-
1976	1574.99	-	-	1397.27	1275.23	-	-	-	1228.36	-	977.15	-	1072.4	980.29	954.72	-
1977	1671.03	-	-	1229.18	1282.14	-	-	-	1386.72	-	975.05	-	1066.31	1044.15	1099.09	-
1978	1648.32	-	1507.53	1436.87	1414.29	995.21	-	-	1391.99	-	1122.49	1229.34	977.85	989.65	989.07	-
1979	1614.08	-	1249.93	1195.29	1493.04	1003.59	-	-	1347.99	-	939.27	1165.75	847.63	869.19	994.67	-
1980	1691.6	-	1300.9	1215.99	1425.61	975.58	-	-	1194.1	-	975.12	1224.44	802.51	935.4	1062.33	-
1981	1414.48	-	1275.98	1219.61	1406.62	903.39	-	-	1174.22	-	1158.1	1214.7	1037.64	1156.53	871.04	-
1982	1578.47	1535.78	1563.67	1338.82	1370.16	1120.83	1416.02	1397.56	1295.05	1000.59	1153.05	1143.23	908.07	1137.66	986.36	986.73
1983	1502.22	1624.02	1506.63	1210.08	1371.62	1236.36	1281.54	1292.28	1040.44	1096.09	921.12	1045.76	781.41	1021.68	915	875.19
1984	1561.63	1569.76	1790.15	1631.02	1424.23	1128.77	1339.9	1510.64	1158.24	1290.35	1104.02	1280.23	1016.46	1027.4	1081.69	1023.47
1985	1706.8	1740.54	1926.75	1683.08	1503.73	1128.77	1441.82	1517.32	1316.3	1413.54	1228.83	1385.18	1128.35	1182.31	1168.33	963.54
1986	1584.35	1770.95	2021.7	1727.63	1568.44	1056.32	1646.58	1562.85	1463.8	1678.94	1397.99	1486.86	1344.11	1484	1365.24	986.34
1987	1867.29	2120.95	2435.77	2328.8	1872.36	1318.5	1357.91	1843.63	1973.2	1494.28	1329.62	1761.58	1241.73	1112.91	1332.31	1211.71
1988	1570.27	1581.54	1373.54	1253.71	1438.72	1078.92	1364.93	1298.8	1399.72	1266.39	1040.25	1233.61	1119.37	1378.93	897.75	890.84
1989	1589.77	1595.71	1399.93	1285.92	1241.29	974.55	1274.13	1283.8	1202.11	1194.32	1031.16	1199.71	1157.32	957.06	853.59	826.85
1990	1750.15	1466.87	1468.72	1397.67	1284.22	868.81	1390.86	1379.54	1083	1213.56	956.73	1218.21	1108.53	1031.55	988.04	768.11
1991	1816.37	1695.1	1588.08	1616.23	1367.39	1152.54	1501.06	1401.84	1235.85	1364.16	1137.18	1324.75	1243.57	1202.89	1152.16	870.56
1992	1521.17	1555.76	1624.8	1642.94	1261.02	1160.96	1466.06	1347.68	1181.63	1210.62	1116.43	1316.63	1227.6	1085.51	1064.79	878.27
1993	1877.56	1812.18	1857.49	1593.86	1437.33	1152.45	1335.12	1500.17	1295.13	1285.89	1058.57	1287.2	1122.29	1095.8	1001.97	796.06
1994	1354.84	1584.15	1537.51	1516.34	970.39	1029.28	1454.92	1295.12	1233.38	1172.18	936.97	1059.8	995	1142.12	984	813.07
1995	1686.56	1777.32	1771.9	1469.8	1248.62	1189.94	1545.69	1494.69	1312.36	1586.21	1156.64	1156.12	1306.76	1175.33	1150.47	928.19
1996	1725.66	1747.03	1621.93	1405.73	1144.29	1029.33	1308.82	1363.49	1371.05	1454.43	1010.99	1095.29	1265.45	1075.75	848.46	812.02
1997	1491.45	1464.56	1259.05	1405.03	1008.38	860.31	1000.06	1028.08	1114.08	1196.75	787.67	862.05	1063.43	909.93	838.81	667.76
1998	1372.07	1680.5	1287	1554.38	1144.1	812.59	1161.49	1137.03	1115.56	1118.04	825.81	1039.86	1120.33	868.91	910.91	777.33
1999	1485.68	2064.47	1643.66	1503.16	1409.16	1079.48	1058.59	1118.4	1273.13	1433.79	1071.64	1111.94	1311.85	771.18	881.97	718.77
2000	1672.44	1741.33	1786.73	1792.77	1501.46	1112.42	1486.84	1431.94	1096.21	1244.83	1154.91	979.89	1395.62	984.95	1118.99	758.29
2001	1541.39	1912.17	1525.62	1511.79	1285.6	924.78	1296.01	1327.41	1142.21	1172.17	1047.3	1221.5	1214.17	1004.93	1010.09	856.34

deficit series of different agro-climatic zones is absent and the observed series were found to be trend free.

Table 4.22 Test statistics (Z) value for trend identification for different stations

Station	Value of statistics (Z)	
	Turning point test	Kendall's rank correlation test
Kothara	0.31	-0.71
Radhanpur	1.11	1.43
Rajkot	-1.34	1.04
Amreli	-2.47	1.42
SK Nagar	-2.47	-1.66
Khedbrahma	-0.84	-0.15
Arnej	1.11	-0.52
Dhandhuka	0.00	-1.69
Junagadh	-1.08	-2.02
Mahuva	-1.67	-0.26
Anand	-2.47	-0.91
Nawagam	-1.85	-1.79
Bharuch	-2.47	2.02
Surat	-2.01	-0.67
Navsari	-0.62	-1.19
Gandevi	-0.56	-2.31

$$Z_{0.01} \pm 2.58$$

4.7.3 Periodic Component

Periodic component is easily identified by its cyclic phenomenon imposed on the series, provided the series is trend free. Presence of periodic component in a series is detected through the construction of a correlogram, which is a graph showing the relationship between the autocorrelation functions on the ordinate and lag K on the abscissa. For proper identification and interpretation of autocorrelogram, the estimate of autocorrelation function for weekly water deficit was made for all the agro-climatic zones of Gujarat.

4.7.3.1 Autocorrelation analysis

The autocorrelation functions for the weekly time series up to lag 104 were determined from Equation (3.32) which has been used to identify the periodic component in the time series. Correlograms for the weekly observed series along with the tolerance limit estimated by Equation (3.33) for an independent series are shown in Figures 4.15a to 4.15d. The resultant oscillating shape of the autocorrelogram shows the presence of periodicity in the time series. Moreover, in all stations the weekly serial correlogram have peaks at about 52 and 104, and troughs at about 26 and 78 with the base period of 52. It is also seen that some of the autocorrelogram of the time series fall out of the confidence limits for all the stations, indicating the presence of time dependant series, i.e., $X_{(t+1)}$ is dependant on $X_{(t)}$, and $X_{(t+2)}$ is dependant on $X_{(t+1)}$, and so on. Values of lag one autocorrelation coefficients for the series lies outside the range of confidence limit and is significantly different from zero which confirms the mutual dependence in water deficit observed series.

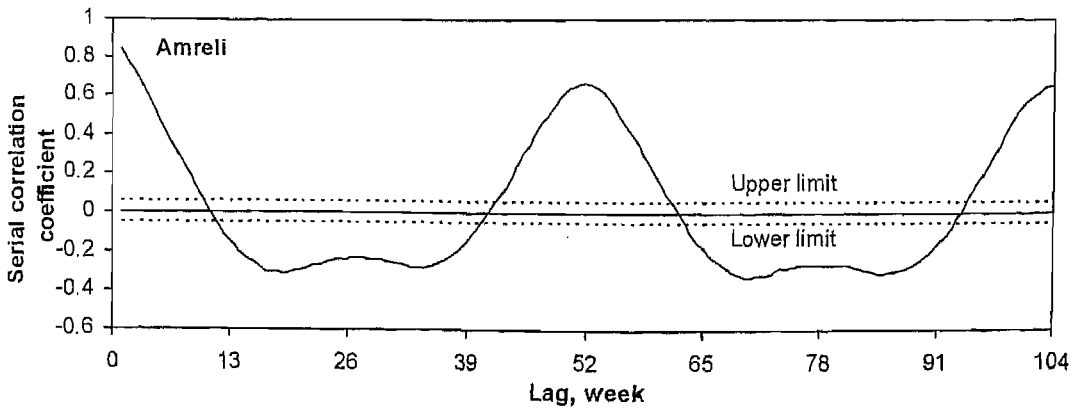
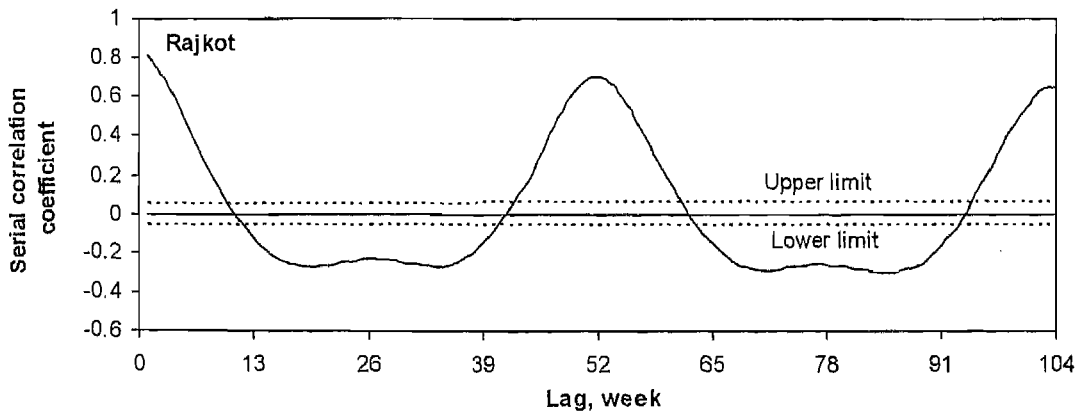
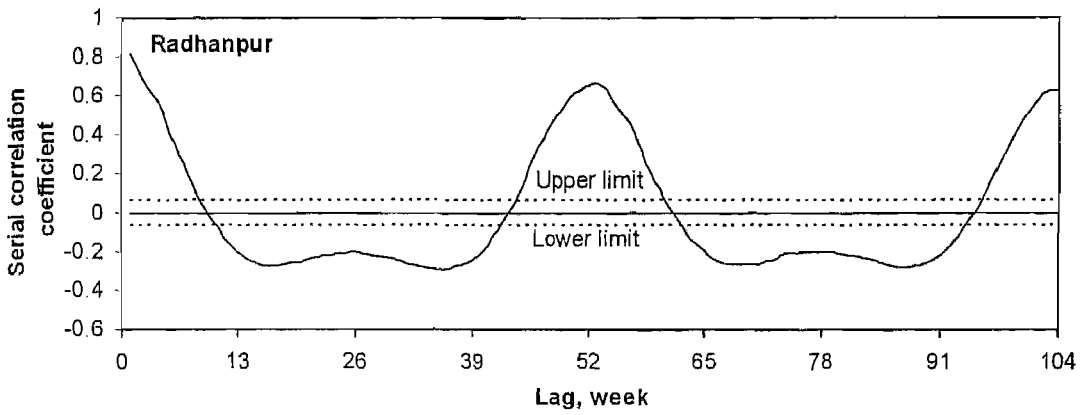
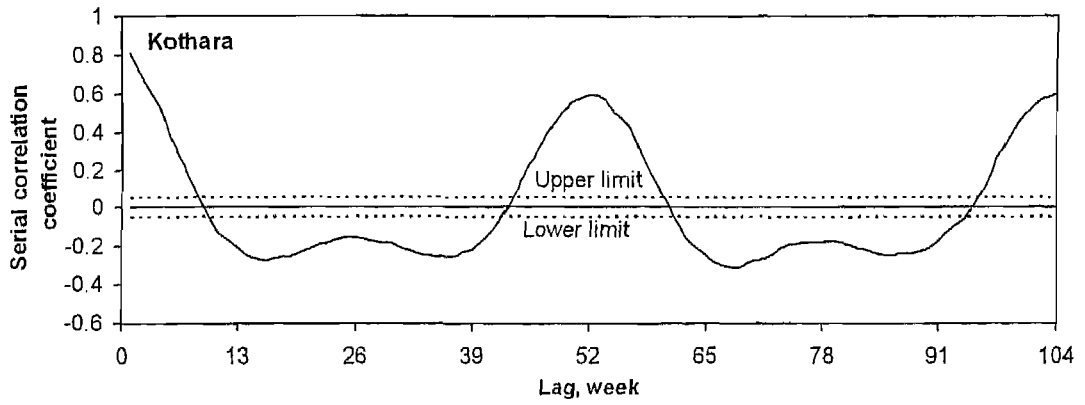


Fig. 4.15a Correlogram of weekly water deficit for Kothara, Radhanpur, Rajkot and Amreli

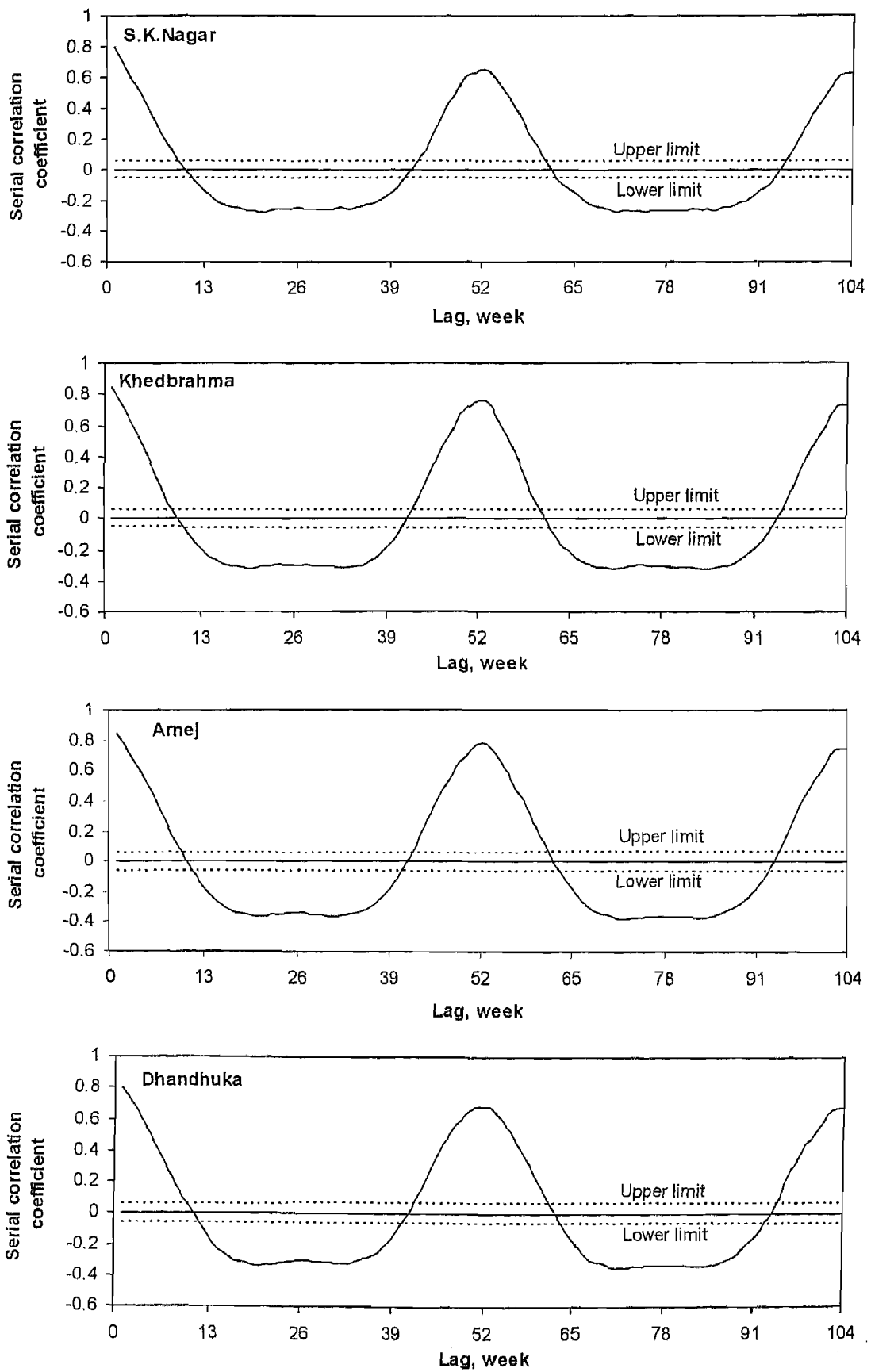


Fig. 4.15b Correlogram of weekly water deficit for SK Nagar, Khedbrahma, Arnej and Dhandhuka

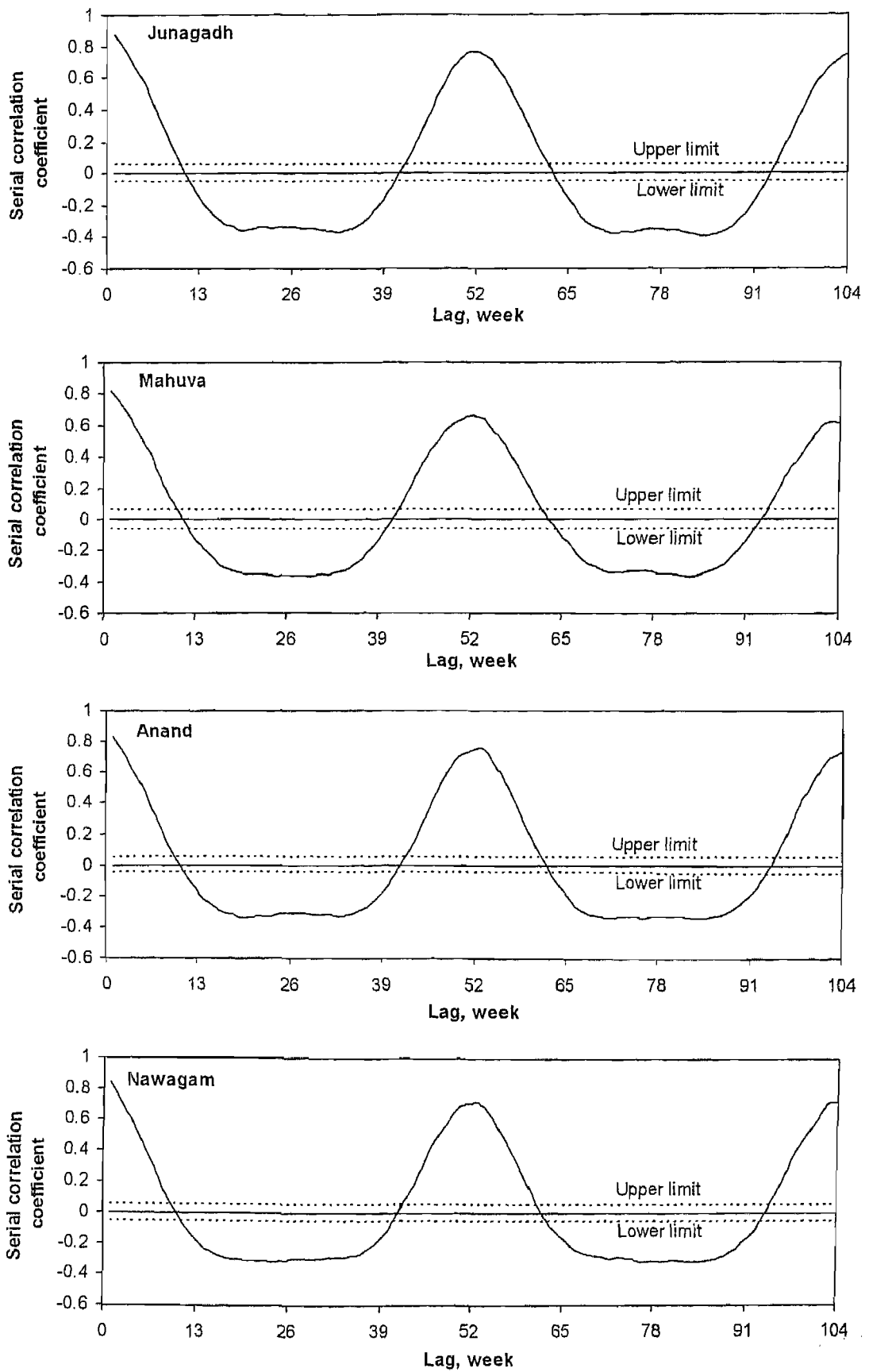


Fig. 4.15c Correlogram of weekly water deficit for Junagadh, Mahuva, Anand and Nawagam

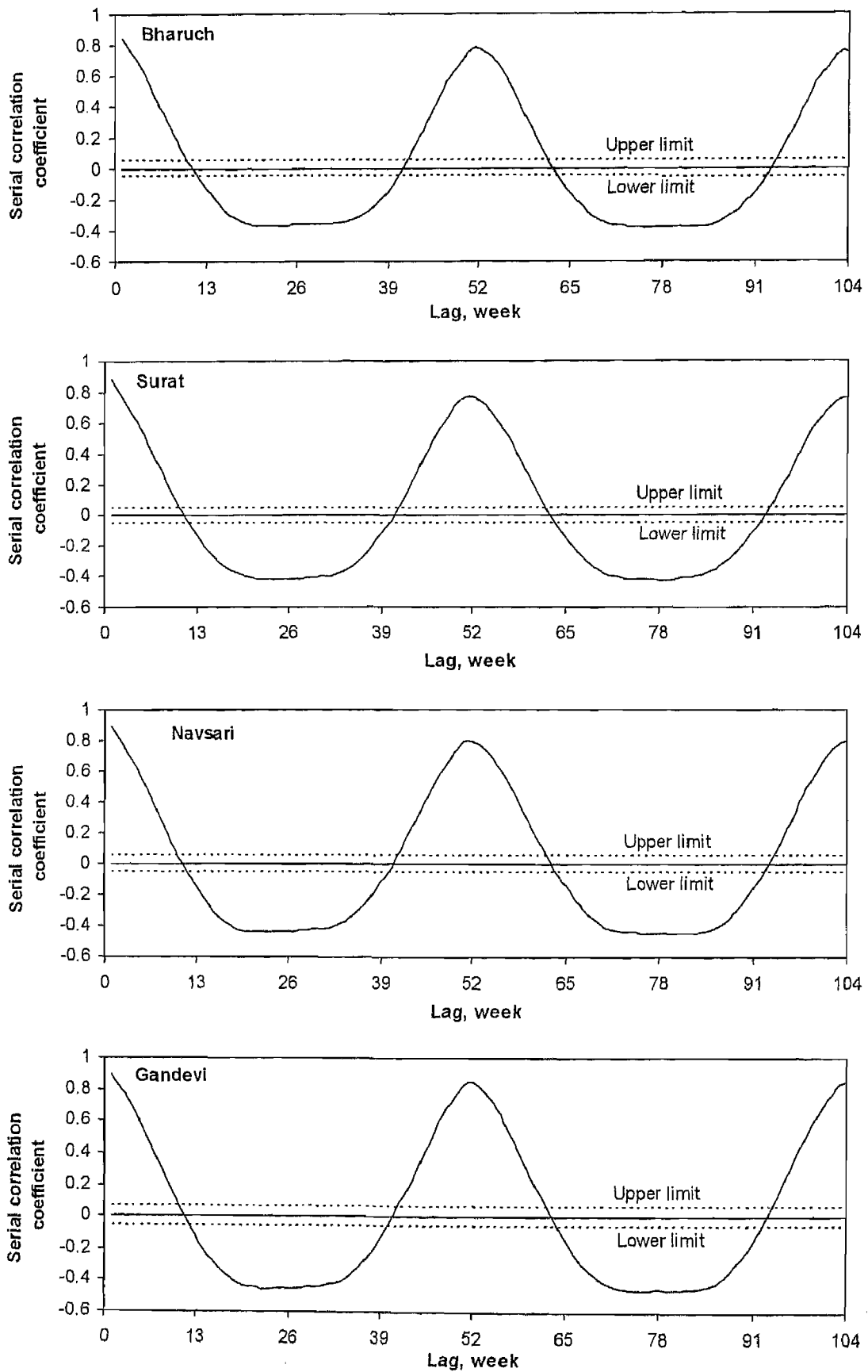


Fig. 4.15d Correlogram of weekly water deficit for Bharuch, Surat, Navsari and Gandevi

4.7.3.2 Selection of significant harmonics

Once the presence of periodic component in the series is detected, the estimation and removal from the time series is done through harmonic analysis. The periodic time series usually is not stationary. It is expanded into a Fourier series representation using Equation (3.40). To estimate the coefficient of harmonics to be fitted in the periodic component, the numbers of harmonics that significantly contribute to periodicities were identified through the following three different test approaches:

Analysis of variance: To determine the number of significant harmonics to be fitted in the periodic series, estimates of α and β parameters were computed. Using periodic mean estimated from observed weekly water deficit series, the parameters α and β were determined using Equations (3.45) to (3.48) for half the base period of series. For a discrete series, the number of possible harmonics is finite which, together with the amplitude and phase differences, can be estimated from an observed sequence (Kottegoda, 1980). Therefore, only few harmonics significantly contribute to periodicity and the rest of harmonics were treated as white noise. Tables 4.23a to 4.23p show the estimates of the parameters along with amplitude and explained variance for weekly time series. The numbers of significant harmonics have been then detected from the analysis of variance given in Tables 4.24a to 4.24p. In this analysis, the parameters α and β were evaluated for all harmonics considered in weekly series to obtain the estimated F-values. The harmonics for which F ratio were greater than the table value of F at 0.05 level of significance have been considered as significant harmonics.

The analysis of variance (Tables 4.24a to 4.24p) revealed that three harmonics each for Kothara, Radhanpur and Dhandhuka, four harmonics each for Rajkot, Amreli, SK Nagar, Khedbrahma, Arnej, Junagadh, Anand, Nawagam, Surat, Bharuch, Navsari and Gandevi and two harmonics for Mahuva were found to be significant in weekly water deficit series.

Table 4.23a Fourier series coefficients for weekly water deficit at Kothara

Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var	Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var
1	11.52	-3.32	11.99	58.50	58.50	14	-0.04	0.41	0.41	0.07	97.73
2	-8.09	-4.47	9.24	34.75	93.25	15	-0.58	-0.21	0.61	0.15	97.88
3	2.74	0.45	2.78	3.14	96.38	16	0.19	0.18	0.26	0.03	97.91
4	-1.15	-0.23	1.17	0.56	96.94	17	-0.05	-0.17	0.18	0.01	97.92
5	0.22	0.17	0.28	0.03	96.97	18	0.09	0.01	0.09	0.00	97.92
6	-0.05	-0.04	0.06	0.00	96.97	19	-0.23	-0.09	0.25	0.02	97.95
7	-0.27	-0.17	0.32	0.04	97.01	20	-0.05	-0.03	0.06	0.00	97.95
8	-0.09	0.47	0.47	0.09	97.11	21	0.51	-0.16	0.53	0.12	98.06
9	0.10	-0.42	0.43	0.08	97.18	22	-0.23	0.18	0.29	0.03	98.10
10	-0.16	-0.04	0.16	0.01	97.19	23	-0.11	-0.30	0.32	0.04	98.14
11	-0.23	-0.45	0.51	0.10	97.30	24	-0.35	0.17	0.39	0.06	98.20
12	0.72	0.26	0.76	0.24	97.53	25	0.14	-0.43	0.45	0.08	98.28
13	-0.54	-0.13	0.56	0.13	97.66	26	0.00	0.45	0.45	0.08	98.36

Table 4.23b Fourier series coefficients for weekly water deficit at Radhanpur

Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var	Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var
1	13.74	-6.02	15.00	57.98	57.98	14	-0.24	0.41	0.47	0.06	97.71
2	-10.64	-3.85	11.32	33.00	90.98	15	-0.11	-0.16	0.20	0.01	97.72
3	4.60	-0.48	4.62	5.50	96.48	16	0.12	0.01	0.12	0.00	97.72
4	-1.57	0.47	1.64	0.69	97.17	17	0.08	-0.35	0.36	0.03	97.75
5	0.46	-0.22	0.52	0.07	97.24	18	-0.29	0.36	0.46	0.05	97.81
6	-0.13	0.14	0.19	0.01	97.25	19	0.21	-0.27	0.34	0.03	97.84
7	-0.42	-0.29	0.51	0.07	97.32	20	-0.68	-0.03	0.68	0.12	97.96
8	0.07	0.25	0.26	0.02	97.34	21	0.56	0.04	0.56	0.08	98.04
9	-0.19	-0.31	0.36	0.03	97.37	22	-0.68	-0.14	0.70	0.13	98.16
10	0.31	0.56	0.64	0.10	97.47	23	0.37	-0.18	0.41	0.04	98.20
11	-0.23	-0.69	0.73	0.14	97.61	24	-0.46	-0.10	0.47	0.06	98.26
12	0.17	0.27	0.32	0.03	97.64	25	0.19	-0.12	0.23	0.01	98.27
13	0.06	-0.21	0.21	0.01	97.65	26	0.00	0.43	0.43	0.05	98.32

Table 4.23c Fourier series coefficients for weekly water deficit at Rajkot

Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var	Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var
1	19.13	-3.22	19.40	63.67	63.67	14	0.20	0.25	0.32	0.02	97.72
2	-12.34	-3.73	12.89	28.11	91.77	15	-0.18	-0.15	0.23	0.01	97.73
3	4.29	1.66	4.60	3.58	95.35	16	-0.22	0.33	0.39	0.03	97.75
4	-2.06	-2.22	3.03	1.55	96.90	17	-0.06	-0.24	0.24	0.01	97.76
5	0.82	1.36	1.59	0.43	97.33	18	-0.52	0.25	0.58	0.06	97.82
6	-0.26	-0.36	0.44	0.03	97.36	19	0.51	0.05	0.51	0.04	97.87
7	-0.45	0.43	0.63	0.07	97.43	20	-0.77	-0.08	0.77	0.10	97.97
8	-0.33	-0.48	0.58	0.06	97.48	21	0.65	-0.18	0.68	0.08	98.04
9	-0.11	-0.12	0.17	0.01	97.49	22	-0.49	0.05	0.50	0.04	98.08
10	-0.02	0.62	0.62	0.07	97.55	23	0.21	0.09	0.23	0.01	98.09
11	-0.39	-0.60	0.72	0.09	97.64	24	-0.44	-0.34	0.55	0.05	98.15
12	0.36	0.35	0.50	0.04	97.68	25	0.49	0.03	0.49	0.04	98.19
13	-0.21	-0.27	0.34	0.02	97.70	26	0.00	0.48	0.48	0.04	98.22

Table 4.23d Fourier series coefficients for weekly water deficit at Amreli

Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var	Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var
1	17.75	-0.26	17.75	64.76	64.76	14	0.15	0.08	0.17	0.01	97.84
2	-10.69	-4.85	11.74	28.35	93.11	15	-0.15	0.00	0.15	0.01	97.85
3	2.29	1.72	2.87	1.69	94.80	16	-0.17	0.11	0.20	0.01	97.86
4	-0.27	-2.82	2.84	1.66	96.46	17	-0.38	-0.34	0.51	0.05	97.91
5	0.55	1.78	1.87	0.72	97.17	18	0.31	0.11	0.33	0.02	97.93
6	0.39	-0.68	0.78	0.13	97.30	19	-0.09	-0.18	0.20	0.01	97.94
7	-1.02	0.65	1.21	0.30	97.60	20	-0.38	0.08	0.39	0.03	97.97
8	0.00	-0.58	0.58	0.07	97.67	21	0.15	-0.09	0.18	0.01	97.98
9	-0.14	-0.35	0.37	0.03	97.70	22	0.05	0.00	0.05	0.00	97.98
10	0.21	0.53	0.57	0.07	97.76	23	0.03	0.17	0.17	0.01	97.99
11	-0.27	-0.27	0.39	0.03	97.79	24	-0.43	-0.48	0.64	0.08	98.07
12	0.13	0.37	0.39	0.03	97.83	25	0.73	0.00	0.73	0.11	98.18
13	-0.14	-0.20	0.25	0.01	97.84	26	0.00	0.46	0.46	0.04	98.22

Table 4.23e Fourier series coefficients for weekly water deficit at SK Nagar

Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var	Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var
1	13.97	-7.00	15.62	63.55	63.55	14	0.21	0.48	0.52	0.07	98.06
2	-9.85	-2.79	10.23	27.27	90.82	15	-0.22	0.05	0.23	0.01	98.07
3	4.51	-0.83	4.59	5.49	96.31	16	0.11	-0.23	0.25	0.02	98.09
4	-1.40	1.38	1.97	1.01	97.31	17	-0.32	-0.26	0.42	0.05	98.13
5	0.92	-0.31	0.97	0.24	97.56	18	0.26	-0.07	0.27	0.02	98.15
6	-0.56	0.37	0.67	0.12	97.68	19	0.05	0.08	0.10	0.00	98.16
7	-0.04	-0.32	0.33	0.03	97.70	20	-0.01	0.09	0.09	0.00	98.16
8	0.21	-0.11	0.24	0.02	97.72	21	0.05	-0.10	0.11	0.00	98.16
9	-0.07	-0.37	0.38	0.04	97.76	22	-0.09	-0.14	0.16	0.01	98.17
10	0.56	0.34	0.66	0.11	97.87	23	0.02	0.21	0.21	0.01	98.18
11	-0.29	-0.30	0.42	0.05	97.91	24	-0.15	-0.11	0.19	0.01	98.19
12	0.33	0.20	0.38	0.04	97.95	25	0.05	-0.04	0.07	0.00	98.19
13	-0.33	-0.19	0.38	0.04	97.99	26	0.00	0.32	0.32	0.03	98.22

Table 4.23f Fourier series coefficients for weekly water deficit at Khedbrahma

Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var	Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var
1	14.79	-3.49	15.19	61.57	61.57	14	0.05	0.44	0.44	0.05	97.90
2	-9.72	-3.15	10.22	27.83	89.40	15	-0.26	-0.11	0.28	0.02	97.93
3	4.53	0.67	4.58	5.59	94.99	16	-0.09	0.02	0.09	0.00	97.93
4	-2.00	-1.23	2.35	1.47	96.46	17	0.14	-0.45	0.47	0.06	97.99
5	1.02	1.10	1.50	0.60	97.06	18	-0.09	0.03	0.09	0.00	97.99
6	0.20	-0.83	0.85	0.19	97.26	19	0.15	0.07	0.17	0.01	98.00
7	-0.55	0.40	0.68	0.13	97.38	20	-0.18	-0.16	0.24	0.02	98.01
8	0.31	0.20	0.37	0.04	97.42	21	0.23	0.17	0.28	0.02	98.03
9	0.11	-0.82	0.83	0.18	97.60	22	-0.33	-0.07	0.34	0.03	98.06
10	0.44	0.62	0.76	0.16	97.75	23	-0.12	0.06	0.14	0.01	98.07
11	-0.30	-0.32	0.44	0.05	97.81	24	-0.12	-0.52	0.53	0.08	98.14
12	-0.01	0.21	0.21	0.01	97.82	25	0.24	0.29	0.38	0.04	98.18
13	0.10	-0.34	0.36	0.03	97.85	26	0.00	0.25	0.25	0.02	98.20

Table 4.23g Fourier series coefficients for weekly water deficit at Arnej

Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var	Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var
1	19.74	-3.37	20.02	68.65	68.65	14	0.40	0.16	0.43	0.03	97.91
2	-11.44	-3.76	12.04	24.82	93.47	15	-0.63	-0.08	0.64	0.07	97.98
3	3.72	1.39	3.97	2.70	96.16	16	0.57	0.13	0.58	0.06	98.04
4	-1.57	-1.93	2.48	1.06	97.22	17	-0.14	-0.06	0.15	0.00	98.04
5	0.53	1.23	1.34	0.31	97.52	18	0.03	0.13	0.14	0.00	98.04
6	0.10	-0.71	0.72	0.09	97.61	19	-0.01	0.18	0.18	0.01	98.05
7	-0.41	0.56	0.69	0.08	97.69	20	-0.23	-0.39	0.45	0.04	98.08
8	0.33	-0.66	0.74	0.09	97.79	21	-0.31	0.10	0.33	0.02	98.10
9	-0.50	0.25	0.56	0.05	97.84	22	0.28	0.10	0.29	0.02	98.12
10	0.26	0.13	0.29	0.02	97.86	23	-0.09	-0.17	0.19	0.01	98.12
11	-0.27	-0.18	0.33	0.02	97.87	24	-0.03	-0.09	0.10	0.00	98.13
12	0.04	0.09	0.10	0.00	97.87	25	0.50	-0.07	0.50	0.04	98.17
13	-0.08	0.09	0.12	0.00	97.88	26	0.00	0.38	0.38	0.03	98.19

Table 4.23h Fourier series coefficients for weekly water deficit at Dhandhuka

Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var	Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var
1	17.89	-3.12	18.16	68.81	68.81	14	-0.10	-0.41	0.42	0.04	97.95
2	-10.10	-4.43	11.03	25.37	94.18	15	0.28	0.13	0.31	0.02	97.97
3	2.83	1.47	3.19	2.12	96.29	16	0.07	-0.26	0.27	0.02	97.99
4	-0.75	-1.67	1.83	0.70	96.99	17	-0.04	0.37	0.38	0.03	98.02
5	0.03	1.16	1.16	0.28	97.28	18	0.15	-0.22	0.27	0.02	98.03
6	0.47	-0.74	0.87	0.16	97.44	19	-0.10	0.43	0.44	0.04	98.07
7	-0.59	0.53	0.79	0.13	97.57	20	-0.45	-0.16	0.48	0.05	98.12
8	0.45	-0.09	0.46	0.05	97.61	21	0.01	-0.13	0.13	0.00	98.13
9	-0.45	-0.13	0.47	0.05	97.66	22	-0.04	0.00	0.04	0.00	98.13
10	-0.35	0.44	0.56	0.07	97.72	23	0.02	0.21	0.21	0.01	98.14
11	0.44	-0.41	0.60	0.08	97.80	24	0.13	-0.38	0.40	0.03	98.17
12	-0.62	0.19	0.65	0.09	97.89	25	0.11	-0.27	0.29	0.02	98.19
13	0.28	0.26	0.38	0.03	97.92	26	0.00	0.38	0.38	0.03	98.22

Table 4.23i Fourier series coefficients for weekly water deficit at Junagadh

Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var	Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var
1	19.07	2.08	19.19	70.45	70.45	14	0.30	0.41	0.51	0.05	97.97
2	-10.23	-4.65	11.24	24.18	94.63	15	-0.42	-0.50	0.66	0.08	98.06
3	1.50	1.82	2.35	1.06	95.69	16	-0.02	0.20	0.21	0.01	98.06
4	-0.88	-2.24	2.40	1.11	96.80	17	-0.01	-0.13	0.13	0.00	98.07
5	0.74	1.29	1.48	0.42	97.22	18	0.01	0.18	0.18	0.01	98.07
6	0.19	-0.74	0.76	0.11	97.33	19	-0.16	-0.15	0.22	0.01	98.08
7	-1.00	0.51	1.13	0.24	97.57	20	-0.06	-0.05	0.08	0.00	98.08
8	-0.06	-0.60	0.60	0.07	97.64	21	-0.06	-0.22	0.23	0.01	98.09
9	-0.33	-0.28	0.43	0.04	97.68	22	-0.18	-0.25	0.31	0.02	98.11
10	0.47	0.30	0.56	0.06	97.74	23	-0.03	-0.12	0.12	0.00	98.11
11	-0.45	-0.24	0.51	0.05	97.79	24	-0.16	-0.27	0.31	0.02	98.13
12	0.67	0.41	0.79	0.12	97.90	25	-0.02	0.31	0.31	0.02	98.15
13	-0.02	-0.32	0.32	0.02	97.92	26	0.00	0.42	0.42	0.03	98.19

Table 4.23j Fourier series coefficients for weekly water deficit at Mahuva

Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var	Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var
1	15.04	1.46	15.11	74.11	74.11	14	0.40	0.59	0.71	0.17	97.67
2	-7.70	-2.67	8.15	21.55	95.66	15	-0.13	-0.19	0.23	0.02	97.69
3	1.05	0.81	1.32	0.57	96.23	16	-0.03	0.13	0.14	0.01	97.69
4	-0.71	-1.41	1.58	0.81	97.04	17	-0.09	-0.15	0.18	0.01	97.71
5	0.20	0.43	0.47	0.07	97.11	18	0.07	-0.02	0.07	0.00	97.71
6	0.25	-0.28	0.38	0.05	97.16	19	-0.05	-0.07	0.08	0.00	97.71
7	-0.38	0.03	0.38	0.05	97.20	20	-0.28	-0.18	0.33	0.04	97.74
8	0.11	-0.20	0.23	0.02	97.22	21	0.39	-0.29	0.48	0.08	97.82
9	-0.48	-0.12	0.50	0.08	97.30	22	-0.73	-0.21	0.76	0.19	98.01
10	0.49	0.12	0.50	0.08	97.38	23	0.44	-0.01	0.44	0.06	98.07
11	-0.41	-0.14	0.43	0.06	97.44	24	-0.39	0.00	0.39	0.05	98.12
12	0.00	0.34	0.34	0.04	97.48	25	0.19	0.00	0.19	0.01	98.13
13	-0.01	-0.29	0.29	0.03	97.51	26	0.00	0.45	0.45	0.07	98.19

Table 4.23k Fourier series coefficients for weekly water deficit at Anand

Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var	Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var
1	15.64	-2.92	15.91	66.68	66.68	14	0.06	0.09	0.10	0.00	97.98
2	-9.44	-3.34	10.01	26.41	93.09	15	-0.01	-0.03	0.03	0.00	97.98
3	3.51	0.55	3.55	3.32	96.41	16	0.09	-0.12	0.15	0.01	97.99
4	-1.34	-1.12	1.75	0.80	97.21	17	-0.05	0.09	0.10	0.00	97.99
5	0.59	1.11	1.26	0.42	97.63	18	-0.01	-0.09	0.09	0.00	97.99
6	-0.08	-0.78	0.78	0.16	97.79	19	0.15	-0.03	0.15	0.01	98.00
7	-0.03	0.51	0.51	0.07	97.86	20	-0.07	-0.12	0.14	0.01	98.00
8	0.10	-0.29	0.30	0.02	97.88	21	0.12	0.22	0.25	0.02	98.02
9	-0.31	0.04	0.31	0.03	97.91	22	-0.07	-0.40	0.40	0.04	98.06
10	0.18	0.16	0.24	0.02	97.92	23	-0.15	0.28	0.32	0.03	98.09
11	-0.25	-0.21	0.32	0.03	97.95	24	0.07	-0.36	0.37	0.04	98.13
12	0.29	0.18	0.34	0.03	97.98	25	0.09	0.33	0.34	0.03	98.16
13	0.02	-0.02	0.03	0.00	97.98	26	0.00	0.28	0.28	0.02	98.18

Table 4.23l Fourier series coefficients for weekly water deficit at Nawagam

Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var	Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var
1	17.27	-3.51	17.62	65.20	65.20	14	0.16	-0.09	0.18	0.01	97.68
2	-10.87	-2.48	11.15	26.11	91.31	15	-0.04	0.11	0.12	0.00	97.69
3	4.56	0.93	4.65	4.54	95.85	16	-0.41	-0.15	0.43	0.04	97.72
4	-1.62	-0.82	1.81	0.69	96.54	17	0.38	0.22	0.44	0.04	97.76
5	0.85	1.55	1.77	0.66	97.20	18	-0.27	-0.29	0.40	0.03	97.80
6	-0.03	-1.00	1.00	0.21	97.41	19	0.31	0.16	0.35	0.03	97.82
7	-0.26	0.57	0.63	0.08	97.49	20	-0.27	-0.04	0.27	0.02	97.84
8	0.13	-0.20	0.24	0.01	97.50	21	0.45	0.30	0.55	0.06	97.90
9	-0.51	-0.24	0.57	0.07	97.57	22	-0.50	-0.31	0.59	0.07	97.97
10	0.28	0.45	0.53	0.06	97.63	23	0.12	0.42	0.44	0.04	98.01
11	-0.01	-0.37	0.37	0.03	97.66	24	-0.26	-0.52	0.58	0.07	98.09
12	0.01	0.03	0.03	0.00	97.66	25	0.13	0.50	0.51	0.06	98.14
13	0.05	0.30	0.30	0.02	97.68	26	0.00	0.36	0.36	0.03	98.17

Table 4.23m Fourier series coefficients for weekly water deficit at Bharuch

Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var	Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var
1	17.99	-1.56	18.05	70.40	70.40	14	0.00	0.21	0.21	0.01	98.07
2	-9.48	-4.11	10.33	23.07	93.46	15	0.05	-0.17	0.17	0.01	98.08
3	3.08	1.72	3.53	2.69	96.15	16	-0.29	-0.08	0.30	0.02	98.09
4	-0.82	-2.21	2.36	1.20	97.36	17	-0.14	-0.02	0.14	0.00	98.10
5	0.45	1.34	1.41	0.43	97.79	18	-0.12	-0.06	0.14	0.00	98.10
6	0.12	-0.38	0.40	0.04	97.82	19	0.06	0.09	0.11	0.00	98.11
7	-0.27	0.52	0.58	0.07	97.89	20	0.05	0.07	0.09	0.00	98.11
8	0.16	-0.40	0.43	0.04	97.93	21	0.31	-0.03	0.31	0.02	98.13
9	-0.25	-0.26	0.36	0.03	97.96	22	0.10	-0.03	0.10	0.00	98.13
10	0.20	0.30	0.36	0.03	97.99	23	0.05	-0.26	0.26	0.02	98.15
11	-0.17	-0.32	0.36	0.03	98.02	24	-0.21	0.00	0.21	0.01	98.16
12	0.06	0.44	0.44	0.04	98.06	25	0.14	0.13	0.20	0.01	98.16
13	0.05	-0.07	0.09	0.00	98.06	26	0.00	0.32	0.32	0.02	98.19

Table 4.23n Fourier series coefficients for weekly water deficit at Surat

Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var	Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var
1	17.17	0.31	17.17	73.28	73.28	14	0.06	-0.06	0.09	0.00	98.06
2	-8.07	-3.98	9.00	20.13	93.41	15	-0.06	0.07	0.09	0.00	98.06
3	2.40	1.89	3.06	2.32	95.74	16	0.01	-0.12	0.12	0.00	98.06
4	-1.07	-2.14	2.39	1.42	97.16	17	-0.12	0.07	0.14	0.01	98.07
5	0.78	1.34	1.55	0.60	97.75	18	0.16	0.02	0.16	0.01	98.08
6	-0.07	-0.43	0.43	0.05	97.80	19	-0.03	-0.03	0.05	0.00	98.08
7	0.04	0.66	0.66	0.11	97.91	20	-0.07	0.18	0.19	0.01	98.09
8	0.08	-0.52	0.53	0.07	97.98	21	0.13	-0.13	0.18	0.01	98.09
9	-0.37	0.13	0.39	0.04	98.01	22	0.09	-0.10	0.13	0.00	98.10
10	0.12	0.08	0.14	0.01	98.02	23	-0.17	-0.07	0.19	0.01	98.11
11	-0.20	-0.15	0.24	0.02	98.03	24	0.07	0.02	0.08	0.00	98.11
12	0.11	0.24	0.26	0.02	98.05	25	-0.09	-0.38	0.39	0.04	98.15
13	-0.03	-0.16	0.17	0.01	98.06	26	0.00	0.34	0.34	0.03	98.17

Table 4.23o Fourier series coefficients for weekly water deficit at Navsari

Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var	Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var
1	17.49	1.65	17.57	73.32	73.32	14	0.17	0.15	0.23	0.01	97.99
2	-8.17	-4.10	9.14	19.87	93.19	15	-0.12	-0.35	0.37	0.03	98.02
3	1.88	2.10	2.82	1.89	95.08	16	0.02	0.19	0.19	0.01	98.03
4	-0.53	-2.57	2.62	1.64	96.71	17	0.02	-0.01	0.03	0.00	98.03
5	0.44	1.64	1.70	0.68	97.39	18	0.06	-0.03	0.07	0.00	98.03
6	0.23	-0.75	0.78	0.14	97.54	19	0.07	-0.11	0.13	0.00	98.03
7	-0.59	0.74	0.94	0.21	97.75	20	0.09	0.10	0.14	0.00	98.04
8	0.48	-0.46	0.66	0.11	97.85	21	0.20	-0.20	0.29	0.02	98.06
9	-0.55	0.03	0.55	0.07	97.92	22	-0.07	-0.07	0.10	0.00	98.06
10	0.21	0.06	0.22	0.01	97.94	23	0.24	-0.07	0.25	0.01	98.07
11	-0.26	0.05	0.27	0.02	97.95	24	-0.41	-0.10	0.42	0.04	98.12
12	0.19	0.20	0.27	0.02	97.97	25	0.07	0.22	0.23	0.01	98.13
13	-0.14	-0.08	0.16	0.01	97.98	26	0.00	0.35	0.35	0.03	98.16

Table 4.23p Fourier series coefficients for weekly water deficit at Gandevi

Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var	Order	Alpha	Beta	Amplitude	Expl. var.	Cum. expl. var
1	16.25	0.02	16.25	72.29	72.29	14	0.06	0.47	0.47	0.06	97.58
2	-7.70	-3.43	8.42	19.42	91.71	15	0.11	-0.59	0.60	0.10	97.68
3	1.90	1.93	2.71	2.01	93.72	16	-0.24	0.52	0.58	0.09	97.77
4	-0.46	-2.51	2.55	1.78	95.50	17	0.24	-0.23	0.33	0.03	97.80
5	0.15	1.53	1.54	0.65	96.15	18	-0.14	0.14	0.20	0.01	97.81
6	0.52	-0.91	1.05	0.30	96.44	19	0.25	-0.39	0.46	0.06	97.87
7	-0.51	0.80	0.95	0.25	96.69	20	-0.29	0.18	0.34	0.03	97.90
8	0.74	-0.58	0.94	0.24	96.93	21	0.33	-0.16	0.37	0.04	97.94
9	-0.81	0.09	0.82	0.18	97.12	22	-0.36	-0.14	0.38	0.04	97.98
10	0.66	0.05	0.67	0.12	97.24	23	0.40	0.00	0.40	0.05	98.02
11	-0.51	-0.44	0.68	0.13	97.36	24	-0.24	-0.33	0.41	0.05	98.07
12	0.23	0.62	0.66	0.12	97.48	25	0.23	0.39	0.45	0.06	98.13
13	-0.06	-0.39	0.39	0.04	97.52	26	0.00	0.26	0.26	0.02	98.15

Table 4.24a Analysis of variance of weekly water deficit at Kothara

S.No.	Harmonic	Degree of freedom	Sum of Squares	Mean squares	F _{cal}	F _{tab}	
						0.01	0.05
1	5,6,---,26	43	2545.1	59.2	0.29	1.57	1.38
2	Residual	1412	288770.6	204.5			
3	4	3	999.6	333.2	1.67	3.78	2.6
4	Residual	1452	290316.1	199.9			
1	4,5, ---,26	45	3544.7	78.8	0.39	1.56	1.37
2	Residual	1410	287771.0	204.1			
3	3	2	5606.4	2803.2	14.26	4.61	3
4	Residual	1453	285709.3	196.6			
1	3,4, ---,26	47	9151.1	194.7	0.97	1.55	1.37
2	Residual	1408	282164.6	200.4			
3	2	2	62126.9	31063.5	196.93	4.61	3
4	Residual	1453	229188.7	157.7			
1	2,3, ---,26	49	71278.0	1454.7	9.29	1.54	1.36
2	Residual	1406	220037.7	156.5			
3	1	2	104584.9	52292.5	406.90	4.61	3
4	Residual	1453	186730.8	128.5			

Table 4.24b Analysis of variance of weekly water deficit at Radhanpur

S.No.	Harmonic	Degree of freedom	Sum of Squares	Mean squares	F _{cal}	F _{tab}	
						0.01	0.05
1	5,6,---,26	43	2318.8	53.9	0.18	1.57	1.38
2	Residual	996	295400.8	296.6			
3	4	3	1392.7	464.2	1.62	3.78	2.6
4	Residual	1036	296326.9	286.0			
1	4,5, ---,26	45	3711.5	82.5	0.28	1.56	1.37
2	Residual	994	294008.1	295.8			
3	3	2	11101.1	5550.6	20.08	4.61	3
4	Residual	1037	286618.5	276.4			
1	3,4, ---,26	47	14812.6	315.2	1.11	1.55	1.37
2	Residual	992	282907.0	285.2			
3	2	2	66613.9	33306.9	149.45	4.61	3
4	Residual	1037	231105.7	222.9			
1	2,3, ---,26	49	81426.5	1661.8	7.61	1.54	1.36
2	Residual	990	216293.1	218.5			
3	1	2	117030.6	58515.3	335.83	4.61	3
4	Residual	1037	180688.9	174.2			

Table 4.24c Analysis of variance of weekly water deficit at Rajkot

S.No.	Harmonic	Degree of freedom	Sum of Squares	Mean squares	F _{cal}	F _{tab}	
						0.01	0.05
1	5,6,---,26	43	4884.6	113.6	0.26	1.57	1.38
2	Residual	1204	520760.6	432.5			
3	4	3	5710.1	1903.4	4.55	3.78	2.6
4	Residual	1244	519935.1	418.0			
1	4,5, ---,26	45	10594.7	235.4	0.55	1.56	1.37
2	Residual	1202	515050.5	428.5			
3	3	2	13204.0	6602.0	16.04	4.61	3
4	Residual	1245	512441.2	411.6			
1	3,4, ---,26	47	23798.7	506.4	1.21	1.55	1.37
2	Residual	1200	501846.5	418.2			
3	2	2	103629.3	51814.6	152.86	4.61	3
4	Residual	1245	422015.9	339.0			
1	2,3, ---,26	49	127428.0	2600.6	7.82	1.54	1.36
2	Residual	1198	398217.2	332.4			
3	1	2	234743.3	117371.7	502.33	4.61	3
4	Residual	1245	290901.9	233.7			

Table 4.24d Analysis of variance of weekly water deficit at Amreli

S.No.	Harmonic	Degree of freedom	Sum of Squares	Mean squares	F _{cal}	F _{tab}	
						0.01	0.05
1	5,6,---,26	43	6248.5	145.3	0.40	1.57	1.38
2	Residual	1412	517736.7	366.7			
3	4	3	5860.0	1953.3	5.47	3.78	2.6
4	Residual	1452	518125.2	356.8			
1	4,5, ---,26	45	12108.5	269.1	0.74	1.56	1.37
2	Residual	1410	511876.7	363.0			
3	3	2	5985.6	2992.8	8.39	4.61	3
4	Residual	1453	517999.6	356.5			
1	3,4, ---,26	47	18094.1	385.0	1.07	1.55	1.37
2	Residual	1408	505891.1	359.3			
3	2	2	100357.0	50178.5	172.11	4.61	3
4	Residual	1453	423628.2	291.6			
1	2,3, ---,26	49	118451.1	2417.4	8.38	1.54	1.36
2	Residual	1406	405534.1	288.4			
3	1	2	229284.8	114642.4	565.24	4.61	3
4	Residual	1453	294700.5	202.8			

Table 4.24e Analysis of variance of weekly water deficit at SK Nagar

S.No.	Harmonic	Degree of freedom	Sum of Squares	Mean squares	F _{cal}	F _{tab}	
						0.01	0.05
1	5,6,---,26	43	2523.0	58.7	0.19	1.57	1.38
2	Residual	1412	429385.4	304.1			
3	4	3	2813.2	937.7	3.17	3.78	2.6
4	Residual	1452	429095.1	295.5			
1	4,5, ---,26	45	5336.2	118.6	0.39	1.56	1.37
2	Residual	1410	426572.2	302.5			
3	3	2	15339.0	7669.5	26.75	4.61	3
4	Residual	1453	416569.3	286.7			
1	3,4, ---,26	47	20675.2	439.9	1.51	1.55	1.37
2	Residual	1408	411233.2	292.1			
3	2	2	76243.8	38121.9	155.74	4.61	3
4	Residual	1453	355664.6	244.8			
1	2,3, ---,26	49	96919.0	1977.9	8.30	1.54	1.36
2	Residual	1406	334989.4	238.3			
3	1	2	177647.4	88823.7	507.59	4.61	3
4	Residual	1453	254261.0	175.0			

Table 4.24f Analysis of variance of weekly water deficit at Khedbrahma

S.No.	Harmonic	Degree of freedom	Sum of Squares	Mean squares	F _{cal}	F _{tab}	
						0.01	0.05
1	5,6,---,26	43	4061.5	94.5	0.39	1.57	1.38
2	Residual	1204	293267.3	243.6			
3	4	3	3447.0	1149.0	4.86	3.78	2.6
4	Residual	1244	293881.9	236.2			
1	4,5, ---,26	45	7508.5	166.9	0.69	1.56	1.37
2	Residual	1202	289820.3	241.1			
3	3	2	13066.5	6533.3	28.61	4.61	3
4	Residual	1245	284262.3	228.3			
1	3,4, ---,26	47	20575.0	437.8	1.90	1.55	1.37
2	Residual	1200	276753.8	230.6			
3	2	2	65102.3	32551.1	174.51	4.61	3
4	Residual	1245	232226.6	186.5			
1	2,3, ---,26	49	85677.3	1748.5	9.90	1.54	1.36
2	Residual	1198	211651.5	176.7			
3	1	2	144032.6	72016.3	584.88	4.61	3
4	Residual	1245	153296.2	123.1			

Table 4.24g Analysis of variance of weekly water deficit at Arnej

S.No.	Harmonic	Degree of freedom	Sum of Squares	Mean squares	F _{cal}	F _{tab}	
						0.01	0.05
1	5,6,---,26	43	2967.4	69.0	0.18	1.57	1.38
2	Residual	996	389793.4	391.4			
3	4	3	3204.2	1068.1	2.84	3.78	2.6
4	Residual	1036	389556.6	376.0			
1	4,5, ---,26	45	6171.6	137.1	0.35	1.56	1.37
2	Residual	994	386589.2	388.9			
3	3	2	8184.2	4092.1	11.03	4.61	3
4	Residual	1037	384576.6	370.9			
1	3,4, ---,26	47	14355.8	305.4	0.80	1.55	1.37
2	Residual	992	378405.0	381.5			
3	2	2	75346.5	37673.3	123.08	4.61	3
4	Residual	1037	317414.3	306.1			
1	2,3, ---,26	49	89702.3	1830.7	5.98	1.54	1.36
2	Residual	990	303058.5	306.1			
3	1	2	208440.6	104220.3	586.35	4.61	3
4	Residual	1037	184320.2	177.7			

Table 4.24h Analysis of variance of weekly water deficit at Dhandhuka

S.No.	Harmonic	Degree of freedom	Sum of Squares	Mean squares	F _{cal}	F _{tab}	
						0.01	0.05
1	5,6,---,26	43	3043.4	70.8	0.20	1.57	1.38
2	Residual	996	346285.6	347.7			
3	4	3	1746.2	582.1	1.73	3.78	2.6
4	Residual	1036	347582.8	335.5			
1	4,5, ---,26	45	4789.6	106.4	0.31	1.56	1.37
2	Residual	994	344539.4	346.6			
3	3	2	5280.9	2640.4	7.96	4.61	3
4	Residual	1037	344048.1	331.8			
1	3,4, ---,26	47	10070.5	214.3	0.63	1.55	1.37
2	Residual	992	339258.5	342.0			
3	2	2	63214.0	31607.0	114.56	4.61	3
4	Residual	1037	286115.0	275.9			
1	2,3, ---,26	49	73284.5	1495.6	5.36	1.54	1.36
2	Residual	990	276044.5	278.8			
3	1	2	171480.1	85740.1	499.93	4.61	3
4	Residual	1037	177848.9	171.5			

Table 4.24i Analysis of variance of weekly water deficit at Junagadh

S.No.	Harmonic	Degree of freedom	Sum of Squares	Mean squares	F _{cal}	F _{tab}	
						0.01	0.05
1	5,6,---,26	43	5282.044	122.8382	0.36	1.57	1.38
2	Residual	1412	488250.1	345.7862			
3	4	3	4202.261	1400.754	4.16	3.78	2.6
4	Residual	1452	489329.9	337.004			
1	4,5, ---,26	45	9484.305	210.7623	0.61	1.56	1.37
2	Residual	1410	484047.8	343.2963			
3	3	2	4034.013	2017.006	5.99	4.61	3
4	Residual	1453	489498.1	336.8879			
1	3,4, ---,26	47	13518.32	287.6238	0.84	1.55	1.37
2	Residual	1408	480013.8	340.9189			
3	2	2	91942.03	45971.02	166.33	4.61	3
4	Residual	1453	401590.1	276.3868			
1	2,3, ---,26	49	105460.4	2152.252	7.80	1.54	1.36
2	Residual	1406	388071.8	276.0112			
3	1	2	267947.1	133973.6	862.93	4.61	3
4	Residual	1453	225585	155.2546			

Table 4.24j Analysis of variance of weekly water deficit at Mahuva

S.No.	Harmonic	Degree of freedom	Sum of Squares	Mean squares	F _{cal}	F _{tab}	
						0.01	0.05
1	5,6,---,26	43	1849.9	43.0	0.18	1.57	1.38
2	Residual	996	238115.8	239.1			
3	4	3	1293.8	431.3	1.87	3.78	2.6
4	Residual	1036	238671.9	230.4			
1	4,5, ---,26	45	3143.6	69.9	0.29	1.56	1.37
2	Residual	994	236822.0	238.3			
3	3	2	909.2	454.6	1.97	4.61	3
4	Residual	1037	239056.5	230.5			
1	3,4, ---,26	47	4052.8	86.2	0.36	1.55	1.37
2	Residual	992	235912.8	237.8			
3	2	2	34530.1	17265.1	87.15	4.61	3
4	Residual	1037	205435.5	198.1			
1	2,3, ---,26	49	38583.0	787.4	3.87	1.54	1.36
2	Residual	990	201382.7	203.4			
3	1	2	118745.9	59372.9	507.92	4.61	3
4	Residual	1037	121219.8	116.9			

Table 4.24k Analysis of variance of weekly water deficit at Anand

S.No.	Harmonic	Degree of freedom	Sum of Squares	Mean squares	F _{cal}	F _{tab}	
						0.01	0.05
1	5,6,---,26	43	2677.3	62.3	0.24	1.57	1.38
2	Residual	1412	362132.4	256.5			
3	4	3	2222.4	740.8	2.97	3.78	2.6
4	Residual	1452	362587.3	249.7			
1	4,5, ---,26	45	4899.6	108.9	0.43	1.56	1.37
2	Residual	1410	359910.0	255.3			
3	3	2	9164.8	4582.4	18.72	4.61	3
4	Residual	1453	355644.9	244.8			
1	3,4, ---,26	47	14064.5	299.2	1.20	1.55	1.37
2	Residual	1408	350745.2	249.1			
3	2	2	72985.4	36492.7	181.70	4.61	3
4	Residual	1453	291824.3	200.8			
1	2,3, ---,26	49	87049.9	1776.5	8.99	1.54	1.36
2	Residual	1406	277759.8	197.6			
3	1	2	184277.3	92138.6	741.57	4.61	3
4	Residual	1453	180532.4	124.2			

Table 4.24l Analysis of variance of weekly water deficit at Nawagam

S.No.	Harmonic	Degree of freedom	Sum of Squares	Mean squares	F _{cal}	F _{tab}	
						0.01	0.05
1	5,6,---,26	43	3796.6	88.3	0.26	1.57	1.38
2	Residual	1204	401266.7	333.3			
3	4	3	4291.0	1430.3	4.44	3.78	2.6
4	Residual	1244	400772.3	322.2			
1	4,5, ---,26	45	8087.6	179.7	0.54	1.56	1.37
2	Residual	1202	396975.7	330.3			
3	3	2	4959.4	2479.7	7.72	4.61	3
4	Residual	1245	400103.9	321.4			
1	3,4, ---,26	47	13047.0	277.6	0.85	1.55	1.37
2	Residual	1200	392016.3	326.7			
3	2	2	52166.3	26083.1	92.02	4.61	3
4	Residual	1245	352897.0	283.5			
1	2,3, ---,26	49	65213.2	1330.9	4.69	1.54	1.36
2	Residual	1198	339850.0	283.7			
3	1	2	192536.8	96268.4	563.95	4.61	3
4	Residual	1245	212526.4	170.7			

Table 4.24m Analysis of variance of weekly water deficit at Bharuch

S.No.	Harmonic	Degree of freedom	Sum of Squares	Mean squares	F _{cal}	F _{tab}	
						0.01	0.05
1	5,6,---,26	43	2798.0	65.1	0.21	1.57	1.38
2	Residual	1412	442423.0	313.3			
3	4	3	4051.9	1350.6	4.45	3.78	2.6
4	Residual	1452	441169.1	303.8			
1	4,5, ---,26	45	6850.0	152.2	0.49	1.56	1.37
2	Residual	1410	438371.0	310.9			
3	3	2	9063.8	4531.9	15.10	4.61	3
4	Residual	1453	436157.3	300.2			
1	3,4, ---,26	47	15913.8	338.6	1.11	1.55	1.37
2	Residual	1408	429307.3	304.9			
3	2	2	77730.9	38865.5	153.67	4.61	3
4	Residual	1453	367490.1	252.9			
1	2,3, ---,26	49	93644.7	1911.1	7.64	1.54	1.36
2	Residual	1406	351576.3	250.1			
3	1	2	237248.4	118624.2	828.77	4.61	3
4	Residual	1453	207972.6	143.1			

Table 4.24n Analysis of variance of weekly water deficit at Surat

S.No.	Harmonic	Degree of freedom	Sum of Squares	Mean squares	F _{cal}	F _{tab}	
						0.01	0.05
1	5,6,---,26	43	2978.858	69.27577	0.26	1.57	1.38
2	Residual	1412	370710.9	262.5431			
3	4	3	4162.781	1387.594	5.45	3.78	2.6
4	Residual	1452	369527	254.4952			
1	4,5, ---,26	45	7141.639	158.7031	0.61	1.56	1.37
2	Residual	1410	366548.1	259.9632			
3	3	2	6801.294	3400.647	13.47	4.61	3
4	Residual	1453	366888.4	252.5041			
1	3,4, ---,26	47	13942.93	296.6582	1.16	1.55	1.37
2	Residual	1408	359746.8	255.502			
3	2	2	58972.04	29486.02	136.13	4.61	3
4	Residual	1453	314717.7	216.5986			
1	2,3, ---,26	49	72914.97	1488.061	6.96	1.54	1.36
2	Residual	1406	300774.8	213.9223			
3	1	2	214691.3	107345.6	980.97	4.61	3
4	Residual	1453	158998.4	109.4277			

Table 4.24o Analysis of variance of weekly water deficit at Navsari

S.No.	Harmonic	Degree of freedom	Sum of Squares	Mean squares	F _{cal}	F _{tab}	
						0.01	0.05
1	5,6,---,26	43	4429.4	103.0	0.39	1.57	1.38
2	Residual	1412	373684.3	264.6			
3	4	3	5006.2	1668.7	6.49	3.78	2.6
4	Residual	1452	373107.5	257.0			
1	4,5, ---,26	45	9435.5	209.7	0.80	1.56	1.37
2	Residual	1410	368678.1	261.5			
3	3	2	5785.9	2893.0	11.29	4.61	3
4	Residual	1453	372327.7	256.2			
1	3,4, ---,26	47	15221.5	323.9	1.26	1.55	1.37
2	Residual	1408	362892.2	257.7			
3	2	2	60860.6	30430.3	139.37	4.61	3
4	Residual	1453	317253.0	218.3			
1	2,3, ---,26	49	76082.1	1552.7	7.23	1.54	1.36
2	Residual	1406	302031.5	214.8			
3	1	2	224626.3	112313.2	1063.22	4.61	3
4	Residual	1453	153487.3	105.6			

Table 4.24p Analysis of variance of weekly water deficit at Gandevi

S.No.	Harmonic	Degree of freedom	Sum of Squares	Mean squares	F _{cal}	F _{tab}	
						0.01	0.05
1	5,6,---,26	43	5021.3	116.8	0.54	1.57	1.38
2	Residual	996	214914.0	215.8			
3	4	3	3383.0	1127.7	5.39	3.78	2.6
4	Residual	1036	216552.3	209.0			
1	4,5, ---,26	45	8404.2	186.8	0.88	1.56	1.37
2	Residual	994	211531.0	212.8			
3	3	2	3820.2	1910.1	9.17	4.61	3
4	Residual	1037	216115.1	208.4			
1	3,4, ---,26	47	12224.5	260.1	1.24	1.55	1.37
2	Residual	992	207710.8	209.4			
3	2	2	36890.7	18445.3	104.50	4.61	3
4	Residual	1037	183044.6	176.5			
1	2,3, ---,26	49	49115.2	1002.4	5.81	1.54	1.36
2	Residual	990	170820.1	172.5			
3	1	2	137295.8	68647.9	861.43	4.61	3
4	Residual	1037	82639.5	79.7			

Fourier decomposition of mean square: The number of significant harmonics that represent the periodic component were obtained by evaluating the Fourier series coefficients A_k and B_k . The Fourier series coefficients A_k and B_k along with amplitude and phase angle (θ) for the corresponding harmonics were computed using Equations (3.36), (3.37), (3.38), (3.39), (3.42) and (3.43). The contribution of the individual harmonics towards the mean square is shown under the explained variance and those harmonics, which dominantly contribute to mean square is selected as the significant harmonics. The results are shown in Tables 4.25a to 4.25p for weekly water deficit series.

The results (Tables 4.25a to 4.25p) indicated that at Kothara, Radhanpur, SK Nagar, Nawagam and Dhandhuka first three harmonics have contributed more than 58.64, 65.3, 62.02, 70.0 and 68.39 % of the total variation caused by the periodic component, while only about 1.03, 1.17, 1.32, 1.67 and 1.27 % have been contributed by the rest of the harmonics, respectively. At Rajkot, Amreli, Khedbrahma, Arnej, Junagadh, Anand, Bharuch, Surat, Navsari and Gandevi the first four harmonics have contributed more than 67.65, 65.11, 75.59, 74.7, 74.34, 73.41, 73.43, 75.99, 78.54 and 82.33 % of the total variation caused by the periodic component, while the rest of the harmonics have contributed only 0.89, 1.14, 1.31, 0.74, 1.0, 0.8, 0.58, 0.73, 1.06 and 2.13 %, respectively. For Mahuva first two harmonics have contributed more than 63.70 % of the total variation caused by the periodic component, while the rest of the harmonics have contributed only 1.75 %.

Cumulative periodogram test: In this test a graphical procedure has been employed as criteria for obtaining the significant harmonics to be fitted in a periodic component. A graph constructed by plotting P_i against i , called the cumulative periodogram is obtained from the solution of Equations (3.49), (3.50) and (3.51). The criterion is based on the concept that the variation of P_i versus i is composed of the two distinct parts: (i) a periodic part of a fast increase of P_i with i and (ii) a sampling part of a slow increase of P_i with i . After determining these two parts, the order of harmonics obtained up to the fast increase in P_i has been considered as a significant harmonics and the rest harmonics were ignored.

Estimates of the mean square deviation and the cumulative periodogram P_i for weekly series are shown in Tables 4.26a to 4.26p and the plot of P_i against i are shown in Figures 4.16a and 4.16d for different agro-climatic zones.

From the cumulative periodogram in the weekly series of the different zones, it is observed that at Kothara, Radhanpur, Dhandhuka and Nawagam the first three harmonics appeared to be the periodic part of the fast increase and after that periodogram remains almost constant which may be treated as non-significant. At Mahuva first two harmonics and at rest of the stations the first four harmonics appeared to be the periodic part of the fast increase in water deficit series, respectively.

Table 4.25a Fourier decomposition of periodic component in weekly water deficit series for Kothara

Order	A_k	B_k	Amplitude	Theta	Explained variance	Cumulative explained variance
1	-2.852	11.641	11.985	-1.331	35.873	35.873
2	-5.077	-7.621	9.157	0.983	20.940	56.813
3	0.766	2.594	2.704	1.284	1.827	58.640
4	-0.493	-1.053	1.163	1.133	0.338	58.978
5	0.263	0.233	0.352	0.724	0.031	59.009
6	-0.038	-0.085	0.093	1.147	0.002	59.011
7	-0.237	-0.189	0.303	0.671	0.023	59.034
8	0.371	-0.256	0.451	-0.604	0.051	59.084
9	-0.326	0.313	0.452	-0.766	0.051	59.136
10	-0.133	-0.133	0.188	0.787	0.009	59.144
11	-0.412	-0.005	0.412	0.011	0.042	59.187
12	0.552	0.484	0.735	0.720	0.135	59.322
13	-0.394	-0.452	0.600	0.853	0.090	59.411
14	0.185	-0.102	0.211	-0.503	0.011	59.423
15	-0.313	-0.308	0.439	0.777	0.048	59.471
16	0.068	-0.050	0.084	-0.631	0.002	59.472
17	-0.041	0.089	0.098	-1.140	0.002	59.475
18	0.004	0.140	0.140	1.539	0.005	59.480
19	-0.026	-0.135	0.138	1.378	0.005	59.484
20	-0.146	0.025	0.149	-0.169	0.006	59.490
21	0.261	0.367	0.451	0.953	0.051	59.541
22	-0.156	-0.174	0.234	0.840	0.014	59.554
23	-0.037	0.139	0.144	-1.311	0.005	59.559
24	-0.396	-0.272	0.480	0.601	0.058	59.617
25	0.014	0.441	0.441	1.540	0.049	59.666
26	0.027	0.000	0.027	0.000	0.000	59.666

Table 4.25b Fourier decomposition of periodic component in weekly water deficit series for Radhanpur

Order	A_k	B_k	Amplitude	Theta	Explained variance	Cumulative explained variance
1	-5.600	13.931	15.015	-1.189	39.338	39.338
2	-4.483	-10.377	11.304	1.163	22.296	61.634
3	-0.073	4.583	4.583	-1.555	3.665	65.299
4	0.266	-1.527	1.550	-1.398	0.419	65.719
5	-0.168	0.442	0.473	-1.207	0.039	65.758
6	0.122	-0.105	0.161	-0.710	0.005	65.762
7	-0.333	-0.348	0.482	0.808	0.041	65.803
8	0.257	-0.053	0.262	-0.204	0.012	65.815
9	-0.321	-0.105	0.338	0.315	0.020	65.835
10	0.522	0.164	0.547	0.305	0.052	65.887
11	-0.665	-0.032	0.666	0.048	0.077	65.964
12	0.290	0.156	0.329	0.494	0.019	65.983
13	-0.136	0.130	0.189	-0.763	0.006	65.989
14	0.285	-0.467	0.547	-1.022	0.052	66.042
15	-0.197	0.040	0.201	-0.200	0.007	66.049
16	0.097	0.087	0.131	0.729	0.003	66.052
17	-0.286	0.138	0.317	-0.449	0.018	66.069
18	0.242	-0.292	0.379	-0.878	0.025	66.094
19	-0.117	0.251	0.277	-1.135	0.013	66.108
20	-0.402	-0.478	0.625	0.873	0.068	66.176
21	0.248	0.504	0.561	1.113	0.055	66.231
22	-0.370	-0.582	0.690	1.005	0.083	66.314
23	0.178	0.457	0.491	1.199	0.042	66.356
24	-0.661	-0.326	0.737	0.458	0.095	66.451
25	0.213	0.230	0.314	0.824	0.017	66.468
26	0.138	0.000	0.138	0.000	0.003	66.471

Table 4.25c Fourier decomposition of periodic component in weekly water deficit series for Rajkot

Order	A_k	B_k	Amplitude	Theta	Explained variance	Cumulative explained variance
1	-2.488	19.219	19.379	-1.442	44.547	44.547
2	-4.594	-11.996	12.846	1.205	19.573	64.120
3	2.063	4.051	4.546	1.100	2.451	66.571
4	-2.508	-1.667	3.011	0.587	1.076	67.647
5	1.521	0.622	1.644	0.388	0.320	67.967
6	-0.415	-0.230	0.475	0.506	0.027	67.994
7	0.366	-0.454	0.583	-0.892	0.040	68.035
8	-0.612	-0.304	0.684	0.461	0.055	68.090
9	-0.051	0.013	0.052	-0.244	0.000	68.090
10	0.507	-0.317	0.598	-0.559	0.042	68.133
11	-0.707	-0.052	0.709	0.074	0.060	68.192
12	0.398	0.138	0.421	0.333	0.021	68.213
13	-0.239	0.009	0.239	-0.040	0.007	68.220
14	0.216	-0.029	0.218	-0.135	0.006	68.226
15	-0.124	-0.056	0.136	0.422	0.002	68.228
16	0.016	-0.410	0.411	-1.531	0.020	68.248
17	-0.143	0.115	0.183	-0.679	0.004	68.252
18	-0.002	-0.592	0.592	1.568	0.042	68.294
19	0.278	0.262	0.382	0.755	0.017	68.311
20	-0.640	-0.370	0.739	0.525	0.065	68.376
21	0.406	0.501	0.645	0.891	0.049	68.425
22	-0.335	-0.464	0.572	0.946	0.039	68.464
23	0.284	-0.015	0.284	-0.053	0.010	68.473
24	-0.483	0.218	0.530	-0.424	0.033	68.507
25	0.405	-0.061	0.410	-0.149	0.020	68.527
26	0.245	0.000	0.245	0.000	0.007	68.534

Table 4.25d Fourier decomposition of periodic component in weekly water deficit series for Amreli

Order	A_k	B_k	Amplitude	Theta	Explained variance	Cumulative explained variance
1	0.503	17.725	17.732	1.542	43.655	43.655
2	-5.747	-10.259	11.759	1.060	19.199	62.854
3	1.966	2.078	2.860	0.813	1.136	63.990
4	-2.835	0.221	2.843	-0.078	1.122	65.113
5	1.848	0.205	1.860	0.110	0.480	65.593
6	-0.537	0.559	0.775	-0.806	0.083	65.676
7	0.308	-1.131	1.172	-1.305	0.191	65.867
8	-0.552	0.168	0.576	-0.295	0.046	65.913
9	-0.364	-0.013	0.364	0.035	0.018	65.932
10	0.582	-0.106	0.592	-0.181	0.049	65.980
11	-0.424	-0.041	0.426	0.097	0.025	66.005
12	0.424	-0.184	0.462	-0.409	0.030	66.035
13	-0.268	-0.002	0.268	0.006	0.010	66.045
14	0.110	0.084	0.139	0.649	0.003	66.048
15	-0.006	-0.176	0.176	1.537	0.004	66.052
16	-0.079	-0.191	0.207	1.180	0.006	66.058
17	-0.509	0.014	0.510	-0.027	0.036	66.094
18	0.361	0.166	0.397	0.430	0.022	66.116
19	-0.150	0.059	0.161	-0.374	0.004	66.120
20	-0.181	-0.274	0.328	0.989	0.015	66.135
21	0.189	0.261	0.322	0.943	0.014	66.149
22	-0.147	-0.095	0.175	0.571	0.004	66.153
23	0.295	-0.122	0.319	-0.393	0.014	66.167
24	-0.602	0.237	0.647	-0.376	0.058	66.225
25	0.408	0.109	0.422	0.260	0.025	66.250
26	0.022	0.000	0.022	0.000	0.000	66.250

Table 4.25e Fourier decomposition of periodic component in weekly water deficit series for SK Nagar

Order	A_k	B_k	Amplitude	Theta	Explained variance	Cumulative explained variance
1	-6.400	14.230	15.603	-1.148	41.005	41.005
2	-3.633	-9.543	10.211	1.207	17.563	58.568
3	-0.280	4.522	4.530	-1.509	3.457	62.025
4	1.099	-1.496	1.857	-0.937	0.581	62.605
5	-0.082	0.969	0.973	-1.487	0.159	62.765
6	0.221	-0.571	0.612	-1.202	0.063	62.828
7	-0.271	-0.031	0.273	0.114	0.013	62.840
8	-0.066	0.206	0.216	-1.262	0.008	62.848
9	-0.447	0.066	0.452	-0.146	0.034	62.883
10	0.523	0.398	0.657	0.651	0.073	62.955
11	-0.361	-0.175	0.401	0.452	0.027	62.982
12	0.269	0.139	0.303	0.477	0.015	62.998
13	-0.309	-0.169	0.352	0.499	0.021	63.019
14	0.394	0.000	0.394	0.001	0.026	63.045
15	0.100	-0.217	0.239	-1.137	0.010	63.055
16	-0.189	0.213	0.285	-0.845	0.014	63.068
17	-0.337	-0.124	0.359	0.353	0.022	63.090
18	-0.066	0.271	0.279	-1.331	0.013	63.103
19	0.307	-0.072	0.316	-0.231	0.017	63.120
20	-0.111	0.211	0.239	-1.088	0.010	63.130
21	0.027	-0.049	0.056	-1.075	0.001	63.130
22	-0.117	0.274	0.298	-1.167	0.015	63.145
23	0.321	-0.513	0.605	-1.012	0.062	63.207
24	-0.316	0.271	0.416	-0.708	0.029	63.236
25	-0.089	-0.268	0.282	1.250	0.013	63.249
26	0.767	0.000	0.767	0.000	0.099	63.349

Table 4.25f Fourier decomposition of periodic component in weekly water deficit series for Khedbrahma

Order	A_k	B_k	Amplitude	Theta	Explained variance	Cumulative explained variance
1	-2.945	14.894	15.183	-1.376	48.339	48.339
2	-3.850	-9.448	10.202	1.184	21.827	70.166
3	1.117	4.407	4.547	1.323	4.335	74.501
4	-1.450	-1.761	2.281	0.882	1.091	75.592
5	1.218	0.826	1.472	0.596	0.454	76.046
6	-0.730	0.323	0.798	-0.417	0.134	76.180
7	0.236	-0.551	0.599	-1.166	0.075	76.255
8	0.272	0.127	0.300	0.436	0.019	76.274
9	-0.752	0.417	0.860	-0.506	0.155	76.429
10	0.665	0.158	0.683	0.233	0.098	76.527
11	-0.335	-0.123	0.357	0.352	0.027	76.554
12	0.104	-0.133	0.169	-0.906	0.006	76.560
13	-0.241	0.274	0.364	-0.849	0.028	76.588
14	0.345	-0.111	0.362	-0.312	0.028	76.615
15	-0.122	-0.186	0.222	0.990	0.010	76.626
16	-0.069	-0.125	0.143	1.065	0.004	76.630
17	-0.218	0.343	0.406	-1.005	0.035	76.664
18	-0.143	-0.061	0.155	0.404	0.005	76.669
19	0.258	0.040	0.261	0.155	0.014	76.684
20	-0.352	0.023	0.352	-0.066	0.026	76.710
21	0.360	0.028	0.361	0.076	0.027	76.737
22	-0.368	-0.100	0.382	0.265	0.031	76.768
23	0.055	-0.200	0.207	-1.302	0.009	76.777
24	-0.524	0.334	0.621	-0.567	0.081	76.858
25	0.394	-0.161	0.426	-0.387	0.038	76.896
26	-0.100	0.000	0.100	0.000	0.002	76.898

Table 4.25g Fourier decomposition of periodic component in weekly water deficit series for Arnej

Order	A _k	B _k	Amplitude	Theta	Explained variance	Cumulative explained variance
1	-2.785	19.798	19.993	-1.431	52.870	52.870
2	-4.415	-11.147	11.989	1.194	19.013	71.883
3	1.680	3.550	3.928	1.129	2.040	73.923
4	-2.039	-1.310	2.424	0.571	0.777	74.700
5	1.300	0.396	1.359	0.296	0.244	74.944
6	-0.736	0.116	0.746	-0.156	0.074	75.018
7	0.503	-0.417	0.653	-0.692	0.056	75.074
8	-0.681	0.325	0.754	-0.445	0.075	75.150
9	0.240	-0.475	0.532	-1.102	0.037	75.187
10	0.084	0.233	0.248	1.224	0.008	75.195
11	-0.210	-0.249	0.326	0.871	0.014	75.209
12	0.083	0.058	0.101	0.609	0.001	75.211
13	0.149	0.002	0.149	0.014	0.003	75.214
14	0.226	0.136	0.264	0.541	0.009	75.223
15	-0.154	-0.484	0.508	1.263	0.034	75.257
16	0.150	0.500	0.522	1.279	0.036	75.293
17	0.076	-0.169	0.186	-1.148	0.005	75.298
18	0.029	0.066	0.072	1.159	0.001	75.298
19	0.195	-0.084	0.212	-0.406	0.006	75.304
20	-0.507	-0.054	0.510	0.105	0.034	75.339
21	0.058	-0.342	0.347	-1.404	0.016	75.354
22	0.246	0.305	0.392	0.893	0.020	75.375
23	-0.404	0.002	0.404	-0.005	0.022	75.396
24	0.033	0.130	0.135	1.323	0.002	75.399
25	0.287	0.417	0.506	0.969	0.034	75.433
26	0.164	0.000	0.164	0.000	0.004	75.436

Table 4.25h Fourier decomposition of periodic component in weekly water deficit series for Dhandhuka

Order	A _k	B _k	Amplitude	Theta	Explained variance	Cumulative explained variance
1	-2.572	17.948	18.132	-1.428	48.891	48.891
2	-5.041	-9.788	11.010	1.095	18.026	66.918
3	1.704	2.649	3.149	0.999	1.475	68.393
4	-1.734	-0.484	1.801	0.272	0.482	68.875
5	1.174	-0.151	1.183	-0.128	0.208	69.083
6	-0.647	0.564	0.858	-0.717	0.110	69.193
7	0.399	-0.626	0.742	-1.003	0.082	69.275
8	-0.041	0.295	0.298	-1.432	0.013	69.288
9	-0.137	-0.211	0.252	0.995	0.009	69.297
10	0.208	-0.555	0.592	-1.212	0.052	69.349
11	-0.213	0.550	0.590	-1.201	0.052	69.401
12	-0.058	-0.492	0.496	1.454	0.037	69.438
13	0.432	0.069	0.438	0.159	0.029	69.466
14	-0.406	0.010	0.406	-0.024	0.025	69.491
15	0.208	0.220	0.303	0.813	0.014	69.504
16	-0.185	0.265	0.323	-0.963	0.016	69.520
17	0.273	-0.231	0.357	-0.702	0.019	69.539
18	-0.039	0.191	0.194	-1.371	0.006	69.545
19	0.230	-0.206	0.309	-0.731	0.014	69.559
20	-0.319	-0.386	0.501	0.880	0.037	69.596
21	0.013	0.188	0.189	1.499	0.005	69.601
22	-0.074	-0.122	0.143	1.026	0.003	69.604
23	0.170	-0.016	0.170	-0.096	0.004	69.609
24	-0.320	0.498	0.591	-1.000	0.052	69.661
25	-0.055	0.009	0.056	-0.167	0.000	69.661
26	0.173	0.000	0.173	0.000	0.004	69.666

Table 4.25i Fourier decomposition of periodic component in weekly water deficit series for Junagdh

Order	A_k	B_k	Amplitude	Theta	Explained variance	Cumulative explained variance
1	2.882	18.953	19.171	1.420	54.177	54.177
2	-5.458	-9.797	11.215	1.063	18.540	72.718
3	1.929	1.229	2.288	0.567	0.771	73.489
4	-2.349	-0.523	2.407	0.219	0.854	74.343
5	1.358	0.562	1.469	0.392	0.318	74.661
6	-0.619	0.294	0.685	-0.444	0.069	74.730
7	0.264	-1.065	1.098	-1.328	0.178	74.908
8	-0.647	0.083	0.652	-0.128	0.063	74.971
9	-0.414	-0.125	0.433	0.294	0.028	74.998
10	0.496	0.232	0.548	0.437	0.044	75.043
11	-0.506	-0.289	0.583	0.520	0.050	75.093
12	0.569	0.185	0.598	0.314	0.053	75.145
13	-0.311	0.212	0.377	-0.599	0.021	75.166
14	0.393	0.015	0.393	0.039	0.023	75.189
15	-0.431	-0.016	0.432	0.036	0.027	75.216
16	0.136	-0.118	0.180	-0.715	0.005	75.221
17	-0.103	0.183	0.210	-1.057	0.007	75.228
18	0.015	-0.065	0.067	-1.347	0.001	75.228
19	-0.130	-0.019	0.131	0.146	0.003	75.231
20	-0.163	0.070	0.177	-0.404	0.005	75.236
21	0.044	0.038	0.058	0.712	0.000	75.236
22	-0.403	0.196	0.448	-0.453	0.030	75.266
23	-0.153	-0.152	0.216	0.782	0.007	75.273
24	-0.251	0.232	0.342	-0.748	0.017	75.290
25	0.009	-0.376	0.376	-1.548	0.021	75.311
26	0.408	0.000	0.408	0.000	0.025	75.335

Table 4.25j Fourier decomposition of periodic component in weekly water deficit series for Mahuva

Order	A_k	B_k	Amplitude	Theta	Explained variance	Cumulative explained variance
1	1.917	14.971	15.093	1.443	49.316	49.316
2	-3.120	-7.531	8.152	1.178	14.385	63.701
3	0.854	0.989	1.307	0.858	0.370	64.071
4	-1.494	-0.502	1.576	0.324	0.538	64.609
5	0.480	0.124	0.496	0.253	0.053	64.662
6	-0.267	0.320	0.417	-0.875	0.038	64.699
7	0.086	-0.387	0.397	-1.351	0.034	64.734
8	-0.261	0.132	0.292	-0.470	0.018	64.752
9	-0.184	-0.470	0.505	1.198	0.055	64.807
10	0.228	0.454	0.508	1.105	0.056	64.863
11	-0.273	-0.375	0.464	0.941	0.047	64.910
12	0.273	-0.099	0.290	-0.347	0.018	64.928
13	-0.226	0.045	0.230	-0.195	0.011	64.939
14	0.622	0.233	0.665	0.358	0.096	65.035
15	-0.244	-0.127	0.275	0.479	0.016	65.051
16	0.200	0.008	0.200	0.039	0.009	65.060
17	-0.255	-0.080	0.267	0.305	0.015	65.075
18	0.255	0.103	0.275	0.384	0.016	65.092
19	-0.214	-0.050	0.219	0.232	0.010	65.102
20	-0.103	-0.138	0.172	0.931	0.006	65.109
21	-0.012	0.504	0.504	-1.547	0.055	65.164
22	-0.568	-0.680	0.886	0.875	0.170	65.334
23	0.270	0.487	0.557	1.064	0.067	65.401
24	-0.158	-0.279	0.321	1.055	0.022	65.423
25	0.309	0.168	0.351	0.498	0.027	65.450
26	0.147	0.000	0.147	0.000	0.005	65.455

Table 4.25k Fourier decomposition of periodic component in weekly water deficit series for Anand

Order	A_k	B_k	Amplitude	Theta	Explained variance	Cumulative explained variance
1	-2.265	15.725	15.887	-1.428	50.336	50.336
2	-4.128	-9.116	10.007	1.146	19.969	70.304
3	0.983	3.398	3.537	1.289	2.495	72.799
4	-1.340	-1.138	1.758	0.704	0.616	73.416
5	1.177	0.397	1.242	0.325	0.307	73.723
6	-0.752	0.118	0.761	-0.155	0.116	73.839
7	0.489	-0.150	0.511	-0.297	0.052	73.891
8	-0.264	0.118	0.289	-0.420	0.017	73.908
9	-0.111	-0.266	0.288	1.175	0.017	73.924
10	0.258	0.082	0.271	0.308	0.015	73.939
11	-0.267	-0.061	0.274	0.224	0.015	73.954
12	0.148	0.063	0.161	0.400	0.005	73.959
13	0.019	0.084	0.086	1.347	0.001	73.960
14	0.012	-0.008	0.014	-0.580	0.000	73.960
15	0.053	-0.056	0.077	-0.815	0.001	73.962
16	-0.170	0.190	0.255	-0.840	0.013	73.975
17	0.065	-0.182	0.193	-1.229	0.007	73.982
18	-0.029	0.134	0.137	-1.354	0.004	73.986
19	0.107	0.100	0.146	0.748	0.004	73.990
20	-0.165	0.033	0.169	-0.199	0.006	73.996
21	0.345	-0.107	0.362	-0.302	0.026	74.022
22	-0.401	0.233	0.464	-0.526	0.043	74.065
23	0.278	-0.382	0.473	-0.941	0.045	74.109
24	-0.116	0.453	0.467	-1.320	0.044	74.153
25	0.168	-0.526	0.552	-1.262	0.061	74.214
26	-0.009	0.000	0.009	0.000	0.000	74.214

Table 4.25l Fourier decomposition of periodic component in weekly water deficit series for Nawagam

Order	A_k	B_k	Amplitude	Theta	Explained variance	Cumulative explained variance
1	-2.905	17.359	17.601	-1.405	47.684	47.684
2	-3.229	-10.647	11.126	1.276	19.055	66.739
3	1.357	4.398	4.603	1.271	3.261	70.000
4	-1.033	-1.469	1.796	0.958	0.496	70.497
5	1.676	0.646	1.796	0.368	0.497	70.993
6	-0.938	0.108	0.944	-0.115	0.137	71.130
7	0.513	-0.312	0.600	-0.547	0.056	71.186
8	-0.222	0.088	0.239	-0.376	0.009	71.195
9	-0.347	-0.414	0.541	0.873	0.045	71.240
10	0.402	0.152	0.430	0.361	0.028	71.268
11	-0.332	0.105	0.348	-0.307	0.019	71.287
12	-0.052	-0.026	0.058	0.463	0.001	71.287
13	0.324	-0.059	0.329	-0.181	0.017	71.304
14	-0.017	0.199	0.200	-1.488	0.006	71.310
15	0.084	-0.104	0.134	-0.891	0.003	71.313
16	-0.229	-0.309	0.385	0.932	0.023	71.336
17	0.392	0.198	0.439	0.468	0.030	71.366
18	-0.338	-0.062	0.343	0.181	0.018	71.384
19	0.330	0.147	0.362	0.420	0.020	71.404
20	-0.213	-0.139	0.254	0.579	0.010	71.414
21	0.424	0.099	0.435	0.230	0.029	71.443
22	-0.525	-0.168	0.551	0.309	0.047	71.490
23	0.586	-0.198	0.619	-0.325	0.059	71.549
24	-0.564	0.221	0.606	-0.374	0.056	71.605
25	0.474	-0.405	0.624	-0.707	0.060	71.665
26	-0.114	0.000	0.114	0.000	0.002	71.667

Table 4.25m Fourier decomposition of periodic component in weekly water deficit series for Bharuch

Order	A_k	B_k	Amplitude	Theta	Explained variance	Cumulative explained variance
1	-0.765	18.016	18.033	-1.528	53.134	53.134
2	-4.933	-9.066	10.321	1.072	17.407	70.541
3	2.092	2.795	3.491	0.928	1.992	72.533
4	-2.305	-0.400	2.340	0.172	0.894	73.427
5	1.358	0.200	1.373	0.146	0.308	73.735
6	-0.312	0.215	0.379	-0.602	0.023	73.758
7	0.400	-0.301	0.500	-0.645	0.041	73.799
8	-0.316	0.087	0.328	-0.270	0.018	73.817
9	-0.421	0.013	0.421	-0.031	0.029	73.846
10	0.351	-0.039	0.353	-0.110	0.020	73.866
11	-0.353	0.126	0.375	-0.343	0.023	73.889
12	0.268	-0.341	0.434	-0.903	0.031	73.920
13	0.002	0.181	0.181	1.558	0.005	73.925
14	0.074	-0.173	0.189	-1.167	0.006	73.931
15	0.063	0.094	0.113	0.976	0.002	73.933
16	-0.298	-0.236	0.380	0.669	0.024	73.957
17	-0.130	-0.081	0.153	0.557	0.004	73.961
18	-0.128	-0.046	0.136	0.346	0.003	73.964
19	0.224	-0.043	0.228	-0.190	0.009	73.972
20	-0.058	0.027	0.064	-0.438	0.001	73.973
21	0.263	0.179	0.318	0.598	0.017	73.989
22	-0.051	0.097	0.110	-1.084	0.002	73.991
23	0.061	0.204	0.213	1.280	0.007	73.999
24	-0.161	-0.082	0.181	0.469	0.005	74.004
25	0.043	-0.163	0.169	-1.313	0.005	74.009
26	0.011	0.000	0.011	0.000	0.000	74.009

Table 4.25n Fourier decomposition of periodic component in weekly water deficit series for Surat

Order	A_k	B_k	Amplitude	Theta	Explained variance	Cumulative explained variance
1	1.029	17.139	17.169	1.511	57.390	57.390
2	-4.656	-7.693	8.992	1.027	15.741	73.130
3	2.161	2.121	3.028	0.776	1.785	74.915
4	-2.254	-0.672	2.352	0.290	1.077	75.992
5	1.410	0.501	1.496	0.341	0.436	76.428
6	-0.382	0.077	0.390	-0.200	0.030	76.457
7	0.570	-0.075	0.575	-0.132	0.064	76.521
8	-0.435	0.132	0.455	-0.293	0.040	76.562
9	-0.073	-0.281	0.290	1.318	0.016	76.578
10	0.126	-0.047	0.135	-0.359	0.004	76.582
11	-0.144	-0.018	0.145	0.121	0.004	76.586
12	0.137	-0.142	0.197	-0.803	0.008	76.593
13	-0.118	0.048	0.128	-0.384	0.003	76.597
14	-0.045	0.099	0.109	-1.148	0.002	76.599
15	0.063	-0.122	0.137	-1.095	0.004	76.602
16	-0.131	0.016	0.132	-0.119	0.003	76.606
17	0.038	-0.141	0.146	-1.306	0.004	76.610
18	0.066	0.068	0.095	0.804	0.002	76.612
19	0.086	0.119	0.147	0.945	0.004	76.616
20	-0.084	-0.054	0.100	0.573	0.002	76.618
21	0.159	0.023	0.161	0.146	0.005	76.623
22	-0.100	0.236	0.256	-1.172	0.013	76.636
23	-0.079	-0.328	0.338	1.336	0.022	76.658
24	0.189	0.248	0.312	0.919	0.019	76.677
25	-0.442	-0.027	0.443	0.062	0.038	76.715
26	0.219	0.000	0.219	0.000	0.009	76.725

Table 4.25o Fourier decomposition of periodic component in weekly water deficit series for Navsari

Order	A_k	B_k	Amplitude	Theta	Explained variance	Cumulative explained variance
1	2.398	17.423	17.588	1.434	59.514	59.514
2	-4.751	-7.840	9.168	1.026	16.170	75.685
3	2.293	1.606	2.799	0.611	1.508	77.192
4	-2.644	-0.092	2.645	0.035	1.346	78.538
5	1.659	0.140	1.665	0.084	0.533	79.072
6	-0.651	0.432	0.781	-0.586	0.117	79.189
7	0.494	-0.709	0.864	-0.962	0.144	79.333
8	-0.270	0.516	0.583	-1.088	0.065	79.398
9	-0.282	-0.514	0.586	1.068	0.066	79.464
10	0.215	0.115	0.243	0.491	0.011	79.476
11	-0.037	-0.203	0.207	1.390	0.008	79.484
12	0.206	0.051	0.213	0.244	0.009	79.493
13	-0.121	-0.063	0.136	0.481	0.004	79.496
14	0.227	0.004	0.227	0.016	0.010	79.506
15	-0.357	0.086	0.367	-0.236	0.026	79.532
16	0.118	-0.223	0.253	-1.084	0.012	79.544
17	0.044	0.186	0.191	1.338	0.007	79.552
18	0.065	0.028	0.070	0.404	0.001	79.552
19	0.124	0.134	0.182	0.823	0.006	79.559
20	-0.024	0.042	0.049	-1.054	0.000	79.559
21	0.038	0.113	0.120	1.247	0.003	79.562
22	-0.123	0.166	0.207	-0.933	0.008	79.570
23	0.066	-0.039	0.077	-0.532	0.001	79.571
24	-0.192	0.099	0.216	-0.478	0.009	79.580
25	0.054	-0.270	0.276	-1.374	0.015	79.595
26	0.054	0.000	0.054	0.000	0.001	79.596

Table 4.25p Fourier decomposition of periodic component in weekly water deficit series for Gandevi

Order	A_k	B_k	Amplitude	Theta	Explained variance	Cumulative explained variance
1	0.499	16.244	16.252	1.540	62.386	62.386
2	-3.873	-7.464	8.409	1.092	16.703	79.089
3	2.070	1.700	2.678	0.688	1.694	80.783
4	-2.557	-0.135	2.561	0.053	1.549	82.332
5	1.515	-0.085	1.518	-0.056	0.544	82.876
6	-0.791	0.681	1.044	-0.711	0.258	83.133
7	0.647	-0.632	0.904	-0.774	0.193	83.327
8	-0.430	0.823	0.928	-1.090	0.204	83.530
9	-0.128	-0.823	0.833	1.416	0.164	83.694
10	0.235	0.603	0.648	1.199	0.099	83.793
11	-0.561	-0.306	0.639	0.499	0.096	83.890
12	0.624	0.030	0.625	0.048	0.092	83.982
13	-0.395	0.055	0.399	-0.140	0.038	84.019
14	0.425	-0.110	0.439	-0.253	0.046	84.065
15	-0.467	0.287	0.548	-0.550	0.071	84.136
16	0.353	-0.345	0.494	-0.773	0.058	84.193
17	-0.141	0.256	0.293	-1.066	0.020	84.214
18	0.108	-0.123	0.164	-0.850	0.006	84.220
19	-0.230	0.350	0.419	-0.990	0.041	84.261
20	0.011	-0.335	0.335	-1.537	0.027	84.288
21	0.039	0.305	0.307	1.443	0.022	84.310
22	-0.332	-0.155	0.366	0.436	0.032	84.342
23	0.224	0.229	0.320	0.795	0.024	84.366
24	-0.434	0.139	0.456	-0.310	0.049	84.415
25	0.355	-0.224	0.420	-0.563	0.042	84.457
26	-0.116	0.000	0.116	0.000	0.003	84.460

Table 4.26a Cumulative periodogram of weekly water deficit series for Kothara

Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i	Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i
1	120.44	71.82	71.82	0.596	14	120.44	0.02	118.97	0.988
2	120.44	41.93	113.75	0.944	15	120.44	0.10	119.07	0.989
3	120.44	3.66	117.41	0.975	16	120.44	0.00	119.07	0.989
4	120.44	0.68	118.08	0.980	17	120.44	0.01	119.08	0.989
5	120.44	0.06	118.15	0.981	18	120.44	0.01	119.09	0.989
6	120.44	0.00	118.15	0.981	19	120.44	0.01	119.10	0.989
7	120.44	0.05	118.20	0.981	20	120.44	0.01	119.11	0.989
8	120.44	0.10	118.30	0.982	21	120.44	0.10	119.21	0.990
9	120.44	0.10	118.40	0.983	22	120.44	0.03	119.24	0.990
10	120.44	0.02	118.42	0.983	23	120.44	0.01	119.25	0.990
11	120.44	0.09	118.50	0.984	24	120.44	0.12	119.36	0.991
12	120.44	0.27	118.77	0.986	25	120.44	0.10	119.46	0.992
13	120.44	0.18	118.95	0.988	26	120.44	0.00	119.46	0.992

Table 4.26b Cumulative periodogram of weekly water deficit series for Radhanpur

Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i	Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i
1	190.35	112.72	112.72	0.592	14	190.35	0.15	189.24	0.994
2	190.35	63.89	176.61	0.928	15	190.35	0.02	189.26	0.994
3	190.35	10.50	187.11	0.983	16	190.35	0.01	189.27	0.994
4	190.35	1.20	188.31	0.989	17	190.35	0.05	189.32	0.995
5	190.35	0.11	188.43	0.990	18	190.35	0.07	189.39	0.995
6	190.35	0.01	188.44	0.990	19	190.35	0.04	189.43	0.995
7	190.35	0.12	188.55	0.991	20	190.35	0.20	189.62	0.996
8	190.35	0.03	188.59	0.991	21	190.35	0.16	189.78	0.997
9	190.35	0.06	188.65	0.991	22	190.35	0.24	190.02	0.998
10	190.35	0.15	188.80	0.992	23	190.35	0.12	190.14	0.999
11	190.35	0.22	189.02	0.993	24	190.35	0.27	190.41	1.000
12	190.35	0.05	189.07	0.993	25	190.35	0.05	190.46	1.001
13	190.35	0.02	189.09	0.993	26	190.35	0.01	190.47	1.001

Table 4.26c Cumulative periodogram of weekly water deficit series for Rajkot

Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i	Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i
1	289.76	187.78	187.78	0.648	14	289.76	0.02	287.59	0.992
2	289.76	82.51	270.28	0.933	15	289.76	0.01	287.60	0.993
3	289.76	10.33	280.62	0.968	16	289.76	0.08	287.69	0.993
4	289.76	4.53	285.15	0.984	17	289.76	0.02	287.70	0.993
5	289.76	1.35	286.50	0.989	18	289.76	0.18	287.88	0.993
6	289.76	0.11	286.61	0.989	19	289.76	0.07	287.95	0.994
7	289.76	0.17	286.78	0.990	20	289.76	0.27	288.22	0.995
8	289.76	0.23	287.02	0.991	21	289.76	0.21	288.43	0.995
9	289.76	0.00	287.02	0.991	22	289.76	0.16	288.59	0.996
10	289.76	0.18	287.20	0.991	23	289.76	0.04	288.64	0.996
11	289.76	0.25	287.45	0.992	24	289.76	0.14	288.78	0.997
12	289.76	0.09	287.54	0.992	25	289.76	0.08	288.86	0.997
13	289.76	0.03	287.57	0.992	26	289.76	0.03	288.89	0.997

Table 4.26d Cumulative periodogram of weekly water deficit series for Amreli

Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i	Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i
1	238.48	157.21	157.21	0.659	14	238.48	0.01	237.86	0.997
2	238.48	69.14	226.36	0.949	15	238.48	0.02	237.87	0.997
3	238.48	4.09	230.45	0.966	16	238.48	0.02	237.89	0.998
4	238.48	4.04	234.49	0.983	17	238.48	0.13	238.02	0.998
5	238.48	1.73	236.22	0.991	18	238.48	0.08	238.10	0.998
6	238.48	0.30	236.52	0.992	19	238.48	0.01	238.12	0.998
7	238.48	0.69	237.21	0.995	20	238.48	0.05	238.17	0.999
8	238.48	0.17	237.37	0.995	21	238.48	0.05	238.22	0.999
9	238.48	0.07	237.44	0.996	22	238.48	0.02	238.24	0.999
10	238.48	0.18	237.61	0.996	23	238.48	0.05	238.29	0.999
11	238.48	0.09	237.70	0.997	24	238.48	0.21	238.50	1.000
12	238.48	0.11	237.81	0.997	25	238.48	0.09	238.59	1.000
13	238.48	0.04	237.85	0.997	26	238.48	0.00	238.59	1.000

Table 4.26e Cumulative periodogram of weekly water deficit series for SK Nagar

Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i	Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i
1	188.31	121.72	121.72	0.646	14	188.31	0.08	187.15	0.994
2	188.31	52.14	173.86	0.923	15	188.31	0.03	187.17	0.994
3	188.31	10.26	184.12	0.978	16	188.31	0.04	187.22	0.994
4	188.31	1.72	185.84	0.987	17	188.31	0.07	187.28	0.995
5	188.31	0.47	186.31	0.989	18	188.31	0.04	187.32	0.995
6	188.31	0.19	186.50	0.990	19	188.31	0.05	187.37	0.995
7	188.31	0.04	186.54	0.991	20	188.31	0.03	187.40	0.995
8	188.31	0.02	186.56	0.991	21	188.31	0.00	187.40	0.995
9	188.31	0.10	186.66	0.991	22	188.31	0.05	187.44	0.995
10	188.31	0.22	186.88	0.992	23	188.31	0.18	187.63	0.996
11	188.31	0.08	186.96	0.993	24	188.31	0.09	187.71	0.997
12	188.31	0.05	187.01	0.993	25	188.31	0.04	187.75	0.997
13	188.31	0.06	187.07	0.993	26	188.31	0.29	188.05	0.999

Table 4.26f Cumulative periodogram of weekly water deficit series for Khedbrahma

Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i	Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i
1	183.85	115.26	115.26	0.627	14	183.85	0.07	182.68	0.994
2	183.85	52.04	167.30	0.910	15	183.85	0.03	182.70	0.994
3	183.85	10.34	177.64	0.966	16	183.85	0.01	182.71	0.994
4	183.85	2.60	180.24	0.980	17	183.85	0.08	182.80	0.994
5	183.85	1.08	181.32	0.986	18	183.85	0.01	182.81	0.994
6	183.85	0.32	181.64	0.988	19	183.85	0.03	182.84	0.995
7	183.85	0.18	181.82	0.989	20	183.85	0.06	182.90	0.995
8	183.85	0.05	181.87	0.989	21	183.85	0.07	182.97	0.995
9	183.85	0.37	182.23	0.991	22	183.85	0.07	183.04	0.996
10	183.85	0.23	182.47	0.993	23	183.85	0.02	183.06	0.996
11	183.85	0.06	182.53	0.993	24	183.85	0.19	183.26	0.997
12	183.85	0.01	182.55	0.993	25	183.85	0.09	183.35	0.997
13	183.85	0.07	182.61	0.993	26	183.85	0.01	183.35	0.997

Table 4.26g Cumulative periodogram of weekly water deficit series for Arnej

Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i	Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i
1	286.34	199.86	199.86	0.698	14	286.34	0.04	284.36	0.993
2	286.34	71.87	271.73	0.949	15	286.34	0.13	284.49	0.994
3	286.34	7.71	279.44	0.976	16	286.34	0.14	284.62	0.994
4	286.34	2.94	282.38	0.986	17	286.34	0.02	284.64	0.994
5	286.34	0.92	283.30	0.989	18	286.34	0.00	284.64	0.994
6	286.34	0.28	283.58	0.990	19	286.34	0.02	284.66	0.994
7	286.34	0.21	283.80	0.991	20	286.34	0.13	284.79	0.995
8	286.34	0.29	284.08	0.992	21	286.34	0.06	284.85	0.995
9	286.34	0.14	284.22	0.993	22	286.34	0.08	284.93	0.995
10	286.34	0.03	284.25	0.993	23	286.34	0.08	285.01	0.995
11	286.34	0.05	284.31	0.993	24	286.34	0.01	285.02	0.995
12	286.34	0.01	284.31	0.993	25	286.34	0.13	285.15	0.996
13	286.34	0.01	284.32	0.993	26	286.34	0.01	285.16	0.996

Table 4.26h Cumulative periodogram of weekly water deficit series for Dhandhuka

Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i	Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i
1	235.02	164.38	164.38	0.699	14	235.02	0.08	233.64	0.994
2	235.02	60.61	224.99	0.957	15	235.02	0.05	233.69	0.994
3	235.02	4.96	229.95	0.978	16	235.02	0.05	233.74	0.995
4	235.02	1.62	231.57	0.985	17	235.02	0.06	233.80	0.995
5	235.02	0.70	232.27	0.988	18	235.02	0.02	233.82	0.995
6	235.02	0.37	232.64	0.990	19	235.02	0.05	233.87	0.995
7	235.02	0.28	232.91	0.991	20	235.02	0.13	233.99	0.996
8	235.02	0.04	232.96	0.991	21	235.02	0.02	234.01	0.996
9	235.02	0.03	232.99	0.991	22	235.02	0.01	234.02	0.996
10	235.02	0.18	233.16	0.992	23	235.02	0.02	234.04	0.996
11	235.02	0.17	233.34	0.993	24	235.02	0.18	234.21	0.997
12	235.02	0.12	233.46	0.993	25	235.02	0.00	234.21	0.997
13	235.02	0.10	233.56	0.994	26	235.02	0.02	234.23	0.997

Table 4.26i Cumulative periodogram of weekly water deficit series for Junagadh

Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i	Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i
1	256.19	183.77	183.77	0.717	14	256.19	0.08	255.04	0.996
2	256.19	62.89	246.66	0.963	15	256.19	0.09	255.13	0.996
3	256.19	2.62	249.27	0.973	16	256.19	0.02	255.15	0.996
4	256.19	2.90	252.17	0.984	17	256.19	0.02	255.17	0.996
5	256.19	1.08	253.25	0.989	18	256.19	0.00	255.17	0.996
6	256.19	0.24	253.48	0.989	19	256.19	0.01	255.18	0.996
7	256.19	0.60	254.09	0.992	20	256.19	0.02	255.20	0.996
8	256.19	0.21	254.30	0.993	21	256.19	0.00	255.20	0.996
9	256.19	0.09	254.39	0.993	22	256.19	0.10	255.30	0.997
10	256.19	0.15	254.54	0.994	23	256.19	0.02	255.32	0.997
11	256.19	0.17	254.71	0.994	24	256.19	0.06	255.38	0.997
12	256.19	0.18	254.89	0.995	25	256.19	0.07	255.45	0.997
13	256.19	0.07	254.96	0.995	26	256.19	0.08	255.54	0.997

Table 4.26j Cumulative periodogram of weekly water deficit series for Mahuva

Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i	Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i
1	151.10	113.90	113.90	0.754	14	151.10	0.22	150.20	0.994
2	151.10	33.22	147.12	0.974	15	151.10	0.04	150.24	0.994
3	151.10	0.85	147.98	0.979	16	151.10	0.02	150.26	0.994
4	151.10	1.24	149.22	0.988	17	151.10	0.04	150.30	0.995
5	151.10	0.12	149.34	0.988	18	151.10	0.04	150.34	0.995
6	151.10	0.09	149.43	0.989	19	151.10	0.02	150.36	0.995
7	151.10	0.08	149.51	0.989	20	151.10	0.02	150.37	0.995
8	151.10	0.04	149.55	0.990	21	151.10	0.13	150.50	0.996
9	151.10	0.13	149.68	0.991	22	151.10	0.39	150.89	0.999
10	151.10	0.13	149.81	0.991	23	151.10	0.16	151.05	1.000
11	151.10	0.11	149.91	0.992	24	151.10	0.05	151.10	1.000
12	151.10	0.04	149.96	0.992	25	151.10	0.06	151.16	1.000
13	151.10	0.03	149.98	0.993	26	151.10	0.01	151.17	1.001

Table 4.26k Cumulative periodogram of weekly water deficit series for Anand

Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i	Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i
1	186.17	126.21	126.21	0.678	14	186.17	0.00	185.44	0.996
2	186.17	50.07	176.27	0.947	15	186.17	0.00	185.44	0.996
3	186.17	6.26	182.53	0.980	16	186.17	0.03	185.48	0.996
4	186.17	1.55	184.08	0.989	17	186.17	0.02	185.49	0.996
5	186.17	0.77	184.85	0.993	18	186.17	0.01	185.50	0.996
6	186.17	0.29	185.14	0.994	19	186.17	0.01	185.51	0.996
7	186.17	0.13	185.27	0.995	20	186.17	0.01	185.53	0.997
8	186.17	0.04	185.31	0.995	21	186.17	0.07	185.59	0.997
9	186.17	0.04	185.35	0.996	22	186.17	0.11	185.70	0.997
10	186.17	0.04	185.39	0.996	23	186.17	0.11	185.81	0.998
11	186.17	0.04	185.42	0.996	24	186.17	0.11	185.92	0.999
12	186.17	0.01	185.44	0.996	25	186.17	0.15	186.07	0.999
13	186.17	0.00	185.44	0.996	26	186.17	0.00	186.08	0.999

Table 4.26l Cumulative periodogram of weekly water deficit series for Nawagam

Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i	Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i
1	233.58	154.89	154.89	0.663	14	233.58	0.02	231.64	0.992
2	233.58	61.90	216.79	0.928	15	233.58	0.01	231.65	0.992
3	233.58	10.59	227.38	0.973	16	233.58	0.07	231.72	0.992
4	233.58	1.61	228.99	0.980	17	233.58	0.10	231.82	0.992
5	233.58	1.61	230.61	0.987	18	233.58	0.06	231.88	0.993
6	233.58	0.45	231.05	0.989	19	233.58	0.07	231.94	0.993
7	233.58	0.18	231.23	0.990	20	233.58	0.03	231.97	0.993
8	233.58	0.03	231.26	0.990	21	233.58	0.10	232.07	0.994
9	233.58	0.15	231.41	0.991	22	233.58	0.15	232.22	0.994
10	233.58	0.09	231.50	0.991	23	233.58	0.19	232.41	0.995
11	233.58	0.06	231.56	0.991	24	233.58	0.18	232.60	0.996
12	233.58	0.00	231.56	0.991	25	233.58	0.19	232.79	0.997
13	233.58	0.05	231.62	0.992	26	233.58	0.01	232.80	0.997

Table 4.26m Cumulative periodogram of weekly water deficit series for Bharuch

Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i	Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i
1	227.01	162.59	162.59	0.716	14	227.01	0.02	226.23	0.997
2	227.01	53.26	215.85	0.951	15	227.01	0.01	226.23	0.997
3	227.01	6.09	221.95	0.978	16	227.01	0.07	226.30	0.997
4	227.01	2.74	224.68	0.990	17	227.01	0.01	226.32	0.997
5	227.01	0.94	225.63	0.994	18	227.01	0.01	226.32	0.997
6	227.01	0.07	225.70	0.994	19	227.01	0.03	226.35	0.997
7	227.01	0.13	225.82	0.995	20	227.01	0.00	226.35	0.997
8	227.01	0.05	225.88	0.995	21	227.01	0.05	226.40	0.997
9	227.01	0.09	225.96	0.995	22	227.01	0.01	226.41	0.997
10	227.01	0.06	226.03	0.996	23	227.01	0.02	226.43	0.997
11	227.01	0.07	226.10	0.996	24	227.01	0.02	226.45	0.998
12	227.01	0.09	226.19	0.996	25	227.01	0.01	226.46	0.998
13	227.01	0.02	226.21	0.996	26	227.01	0.00	226.46	0.998

Table 4.26n Cumulative periodogram of weekly water deficit series for Surat

Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i	Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i
1	197.35	147.40	147.40	0.747	14	197.35	0.01	196.73	0.997
2	197.35	40.43	187.82	0.952	15	197.35	0.01	196.74	0.997
3	197.35	4.58	192.41	0.975	16	197.35	0.01	196.75	0.997
4	197.35	2.77	195.17	0.989	17	197.35	0.01	196.76	0.997
5	197.35	1.12	196.29	0.995	18	197.35	0.01	196.76	0.997
6	197.35	0.08	196.37	0.995	19	197.35	0.01	196.77	0.997
7	197.35	0.17	196.53	0.996	20	197.35	0.01	196.78	0.997
8	197.35	0.10	196.64	0.996	21	197.35	0.01	196.79	0.997
9	197.35	0.04	196.68	0.997	22	197.35	0.03	196.83	0.997
10	197.35	0.01	196.69	0.997	23	197.35	0.06	196.88	0.998
11	197.35	0.01	196.70	0.997	24	197.35	0.05	196.93	0.998
12	197.35	0.02	196.72	0.997	25	197.35	0.10	197.03	0.998
13	197.35	0.01	196.72	0.997	26	197.35	0.02	197.05	0.999

Table 4.26o Cumulative periodogram of weekly water deficit series for Navsari

Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i	Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i
1	206.36	154.66	154.66	0.749	14	206.36	0.03	206.61	1.001
2	206.36	42.02	196.68	0.953	15	206.36	0.07	206.68	1.002
3	206.36	3.92	200.60	0.972	16	206.36	0.03	206.71	1.002
4	206.36	3.50	204.10	0.989	17	206.36	0.02	206.73	1.002
5	206.36	1.39	205.49	0.996	18	206.36	0.00	206.74	1.002
6	206.36	0.31	205.79	0.997	19	206.36	0.02	206.75	1.002
7	206.36	0.37	206.16	0.999	20	206.36	0.00	206.75	1.002
8	206.36	0.17	206.33	1.000	21	206.36	0.01	206.76	1.002
9	206.36	0.17	206.51	1.001	22	206.36	0.02	206.78	1.002
10	206.36	0.03	206.54	1.001	23	206.36	0.00	206.78	1.002
11	206.36	0.02	206.56	1.001	24	206.36	0.02	206.81	1.002
12	206.36	0.02	206.58	1.001	25	206.36	0.04	206.85	1.002
13	206.36	0.01	206.59	1.001	26	206.36	0.00	206.85	1.002

Table 4.26p Cumulative periodogram of weekly water deficit series for Gandevi

Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i	Order	MSD(u)	MSD(j)	Cum. MSD(j)	P _i
1	179.12	132.06	132.06	0.737	14	179.12	0.10	177.95	0.993
2	179.12	35.36	167.42	0.935	15	179.12	0.15	178.10	0.994
3	179.12	3.59	171.00	0.955	16	179.12	0.12	178.22	0.995
4	179.12	3.28	174.28	0.973	17	179.12	0.04	178.26	0.995
5	179.12	1.15	175.43	0.979	18	179.12	0.01	178.28	0.995
6	179.12	0.55	175.98	0.982	19	179.12	0.09	178.36	0.996
7	179.12	0.41	176.39	0.985	20	179.12	0.06	178.42	0.996
8	179.12	0.43	176.82	0.987	21	179.12	0.05	178.47	0.996
9	179.12	0.35	177.16	0.989	22	179.12	0.07	178.54	0.997
10	179.12	0.21	177.37	0.990	23	179.12	0.05	178.59	0.997
11	179.12	0.20	177.58	0.991	24	179.12	0.10	178.69	0.998
12	179.12	0.20	177.77	0.992	25	179.12	0.09	178.78	0.998
13	179.12	0.08	177.85	0.993	26	179.12	0.01	178.79	0.998

The three criteria used to identify the number of significant harmonics to be used in modelling periodic component were found to be consistent at different stations, except for SK Nagar and Nawagam. Thus, a compromised decision was made to limit the actual number of harmonics to be fitted in the periodic modelling (for the stations where number of significant harmonics were inconsistent in above tests), considering the periodic leak that may occur and thereby to avoid passing on to the stochastic component. Accordingly, first three harmonics each for Kothara, Radhanpur and Dhandhuka and first two harmonics for Mahuva were treated as significantly contributing towards periodicity and remaining were considered as white noise. For rest of the stations, first four harmonics were considered in modelling the periodic component of weekly series.

The Fourier series coefficients, A_k and B_k for the respective zones, were substituted in the Equation (3.40) and deterministic periodic components, P_t , have been computed for all values of t , where t is total period, which is 1144 weeks for Radhanpur, Arnej, Dhandhuka, Mahuva and Gandevi, 1248 weeks for Rajkot, Khedbrahma and Nawagam and 1456 each for rest of the station. After determination of the periodic component, the same was then removed by deducting it from the observed time series. The remaining series is a stochastic component part, which is required to be fitted by an autoregressive model of suitable order. Estimated periodic component for the weekly series for different agro-climatic zones are shown in Table 4.29.

4.7.4 Stochastic Component

The stochastic component that was obtained by the removal of periodic component from the observed series is treated as random variable. Autoregressive stochastic model of order p , AR (p), was applied to the stochastic component of weekly water deficit series to generate synthetic data sequence of the weekly series. In autoregressive model, the current

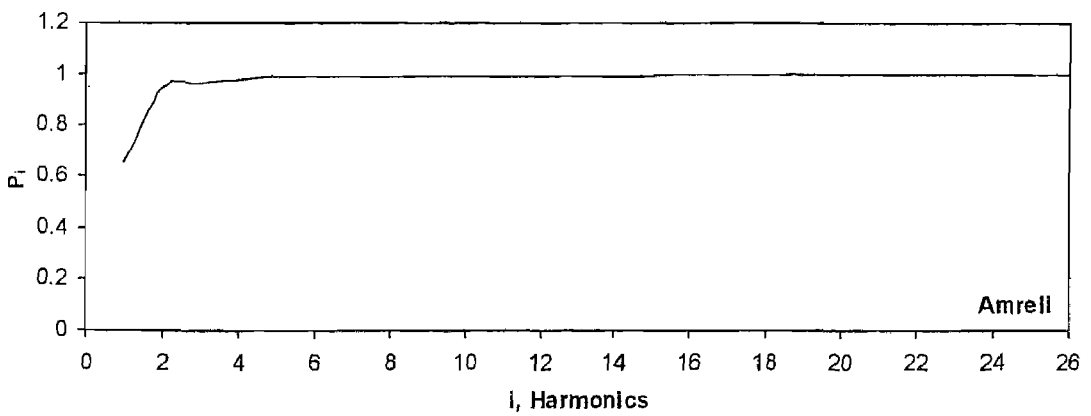
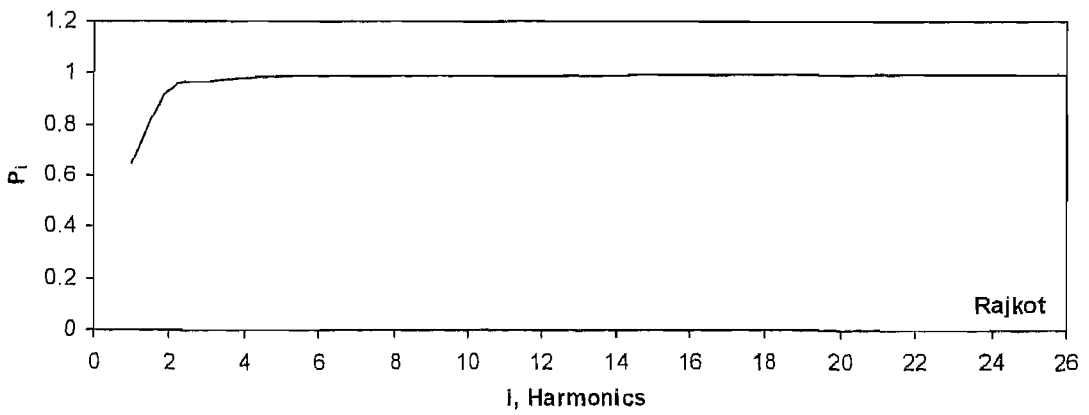
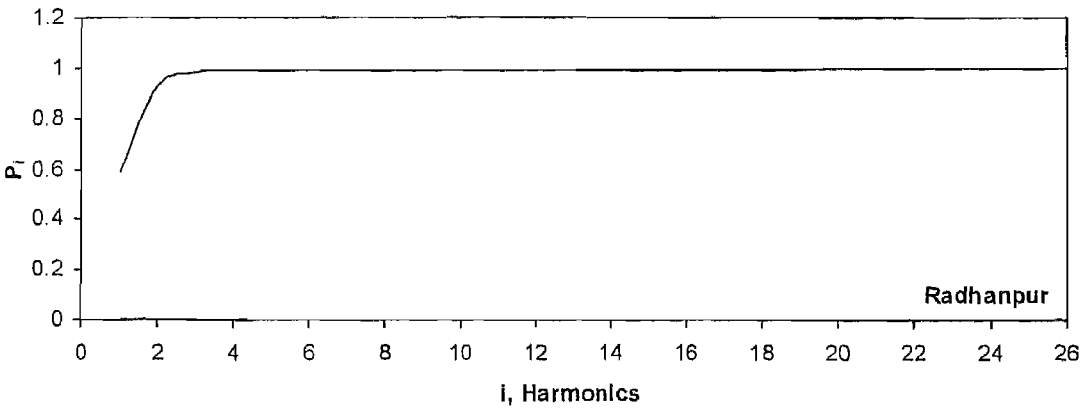
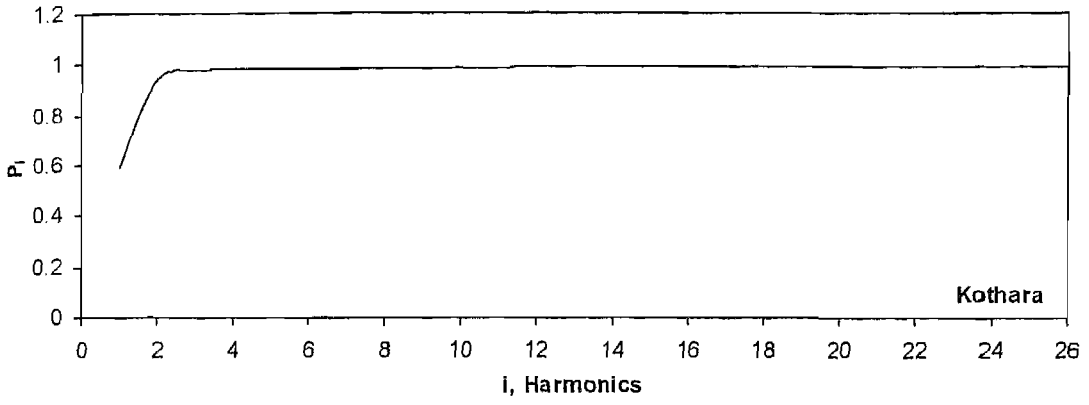


Fig. 4.16a Cumulative periodogram of weekly water deficit for Kothara, Radhanpur, Rajkot and Amreli

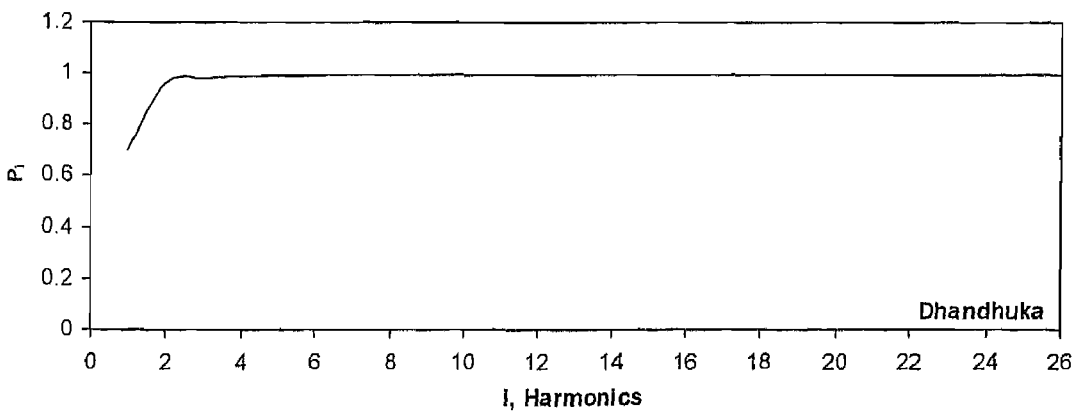
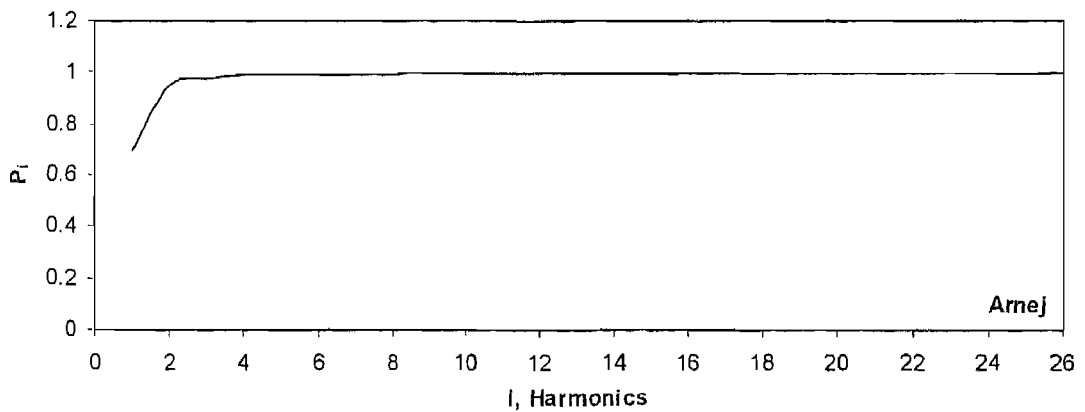
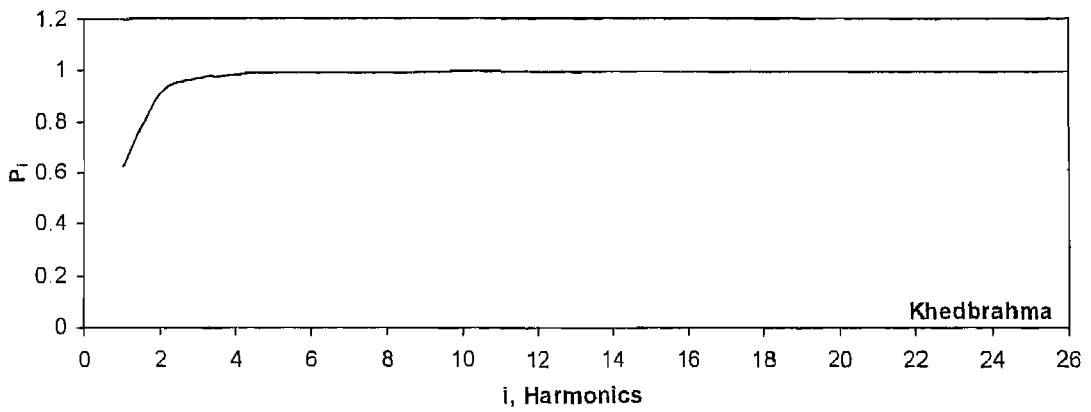
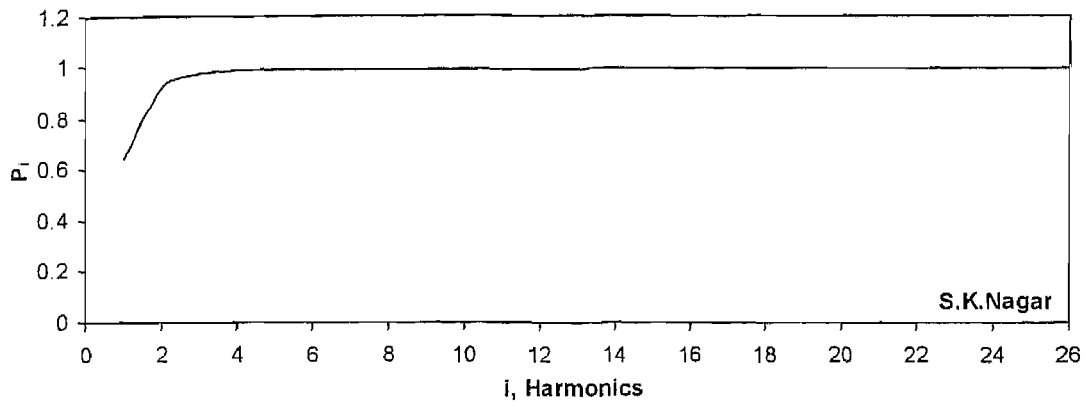


Fig. 4.16b Cumulative periodogram of weekly water deficit for SK Nagar, Khedbrahma, Arnej and Dhandhuka

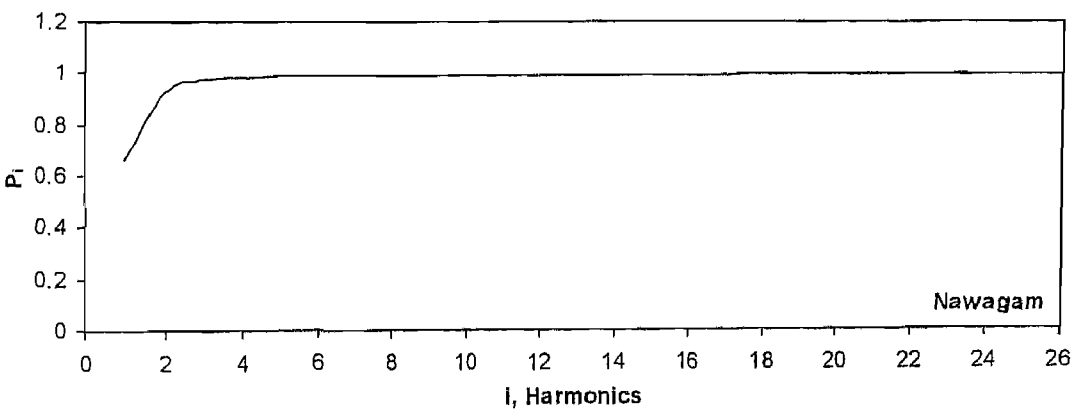
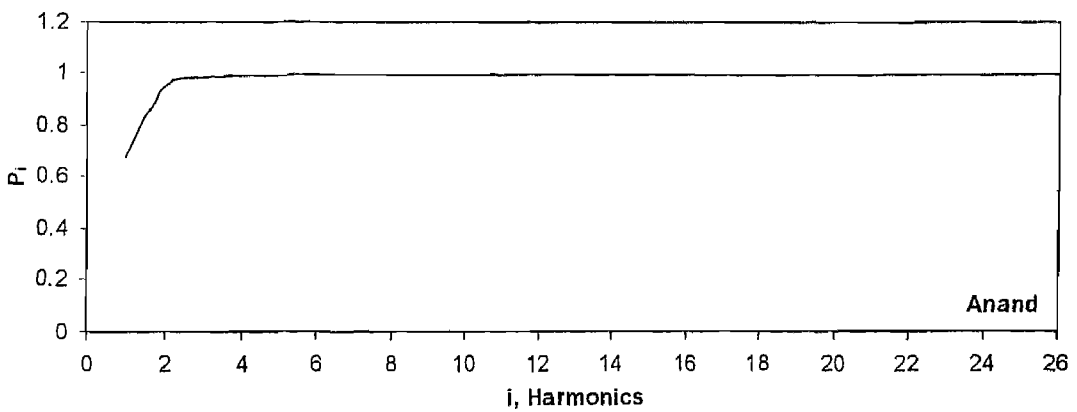
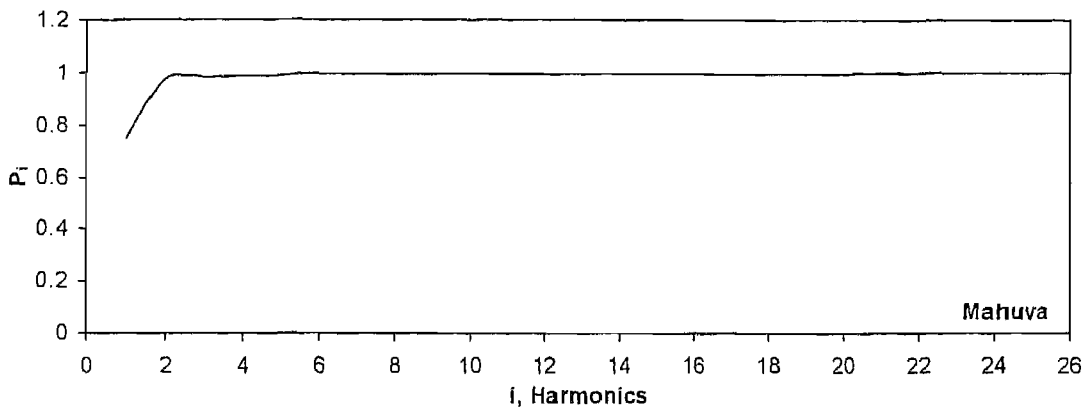
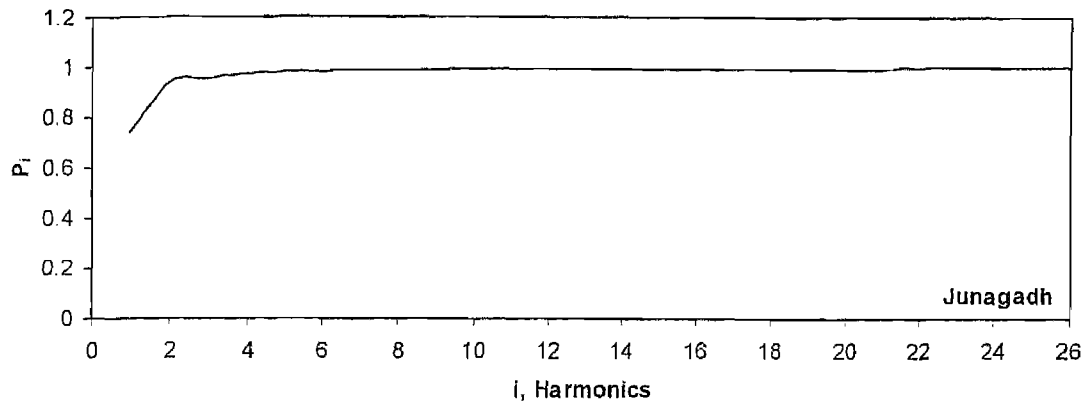


Fig. 4.16c Cumulative periodogram of weekly water deficit for Junagadh, Mahuva, Anand and Nawagam

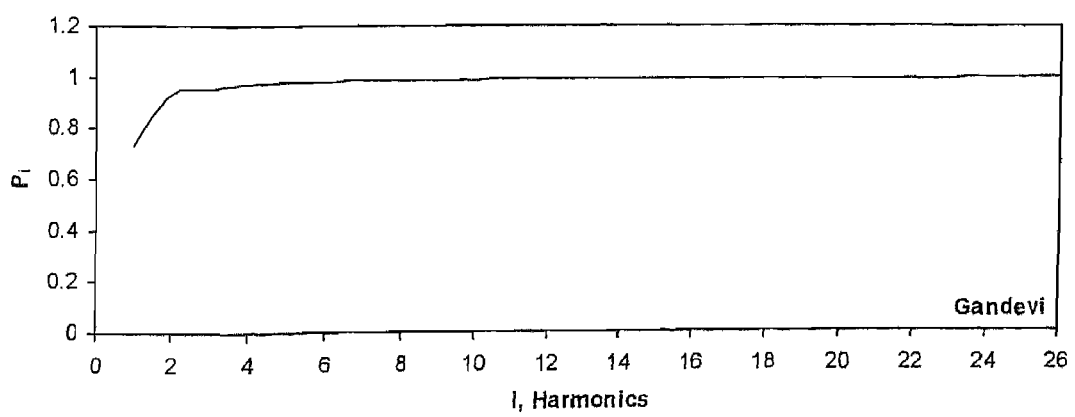
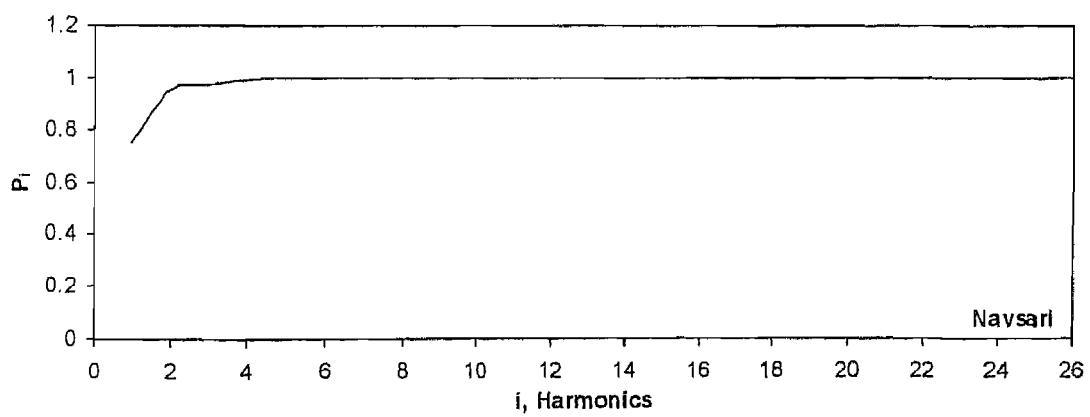
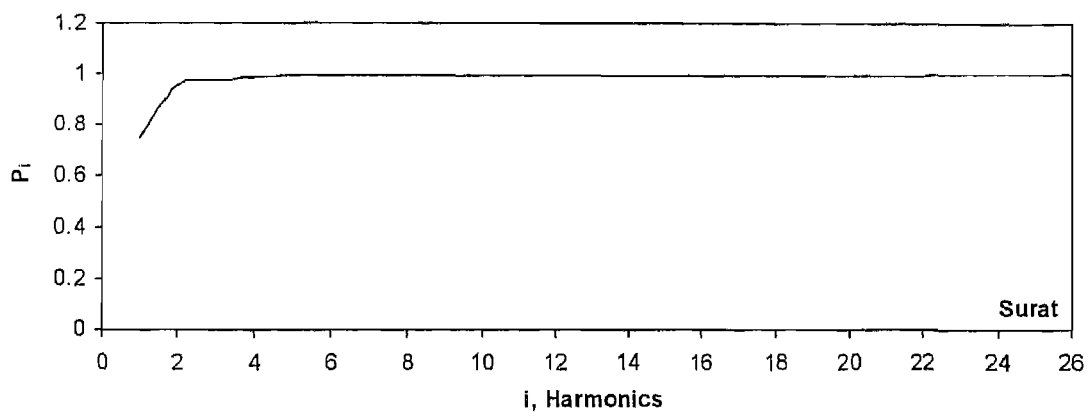
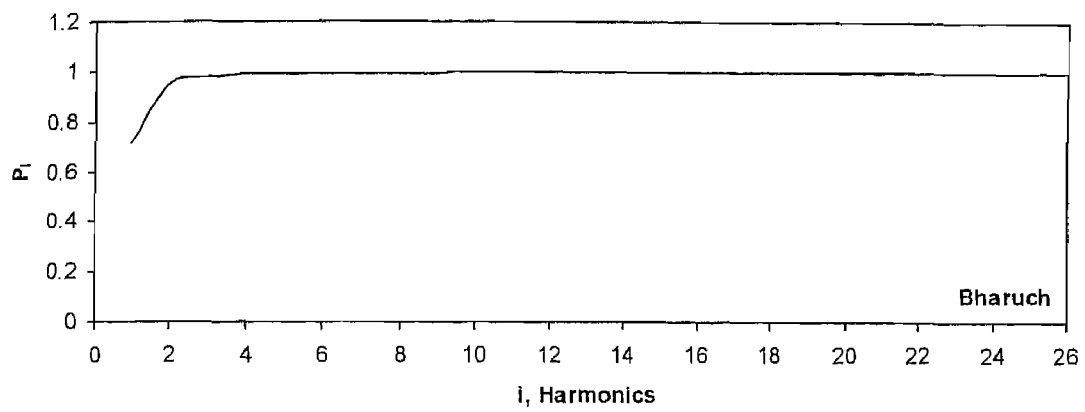


Fig. 4.16d Cumulative periodogram of weekly water deficit for Bharuch, Surat, Navsari, and Gandevi

value of a variable was equated to the weighted sum of a pre assigned number of past values and a variate that is completely random.

4.7.4.1 Model parameter estimation

For modelling the stochastic component, autocorrelation function estimated from Equation (3.32) is required. Selection and estimation of autoregressive parameters is based upon the determined values of autocorrelation function of different lags. To obtain the estimates of the parameters for different model order, Equations (3.55) and (3.56) were computed recursively.

4.7.4.2 Model identification

Residual variance has been used as a criterion to determine the order of autoregressive model. Residual variance at different lags was computed using Equations (3.53) and (3.54) for the weekly water deficit series of different zones. The estimated values for weekly series of 26 lags are represented in Tables 4.27a to 4.27p. A suitable model order is the order for which the value of residual variance is minimum. Here, the minimum residual variance has been observed for first order model in weekly series of all the agro-climatic zones. However, the serial autocorrelation of residual series from first, second and third order model were compared in each weekly series and the residual series that gave well within the minimum range of values has been selected to represent the stochastic component of autoregressive model.

According to the comparison made, for all the regions of Gujarat, except Amreli, autoregressive model order two has been selected for weekly water deficit series. For Amreli, third order autoregressive model has been selected.

Table 4.27a Residual variance [$Sz^2(p)$] values for weekly water deficit series for Kothara

Autocovariance at lag zero, (C_0) = 291315.675

Lag	Auto-correlation	Auto-covariance	Residual variance [$Sz^2(p)$]	Lag	Auto-correlation	Auto-covariance	Residual variance [$Sz^2(p)$]
1	0.80	234267.32	102924.94	14	-0.25	-71807.87	209300.17
2	0.72	208581.48	180923.25	15	-0.26	-76754.62	209760.32
3	0.64	184992.06	185138.16	16	-0.27	-78105.79	209989.65
4	0.54	158070.06	184498.68	17	-0.27	-77587.47	210217.62
5	0.43	124830.07	189468.26	18	-0.26	-74556.39	210390.71
6	0.32	92765.71	197171.41	19	-0.24	-69528.01	210569.82
7	0.22	64615.70	200457.51	20	-0.22	-64994.24	210937.93
8	0.12	33577.79	203877.62	21	-0.21	-60911.69	211691.02
9	0.02	6663.65	206615.03	22	-0.19	-55167.72	212231.63
10	-0.06	-17079.88	207980.61	23	-0.18	-51336.15	212867.66
11	-0.13	-38131.69	209087.75	24	-0.17	-48110.39	213785.82
12	-0.17	-50050.99	208745.33	25	-0.15	-43787.63	214318.33
13	-0.21	-61188.91	208775.02	26	-0.15	-44518.23	215497.43

Table 4.27b Residual variance $[S_z^2(p)]$ values for weekly water deficit series for Radhanpur

Autocovariance at lag zero, $(C_0) = 297719.568$

Lag	Auto-correlation	Auto-covariance	Residual variance $[S_z^2(p)]$	Lag	Auto-correlation	Auto-covariance	Residual variance $[S_z^2(p)]$
1	0.82	242653.52	99947.11	14	-0.24	-70278.45	212265.26
2	0.73	217730.06	183091.77	15	-0.25	-74818.85	212458.96
3	0.65	193419.16	186336.08	16	-0.27	-80230.14	212689.25
4	0.57	170157.72	186321.21	17	-0.27	-80948.11	212952.58
5	0.46	137315.01	189286.39	18	-0.27	-79406.73	213221.60
6	0.35	103151.66	200296.37	19	-0.26	-76721.79	213676.03
7	0.26	76349.05	203124.95	20	-0.25	-75478.58	214600.01
8	0.15	44082.72	206375.01	21	-0.24	-71411.57	215262.45
9	0.05	16059.43	209844.99	22	-0.23	-68243.52	216041.56
10	-0.04	-10827.87	211873.66	23	-0.22	-65865.77	217313.15
11	-0.09	-27354.94	211464.59	24	-0.21	-62225.09	218006.59
12	-0.16	-46017.04	211374.98	25	-0.21	-62790.02	219343.36
13	-0.20	-60606.34	211971.55	26	-0.20	-58774.30	219942.83

Table 4.27c Residual variance $[S_z^2(p)]$ values for weekly water deficit series for Rajkot

Autocovariance at lag zero, $(C_0) = 525645.196$

Lag	Auto-correlation	Auto-covariance	Residual variance $[S_z^2(p)]$	Lag	Auto-correlation	Auto-covariance	Residual variance $[S_z^2(p)]$
1	0.81	427039.71	178713.58	14	-0.17	-91052.85	437362.81
2	0.75	392618.83	368071.40	15	-0.21	-109054.58	438654.78
3	0.69	363814.86	392690.15	16	-0.24	-126042.46	439955.50
4	0.60	317302.58	387076.58	17	-0.26	-136297.08	440693.58
5	0.51	265965.49	398531.34	18	-0.27	-141445.03	441069.81
6	0.40	211486.92	416458.30	19	-0.28	-144362.23	441454.35
7	0.31	163425.00	425579.27	20	-0.27	-142275.24	441832.36
8	0.22	115393.95	429514.70	21	-0.26	-138163.15	442224.86
9	0.13	69681.33	431855.55	22	-0.26	-138284.98	443487.88
10	0.05	27564.08	433601.26	23	-0.25	-131590.47	444940.38
11	-0.01	-6628.95	434235.96	24	-0.24	-127473.44	446292.99
12	-0.07	-37451.27	434742.62	25	-0.24	-126001.73	448802.17
13	-0.13	-65794.12	435617.65	26	-0.23	-119527.52	449973.13

Table 4.27d Residual variance $[S_z^2(p)]$ values for weekly water deficit series for Amreli

Autocovariance at lag zero, $(C_0) = 523985.207$

Lag	Auto-correlation	Auto-covariance	Residual variance $[S_z^2(p)]$	Lag	Auto-correlation	Auto-covariance	Residual variance $[S_z^2(p)]$
1	0.84	441059.68	152727.27	14	-0.20	-103436.97	325945.34
2	0.76	398313.37	289254.99	15	-0.24	-125774.20	326848.62
3	0.68	355136.28	290648.10	16	-0.27	-140579.48	327009.32
4	0.59	310552.57	290852.57	17	-0.30	-155188.44	327246.42
5	0.50	259813.40	296338.94	18	-0.30	-159390.52	327190.19
6	0.41	211988.55	302674.56	19	-0.31	-162960.81	327293.84
7	0.32	167556.32	305471.03	20	-0.30	-159402.30	327418.71
8	0.24	125502.57	307221.26	21	-0.29	-150610.30	327793.56
9	0.15	76028.01	312437.47	22	-0.27	-143234.89	327774.67
10	0.07	36273.58	316001.14	23	-0.26	-137793.87	329331.21
11	-0.01	-3005.65	318163.72	24	-0.25	-129194.11	330816.95
12	-0.08	-41215.11	321747.12	25	-0.24	-124519.13	332688.80
13	-0.14	-73996.96	324126.51	26	-0.23	-122378.35	336709.46

Table 4.27e Residual variance [Sz²(p)] values for weekly water deficit series for SK Nagar

Autocovariance at lag zero, (C₀) = 431908.339

Lag	Auto-correlation	Auto-covariance	Residual variance[Sz ² (p)]	Lag	Auto-correlation	Auto-covariance	Residual variance[Sz ² (p)]
1	0.80	346173.23	154451.56	14	-0.17	-73351.88	295587.80
2	0.71	307951.51	270219.59	15	-0.21	-88614.59	296662.47
3	0.62	268343.09	272187.44	16	-0.23	-97293.38	297246.09
4	0.55	237203.23	272574.27	17	-0.24	-105064.94	297697.90
5	0.45	194278.66	272960.72	18	-0.25	-105896.88	297830.96
6	0.35	149942.74	281638.95	19	-0.27	-114923.67	298494.66
7	0.26	111662.83	285908.19	20	-0.27	-115217.90	299551.99
8	0.17	74554.96	288572.34	21	-0.27	-116663.08	300295.05
9	0.10	41610.01	290426.58	22	-0.27	-114657.90	301169.93
10	0.03	12095.62	291401.83	23	-0.26	-111718.20	301686.49
11	-0.03	-12628.79	292036.05	24	-0.26	-110748.22	302562.38
12	-0.08	-34561.46	292704.22	25	-0.26	-110607.13	304544.21
13	-0.13	-57487.38	294393.06	26	-0.25	-106387.06	305428.23

Table 4.27f Residual variance [Sz²(p)] values for weekly water deficit series for Khedbrahma

Autocovariance at lag zero, (C₀) = 297328.829

Lag	Auto-correlation	Auto-covariance	Residual variance[Sz ² (p)]	Lag	Auto-correlation	Auto-covariance	Residual variance[Sz ² (p)]
1	0.85	252117.10	83548.58	14	-0.23	-67973.63	174615.74
2	0.76	225764.63	146715.43	15	-0.26	-77095.25	175352.45
3	0.68	202026.72	148548.11	16	-0.28	-84472.08	176031.85
4	0.59	174539.82	148253.76	17	-0.30	-89187.26	176631.06
5	0.48	141950.55	154646.81	18	-0.31	-90618.03	176882.99
6	0.37	109085.14	162987.57	19	-0.31	-93168.35	177466.72
7	0.26	77289.31	168194.35	20	-0.32	-95161.21	179261.19
8	0.16	48427.69	170297.86	21	-0.31	-92740.52	179625.01
9	0.07	20468.11	171755.89	22	-0.30	-89268.09	179853.24
10	-0.01	-2814.26	172261.11	23	-0.30	-90347.87	181208.37
11	-0.07	-21989.82	172438.26	24	-0.30	-88532.36	183011.02
12	-0.14	-40445.11	172829.79	25	-0.30	-88251.05	184754.66
13	-0.19	-55362.97	173702.22	26	-0.30	-88290.65	187403.20

Table 4.27g Residual variance [Sz²(p)] values for weekly water deficit series for Arnej

Autocovariance at lag zero, (C₀) = 392760.783

Lag	Auto-correlation	Auto-covariance	Residual variance[Sz ² (p)]	Lag	Auto-correlation	Auto-covariance	Residual variance[Sz ² (p)]
1	0.84	331246.91	113393.50	14	-0.22	-86612.92	282245.75
2	0.78	304598.30	243565.44	15	-0.26	-103348.36	282961.45
3	0.69	272363.19	242340.37	16	-0.31	-120206.38	283994.88
4	0.62	243319.47	242770.55	17	-0.33	-130784.91	285028.99
5	0.53	209755.72	244717.28	18	-0.34	-134950.30	285088.59
6	0.44	171040.46	252705.63	19	-0.35	-137923.18	285236.17
7	0.33	131149.41	263301.31	20	-0.36	-141896.40	286347.62
8	0.23	90613.14	272052.61	21	-0.36	-140967.21	287553.66
9	0.13	52538.22	277616.53	22	-0.36	-140901.42	288984.03
10	0.06	22512.74	277729.69	23	-0.35	-137256.34	290715.18
11	-0.03	-10102.41	278152.22	24	-0.35	-137608.69	293529.33
12	-0.09	-36970.31	279223.32	25	-0.34	-135051.83	297074.43
13	-0.16	-63734.22	280384.12	26	-0.34	-133318.95	299561.47

Table 4.27h Residual variance [Sz²(p)] values for weekly water deficit series for Dhandhuka

Autocovariance at lag zero, (C₀) = 349328.994

Lag	Auto-correlation	Auto-covariance	Residual variance[Sz ² (p)]	Lag	Auto-correlation	Auto-covariance	Residual variance[Sz ² (p)]
1	0.81	281384.05	122674.50	14	-0.21	-73906.48	283982.24
2	0.74	256776.06	241609.08	15	-0.25	-87070.10	284332.96
3	0.66	232088.82	250610.38	16	-0.29	-100119.20	284698.57
4	0.59	206022.62	250246.10	17	-0.31	-107429.29	284923.88
5	0.51	178015.34	251532.46	18	-0.31	-109820.08	285338.28
6	0.41	143732.22	257365.97	19	-0.33	-116247.58	285240.82
7	0.32	111141.24	264977.24	20	-0.34	-118955.63	286964.77
8	0.22	78343.92	270695.53	21	-0.33	-116556.62	287591.84
9	0.14	48990.56	273815.42	22	-0.33	-115643.60	288418.91
10	0.06	21929.73	275302.08	23	-0.32	-112453.92	289661.94
11	-0.01	-1875.41	276028.42	24	-0.31	-109676.94	290789.06
12	-0.08	-26799.77	277202.84	25	-0.31	-108142.81	292550.53
13	-0.15	-51620.35	280270.57	26	-0.30	-105196.69	294607.16

Table 4.27i Residual variance [Sz²(p)] values for weekly water deficit series for Junagadh

Autocovariance at lag zero, (C₀) = 493532.121

Lag	Auto-correlation	Auto-covariance	Residual variance[Sz ² (p)]	Lag	Auto-correlation	Auto-covariance	Residual variance[Sz ² (p)]
1	0.88	432100.65	115216.38	14	-0.21	-103958.61	329731.13
2	0.81	401301.59	270937.44	15	-0.26	-128405.65	330075.32
3	0.74	366709.35	269957.78	16	-0.30	-146817.37	330325.24
4	0.67	329110.80	271039.72	17	-0.32	-160035.95	330560.89
5	0.57	282473.12	281688.57	18	-0.34	-165681.36	330817.96
6	0.47	231141.54	302299.32	19	-0.36	-176407.78	330453.54
7	0.37	183178.38	312498.42	20	-0.35	-174802.99	329762.22
8	0.28	135707.44	316596.00	21	-0.35	-170692.85	330008.71
9	0.18	87639.14	320305.82	22	-0.34	-167248.86	330415.01
10	0.09	42481.83	323142.37	23	-0.34	-169310.12	336012.87
11	0.00	593.52	324939.63	24	-0.34	-167458.18	342442.72
12	-0.08	-38749.79	326883.10	25	-0.34	-166557.00	347310.09
13	-0.15	-74974.63	329139.73	26	-0.34	-165485.95	351724.53

Table 4.27j Residual variance [Sz²(p)] values for weekly water deficit series for Mahuva

Autocovariance at lag zero, (C₀) = 239965.665

Lag	Auto-correlation	Auto-covariance	Residual variance[Sz ² (p)]	Lag	Auto-correlation	Auto-covariance	Residual variance[Sz ² (p)]
1	0.82	196240.72	79482.61	14	-0.17	-39675.67	214570.79
2	0.76	183301.94	178352.63	15	-0.22	-51971.67	214496.85
3	0.70	168611.96	187295.89	16	-0.26	-63233.82	215540.84
4	0.65	154841.21	187841.35	17	-0.31	-73515.84	217178.18
5	0.56	133640.24	188471.86	18	-0.32	-77270.26	217268.34
6	0.46	109122.71	198374.03	19	-0.34	-81251.74	217469.76
7	0.37	89124.27	204134.62	20	-0.35	-84230.32	217804.96
8	0.28	66175.37	208004.74	21	-0.35	-83880.05	217999.92
9	0.18	43208.97	212136.67	22	-0.35	-84109.04	218249.75
10	0.10	24500.08	212841.16	23	-0.36	-86871.27	220456.60
11	0.02	5790.70	213251.88	24	-0.36	-86835.46	223185.76
12	-0.05	-11280.76	213801.74	25	-0.37	-87713.40	225792.78
13	-0.13	-30073.53	215085.44	26	-0.36	-86522.92	227922.84

Table 4.27k Residual variance [$S_z^2(p)$] values for weekly water deficit series for Anand

Autocovariance at lag zero, (C_0) = 364809.691

Lag	Auto-correlation	Auto-covariance	Residual variance [$S_z^2(p)$]	Lag	Auto-correlation	Auto-covariance	Residual variance [$S_z^2(p)$]
1	0.83	301137.18	116231.83	14	-0.22	-79502.05	288626.76
2	0.76	277937.59	249399.18	15	-0.26	-94707.60	290041.44
3	0.69	252595.54	256882.60	16	-0.29	-106456.15	290766.53
4	0.60	218786.52	255378.66	17	-0.31	-114034.73	291085.66
5	0.51	187643.56	260389.26	18	-0.32	-117227.03	291291.11
6	0.41	148363.07	268759.81	19	-0.33	-121725.46	291659.17
7	0.31	114092.48	275511.86	20	-0.34	-122892.08	292883.21
8	0.22	79035.23	279332.19	21	-0.33	-121677.94	293786.58
9	0.12	42850.55	283659.99	22	-0.33	-120211.09	294782.34
10	0.04	13204.21	285500.40	23	-0.33	-118556.92	296438.66
11	-0.04	-13256.08	285947.91	24	-0.32	-116099.62	298299.46
12	-0.10	-37883.32	286435.21	25	-0.32	-114915.24	300606.39
13	-0.16	-58857.73	287188.20	26	-0.31	-112814.07	302955.06

Table 4.27l Residual variance [$S_z^2(p)$] values for weekly water deficit series for Nawagam

Autocovariance at lag zero, (C_0) = 405063.271

Lag	Auto-correlation	Auto-covariance	Residual variance [$S_z^2(p)$]	Lag	Auto-correlation	Auto-covariance	Residual variance [$S_z^2(p)$]
1	0.84	341174.24	117701.09	14	-0.22	-88039.59	264211.05
2	0.76	308576.82	225294.93	15	-0.25	-100020.10	264348.47
3	0.69	277366.28	228587.94	16	-0.28	-112018.80	264583.82
4	0.61	246011.87	228402.04	17	-0.29	-118660.89	265089.09
5	0.50	204250.45	233120.53	18	-0.30	-122210.82	265464.96
6	0.40	162791.91	244419.67	19	-0.30	-122635.17	265949.63
7	0.31	124287.56	249837.38	20	-0.31	-125289.83	267265.31
8	0.21	83934.74	254595.93	21	-0.31	-123930.49	268689.96
9	0.11	45248.86	259038.59	22	-0.31	-126397.28	271170.61
10	0.03	10539.85	261249.87	23	-0.31	-126823.40	274727.94
11	-0.05	-18552.41	261938.24	24	-0.31	-127024.32	277000.84
12	-0.11	-44204.77	262347.25	25	-0.31	-124366.15	278058.67
13	-0.17	-68921.58	263223.26	26	-0.31	-123881.47	279300.54

Table 4.27m Residual variance [$S_z^2(p)$] values for weekly water deficit series for Bharuch

Autocovariance at lag zero, (C_0) = 445221.036

Lag	Auto-correlation	Auto-covariance	Residual variance [$S_z^2(p)$]	Lag	Auto-correlation	Auto-covariance	Residual variance [$S_z^2(p)$]
1	0.85	378280.19	123816.88	14	-0.19	-83856.55	289265.24
2	0.77	343101.08	240426.13	15	-0.24	-105425.10	290206.58
3	0.71	315668.82	251160.77	16	-0.28	-124695.26	291497.20
4	0.64	282751.62	249279.90	17	-0.31	-139097.50	292178.66
5	0.55	244335.96	253357.02	18	-0.34	-149340.41	292617.88
6	0.44	197649.69	267269.16	19	-0.35	-156649.56	293132.96
7	0.35	157798.71	275263.84	20	-0.37	-162291.81	294092.38
8	0.26	116534.67	279833.34	21	-0.37	-164084.78	294839.70
9	0.18	77749.77	282826.90	22	-0.37	-163134.50	295503.46
10	0.08	35030.11	287050.06	23	-0.36	-161266.00	296601.05
11	0.01	5231.12	285845.45	24	-0.37	-162545.73	299501.80
12	-0.06	-27614.22	285510.42	25	-0.36	-160968.30	302875.22
13	-0.13	-58087.32	287739.63	26	-0.36	-159970.48	306276.20

Table 4.27n Residual variance $[Sz^2(p)]$ values for weekly water deficit series for Surat

Autocovariance at lag zero, $(C_0) = 373689.74$

Lag	Auto-correlation	Auto-covariance	Residual variance $[Sz^2(p)]$	Lag	Auto-correlation	Auto-covariance	Residual variance $[Sz^2(p)]$
1	0.88	329288.57	83526.72	14	-0.20	-73541.16	196584.40
2	0.81	300794.93	158857.47	15	-0.25	-93805.29	196898.66
3	0.74	276255.40	162167.99	16	-0.30	-112339.83	197242.78
4	0.66	244796.37	160669.56	17	-0.34	-126026.94	197371.52
5	0.57	212084.41	167206.92	18	-0.36	-135753.86	197515.89
6	0.47	176563.46	174552.93	19	-0.39	-144038.27	197935.86
7	0.38	142220.47	179613.30	20	-0.40	-150417.94	199227.75
8	0.29	109146.82	182044.52	21	-0.41	-152995.59	200128.79
9	0.20	73806.73	185508.62	22	-0.41	-154395.62	201003.41
10	0.11	40192.46	189376.05	23	-0.42	-155003.44	202678.17
11	0.03	10098.95	190986.70	24	-0.42	-156039.74	205763.75
12	-0.05	-19754.11	192667.18	25	-0.42	-157072.80	210079.95
13	-0.12	-46074.26	194097.35	26	-0.42	-156181.02	213453.71

Table 4.27o Residual variance $[Sz^2(p)]$ values for weekly water deficit series for Navsari

Autocovariance at lag zero, $(C_0) = 378113.657$

Lag	Auto-correlation	Auto-covariance	Residual variance $[Sz^2(p)]$	Lag	Auto-correlation	Auto-covariance	Residual variance $[Sz^2(p)]$
1	0.89	337135.08	77516.07	14	-0.22	-82318.25	187870.69
2	0.82	309383.72	146755.90	15	-0.28	-106135.87	190844.19
3	0.75	283381.55	147443.36	16	-0.33	-126154.04	192236.82
4	0.67	253029.32	147665.15	17	-0.37	-140642.11	192467.27
5	0.58	217899.22	156201.36	18	-0.40	-150935.10	192598.98
6	0.48	181786.85	165350.15	19	-0.42	-160112.98	192817.73
7	0.38	143725.44	173051.28	20	-0.44	-165635.63	193830.59
8	0.29	107656.55	177029.68	21	-0.44	-165511.98	193933.81
9	0.19	70837.32	180143.37	22	-0.44	-165256.54	194172.76
10	0.09	35124.37	183535.32	23	-0.44	-166557.74	197734.68
11	0.01	3770.03	184468.40	24	-0.44	-165127.59	201853.61
12	-0.07	-28152.31	185852.84	25	-0.44	-164549.93	206122.97
13	-0.15	-54659.56	186547.77	26	-0.44	-164407.06	212263.50

Table 4.27p Residual variance $[Sz^2(p)]$ values for weekly water deficit series for Gandevi

Autocovariance at lag zero, $(C_0) = 349328.994$

Lag	Auto-correlation	Auto-covariance	Residual variance $[Sz^2(p)]$	Lag	Auto-correlation	Auto-covariance	Residual variance $[Sz^2(p)]$
1	0.81	281384.05	122674.50	14	-0.21	-73906.48	283982.24
2	0.74	256776.06	241609.08	15	-0.25	-87070.10	284332.96
3	0.66	232088.82	250610.38	16	-0.29	-100119.20	284698.57
4	0.59	206022.62	250246.10	17	-0.31	-107429.29	284923.88
5	0.51	178015.34	251532.46	18	-0.31	-109820.08	285338.28
6	0.41	143732.22	257365.97	19	-0.33	-116247.58	285240.82
7	0.32	111141.24	264977.24	20	-0.34	-118955.63	286964.77
8	0.22	78343.92	270695.53	21	-0.33	-116556.62	287591.84
9	0.14	48990.56	273815.42	22	-0.33	-115643.60	288418.91
10	0.06	21929.73	275302.08	23	-0.32	-112453.92	289661.94
11	-0.01	-1875.41	276028.42	24	-0.31	-109676.94	290789.06
12	-0.08	-26799.77	277202.84	25	-0.31	-108142.81	292550.53
13	-0.15	-51620.35	280270.57	26	-0.30	-105196.69	294607.16

The selected model order and parameters for different regions are given in Table 4.28. The stochastic component was estimated by fitting the autoregressive parameters in the Equation (3.52) for the selected model order. The final forms of expression for estimating the stochastic component in weekly water deficit series for the different regions are as under:

Table 4.28 Model order and autoregressive parameters of weekly water deficit Series

Region	Model order	$\Phi_{(p,k)}$	Values
Kothara	2	$\Phi_{(2,1)}$	0.646
		$\Phi_{(2,2)}$	0.196
Radhanpur	2	$\Phi_{(2,1)}$	0.652
		$\Phi_{(2,2)}$	0.200
Rajkot	2	$\Phi_{(2,1)}$	0.605
		$\Phi_{(2,2)}$	0.256
Amreli	3	$\Phi_{(3,1)}$	0.691
		$\Phi_{(3,2)}$	0.172
		$\Phi_{(3,3)}$	0.008
SK Nagar	2	$\Phi_{(2,1)}$	0.643
		$\Phi_{(2,2)}$	0.197
Khedbrahma	2	$\Phi_{(2,1)}$	0.726
		$\Phi_{(2,2)}$	0.143
Arnej	2	$\Phi_{(2,1)}$	0.656
		$\Phi_{(2,2)}$	0.223
Dhandhuka	2	$\Phi_{(2,1)}$	0.608
		$\Phi_{(2,2)}$	0.246
Junagadh	2	$\Phi_{(2,1)}$	0.701
		$\Phi_{(2,2)}$	0.200
Mahuva	2	$\Phi_{(2,1)}$	0.583
		$\Phi_{(2,2)}$	0.287
Anand	2	$\Phi_{(2,1)}$	0.617
		$\Phi_{(2,2)}$	0.253
Nawagam	2	$\Phi_{(2,1)}$	0.690
		$\Phi_{(2,2)}$	0.180
Bharuch	2	$\Phi_{(2,1)}$	0.701
		$\Phi_{(2,2)}$	0.175
Surat	2	$\Phi_{(2,1)}$	0.769
		$\Phi_{(2,2)}$	0.127
Navsari	2	$\Phi_{(2,1)}$	0.791
		$\Phi_{(2,2)}$	0.113
Gandevi	2	$\Phi_{(2,1)}$	0.782
		$\Phi_{(2,2)}$	0.123

Kothara	$S_t = 0.646S_{t-1} + 0.196S_{t-2} + a_t$	... (4.1)
Radhanpur	$S_t = 0.652S_{t-1} + 0.200S_{t-2} + a_t$	... (4.2)
Rajkot	$S_t = 0.605S_{t-1} + 0.256S_{t-2} + a_t$	... (4.3)
Amreli	$S_t = 0.691S_{t-1} + 0.172S_{t-2} + 0.008S_{t-3} + a_t$	... (4.4)
SK Nagar	$S_t = 0.643S_{t-1} + 0.197S_{t-2} + a_t$	... (4.5)
Khedbrahma	$S_t = 0.726S_{t-1} + 0.143S_{t-2} + a_t$	... (4.6)
Arnej	$S_t = 0.656S_{t-1} + 0.223S_{t-2} + a_t$	... (4.7)
Dhandhuka	$S_t = 0.608S_{t-1} + 0.246S_{t-2} + a_t$	(4.8)
Junagadh	$S_t = 0.701S_{t-1} + 0.200S_{t-2} + a_t$	(4.9)
Mahuva	$S_t = 0.583S_{t-1} + 0.287S_{t-2} + a_t$	(4.10)
Anand	$S_t = 0.617S_{t-1} + 0.253S_{t-2} + a_t$	... (4.11)
Nawagam	$S_t = 0.690S_{t-1} + 0.180S_{t-2} + a_t$	... (4.12)
Bharuch	$S_t = 0.701S_{t-1} + 0.175S_{t-2} + a_t$	... (4.13)
Surat	$S_t = 0.769S_{t-1} + 0.127S_{t-2} + a_t$	... (4.14)
Navsari	$S_t = 0.791S_{t-1} + 0.113S_{t-2} + a_t$	... (4.15)
Gandevi	$S_t = 0.782S_{t-1} + 0.123S_{t-2} + a_t$	... (4.16)

4.7.5 Residual Series

As observed from the Section (4.7.4), the S_t series of stochastic component, which was obtained after the removal of the deterministic components from the time series, consists of two components. These are the dependent part represented by an autoregressive model and the independent or residual part that is completely random also called as a white noise. The residual series, a_t , is obtained by deducting the generated series, which is the sum of periodic and stochastic component, from the observed time series.

4.7.6 Model Structure

The model structure of a time series constitutes the sum of trend, periodic and stochastic component. Since the observed weekly series in each agro-climatic region are trend free, the sub-models of periodic and stochastic component are added together to form the newly developed model structure of the water deficit series. The mathematical structure of the additive model as described by Equation (3.31) can now be presented for weekly water deficit series as given in Tables 4.29 for different agro-climatic zones. The formulated model structure has been used to generate similar sequenced series of weekly water deficit.

Table 4.29 Model structure of weekly water deficit series

Region	Mean, mm week ⁻¹	Periodic component, mm week ⁻¹	Stochastic component, mm week ⁻¹
Kothara	31.12	-2.85Cos(2πt/p)+11.64Sin(2πt/p) -5.08Cos(4πt/p)-7.62Sin(4πt/p) 0.77Cos(6πt/p)+2.59Sin(6πt/p)	0.646S _{t-1} +0.196S _{t-2} +a _t
Radhanpur	32.73	-5.60Cos(2πt/p)+13.93Sin(2πt/p) -4.48Cos(4πt/p)-10.38Sin(4πt/p) -0.07Cos(6πt/p)+4.58Sin(6πt/p)	0.652S _{t-1} +0.200S _{t-2} +a _t
Rajkot	30.71	-2.49Cos(2πt/p)+19.22Sin(2πt/p) -4.59Cos(4πt/p)-11.99Sin(4πt/p) 2.06Cos(6πt/p)+4.05Sin(6πt/p) -2.51Cos(8πt/p)-1.67Sin(8πt/p)	0.605S _{t-1} +0.256S _{t-2} +a _t
Amreli	28.74	0.50Cos(2πt/p)+17.73Sin(2πt/p) -5.75Cos(4πt/p)-10.26Sin(4πt/p) 1.97Cos(6πt/p)+2.08Sin(6πt/p) -2.84Cos(8πt/p)+0.22Sin(8πt/p)	0.691S _{t-1} +0.172S _{t-2} + 0.008S _{t-3} +a _t
SK Nagar	26.23	-6.4Cos(2πt/p)+14.23Sin(2πt/p) -3.63Cos(4πt/p)-9.54Sin(4πt/p) -0.28Cos(6πt/p)+4.52Sin(6πt/p)	0.643S _{t-1} +0.197S _{t-2} +a _t
Khedbrahma	20.19	-2.95Cos(2πt/p)+14.89Sin(2πt/p) -3.85Cos(4πt/p)-9.45Sin(4πt/p) 1.12Cos(6πt/p)+4.41Sin(6πt/p) -1.45Cos(8πt/p)-1.76Sin(8πt/p)	0.726S _{t-1} +0.143S _{t-2} +a _t
Arnej	26.28	-2.78Cos(2πt/p)+19.79Sin(2πt/p) -4.42Cos(4πt/p)-11.15Sin(4πt/p) 1.68Cos(6πt/p)+3.55Sin(6πt/p) -2.04Cos(8πt/p)-1.31Sin(8πt/p)	0.656S _{t-1} +0.223S _{t-2} +a _t
Dhandhuka	26.47	-2.57Cos(2πt/p)+17.95Sin(2πt/p) -5.04Cos(4πt/p)-9.79Sin(4πt/p) 1.70Cos(6πt/p)+2.65Sin(6πt/p)	0.608S _{t-1} +0.246S _{t-2} +a _t
Junagadh	24.78	2.88Cos(2πt/p)+18.95Sin(2πt/p) -5.46Cos(4πt/p)-9.80Sin(4πt/p) 1.93Cos(6πt/p)+1.23Sin(6πt/p) -2.35Cos(8πt/p)-0.52Sin(8πt/p)	0.701S _{t-1} +0.20S _{t-2} +a _t
Mahuva	24.89	1.92Cos(2πt/p)+14.97Sin(2πt/p) -3.12Cos(4πt/p)-7.53Sin(4πt/p)	0.583S _{t-1} +0.287S _{t-2} +a _t
Anand	20.66	-2.27Cos(2πt/p)+15.73Sin(2πt/p) -4.13Cos(4πt/p)-9.12Sin(4πt/p) 0.98Cos(6πt/p)+3.39Sin(6πt/p) -1.34Cos(8πt/p)-1.14Sin(8πt/p)	0.617S _{t-1} +0.253S _{t-2} +a _t
Nawagam	23.27	-2.91Cos(2πt/p)+17.36Sin(2πt/p) -3.23Cos(4πt/p)-10.65Sin(4πt/p) 1.36Cos(6πt/p)+4.40Sin(6πt/p)	0.690S _{t-1} +0.180S _{t-2} +a _t
Bharuch	21.71	-0.765Cos(2πt/p)+18.02Sin(2πt/p) -4.93Cos(4πt/p)-9.07Sin(4πt/p) 2.09Cos(6πt/p)+2.79Sin(6πt/p) -2.31Cos(8πt/p)-0.40Sin(8πt/p)	0.701S _{t-1} +0.175S _{t-2} +a _t
Surat	20.50	1.03Cos(2πt/p)+17.14Sin(2πt/p) -4.656Cos(4πt/p)-7.69Sin(4πt/p) 2.16Cos(6πt/p)+2.12Sin(6πt/p) -2.25Cos(8πt/p)-0.67Sin(8πt/p)	0.769S _{t-1} +0.127S _{t-2} +a _t
Navsari	19.73	2.39Cos(2πt/p)+17.42Sin(2πt/p) -4.75Cos(4πt/p)-7.84Sin(4πt/p) 2.29Cos(6πt/p)+1.61Sin(6πt/p) -2.64Cos(8πt/p)-0.09Sin(8πt/p)	0.791S _{t-1} +0.113S _{t-2} +a _t
Gandevi	16.74	0.499Cos(2πt/p)+16.244Sin(2πt/p) -3.873Cos(4πt/p)-7.464Sin(4πt/p) 2.07Cos(6πt/p)+1.7Sin(6πt/p) -2.557Cos(8πt/p)-0.135Sin(8πt/p)	0.782S _{t-1} +0.123S _{t-2} +a _t

4.7.7 Diagnostic Checking

The formulated models were subjected to diagnostic checking for either rejection or acceptance. Test of goodness of fit for observed weekly water deficit models was carried out for all the zones. Two different test of goodness of fit like sum of squares analysis and autocorrelation analysis were used for diagnostic checking.

4.7.7.1 Sum of squares analysis

In this analysis, the sum of squares of residuals and deviation of observed series from their mean value were estimated by using Equations (3.59) and (3.60). The required measure value, R^2 was obtained using Equation (3.61). The value of R^2 obtained for each agro-climatic zones are presented in Table 4.30. These values for weekly series model were found to range from 0.9521 at Mahuva to 0.9983 at Gandevi. From the results it is inferred that the developed model has a best goodness of fit to generate weekly water deficit series.

Table 4.30 Sum of squares analysis of residual series of water deficit at different stations

Station	R^2
Kothara	0.9633
Radhanpur	0.9672
Rajkot	0.9569
Amreli	0.9773
SK Nagar	0.9626
Khedbrahma	0.9838
Arnej	0.9770
Dhandhuka	0.9852
Junagadh	0.9835
Mahuva	0.9521
Anand	0.9630
Nawagam	0.9778
Bharuch	0.9806
Surat	0.9903
Navsari	0.9930
Gandevi	0.9983

4.7.7.2 Autocorrelation analysis

The autocorrelation function of weekly residual series was estimated for lag k using Equation (3.32) for each region. The value of autocorrelation function was plotted against the lag to obtain a correlogram. The resulting correlogram of weekly series, along with the confidence limit at 0.01 level of significance for each agro-climatic zone are shown in Figures 4.17a to 4.17d. The confidence limits were estimated using Equation (3.32). The results show that for all lags the autocorrelation function falls fairly within the confidence limits. So we can use these models and generate values of weekly water deficit and compare the statistical characteristics of observed and generated series.

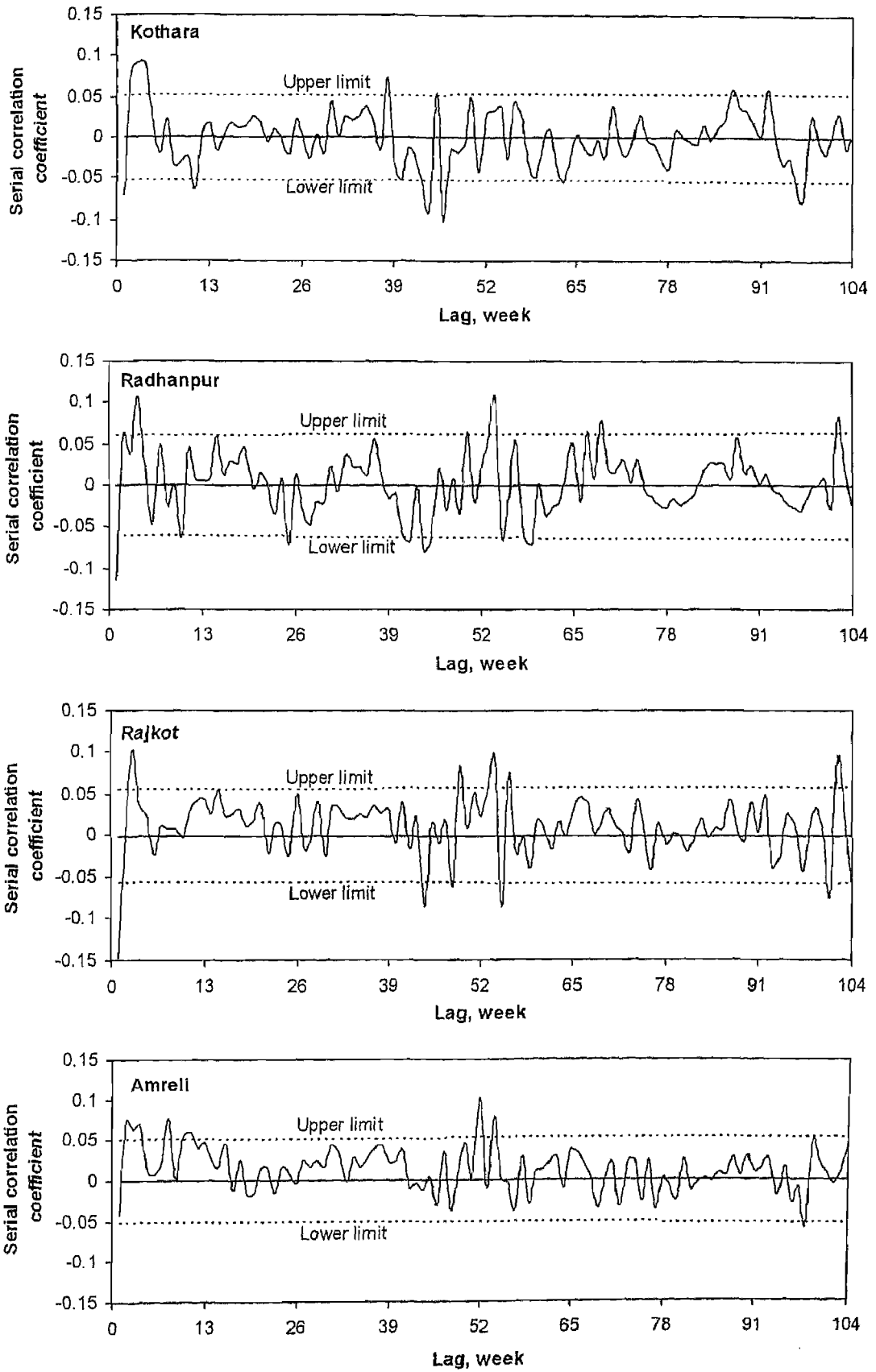


Fig. 4.17a Correlogram of the residual series of weekly water deficit for Kothara, Radhanpur, Rajkot and Amreli

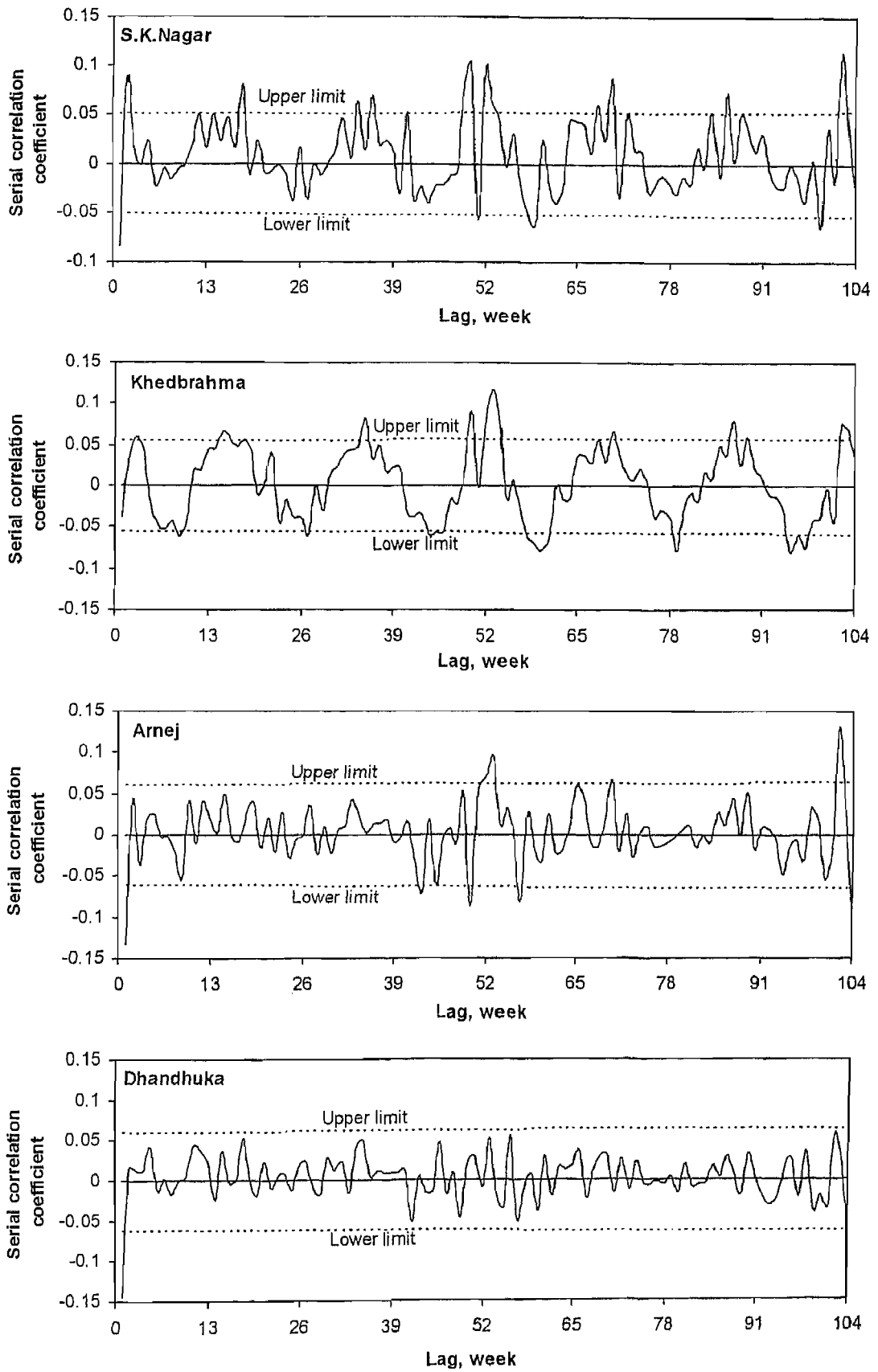


Fig. 4.17b Correlogram of the residual series of weekly water deficit for SK Nagar, Khedbrahma, Arnej and Dhandhuka

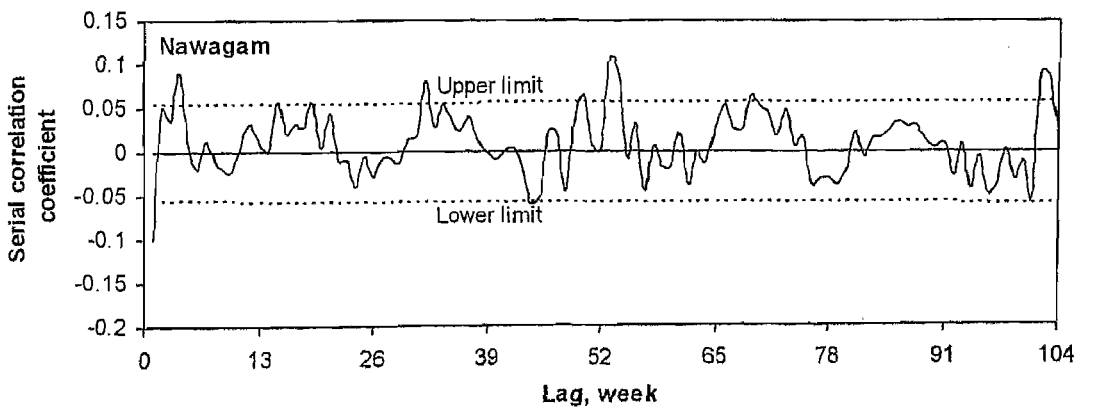
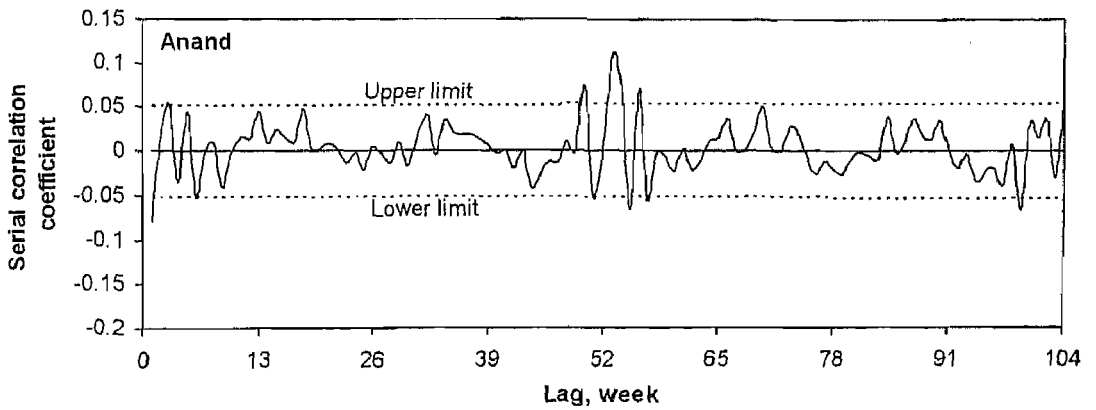
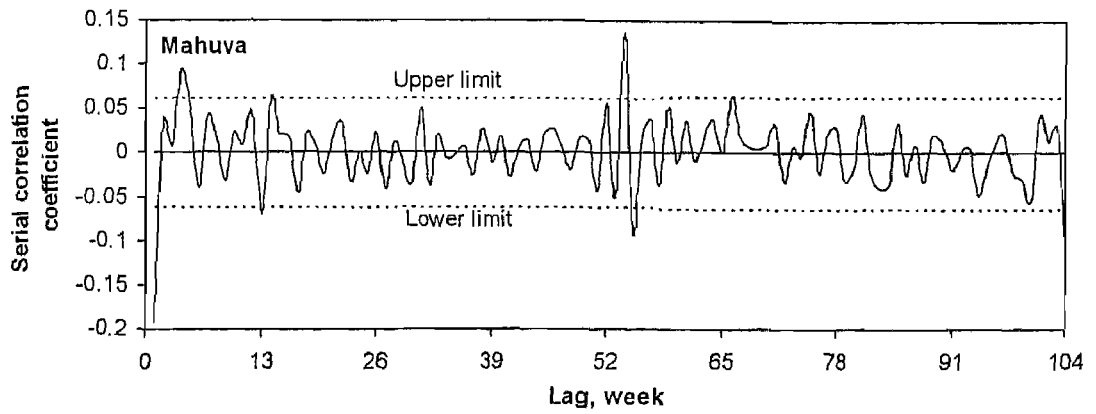
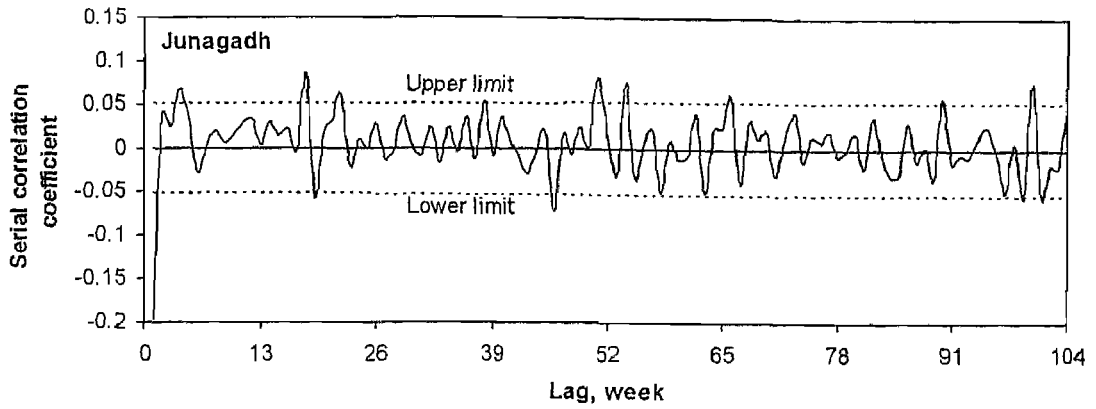


Fig. 4.17c Correlogram of the residual series of weekly water deficit for Junagadh, Mahuva, Anand and Nawagam

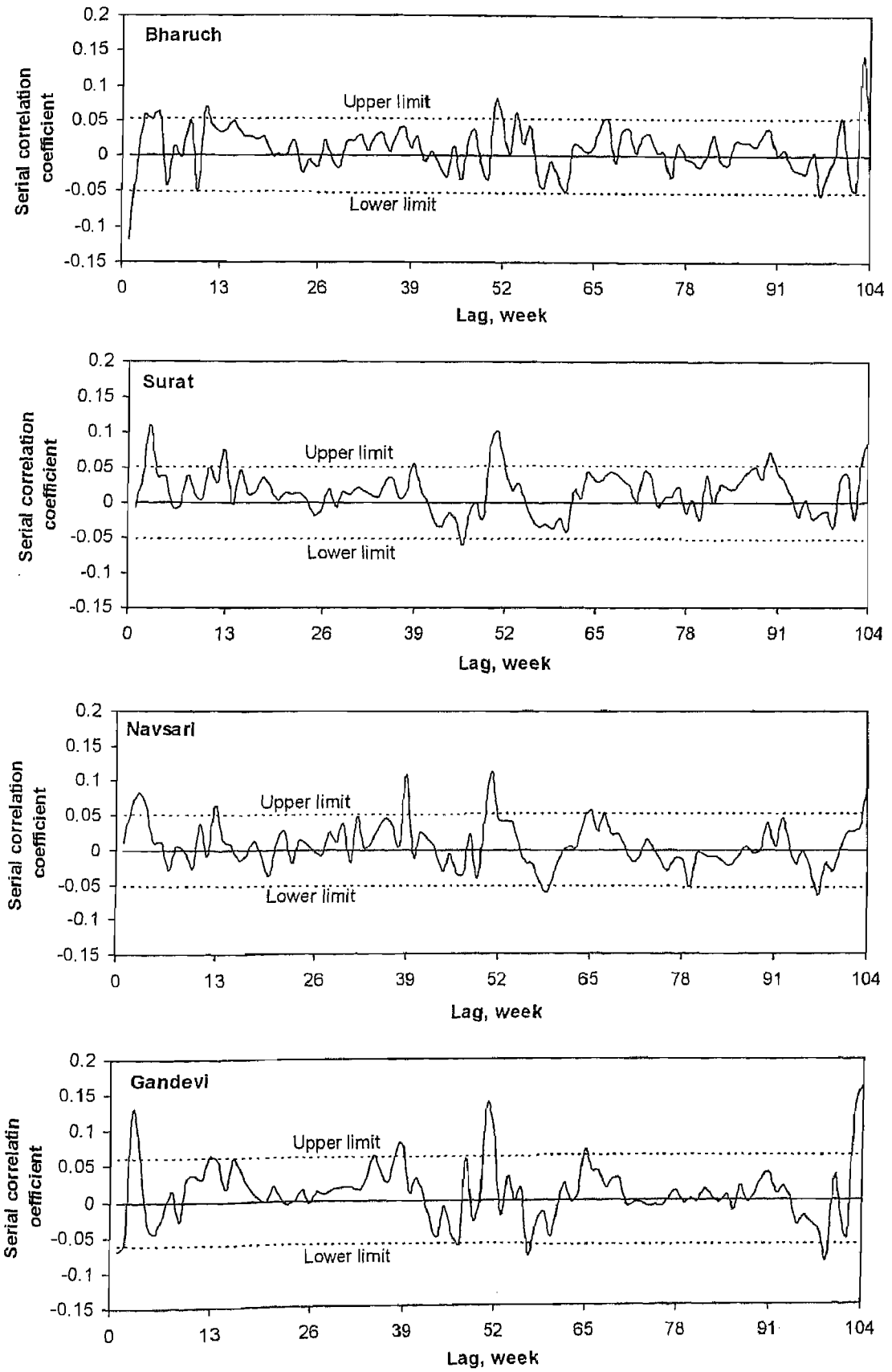


Fig. 4.17d Correlogram of the residual series of weekly water deficit for Bharuch, Surat, Navsari, and Gandevi

4.7.8 Validation of Stochastic Model

Comparison of generated with observed water deficit series was made to validate the model. Figures 4.18a to 4.18d depict the variation of observed and generated weekly water deficit series for the study period for all the stations. Figures 4.18a to 4.18d indicate that there is a close agreement between observed and generated water deficit series.

The basic statistical characteristics for the modelling period are shown in Table 4.31. Values of mean, standard deviation, coefficient of skewness, kurtosis and variance show that for observed and generated series statistical characteristics are not significantly different. Also very low integral square error (ISE) shows that the formulated models are significantly adequate for generating weekly water deficit.

The values of correlation coefficient (r) between observed and generated weekly series for the modelled period were worked out as shown in Table 4.32. The correlation coefficient ranged from 0.9772 at Mahuva to 0.9969 at Navsari in weekly series. The mean weekly observed water deficit series of period under consideration were also compared with their respective generated series. Figures 4.19a to 4.19d depict the variation between the mean weekly observed and generated series of the modelled period for all the stations.

The values of correlation coefficient r , between the mean observed and generated weekly water deficit series were also worked out as shown in Table 4.32. The correlation coefficient ranged from 0.9978 at Rajkot to 0.9996 at Navsari in mean weekly series. Therefore, the model structures formulated can be used for long-term prediction of weekly water deficit for their respective agro-climatic stations. Similar results were also obtained by Jat et al., (2003a) for semi-arid region of Rajasthan state.

The results of predicted water deficit for weekly series of two years ahead (2002 and 2003) are depicted in Figures 4.20a to 4.20d. The basic statistical characteristics of observed and predicted weekly series such as mean, standard deviation, coefficient of skewness, kurtosis and variance were also estimated for comparison. As shown in Table 4.33, the observed and predicted series have not produced significantly different results indicating the adequacy of the model for predicting water deficit for their respective zones. The values of correlation coefficient r , between the mean observed and predicted weekly water deficit series were worked out as shown in Table 4.34. The correlation coefficient ranged from 0.9794 at SK Nagar to 0.9981 at Navsari in weekly series and from 0.9870 at SK Nagar to 0.9985 at Navsari in mean weekly series.

Above results for predicted and observed weekly water deficit series of two years (2002 and 2003) indicate adequacy of the model for predicting water deficit series for respective periods in different agro-climatic zones of Gujarat. Values of correlation coefficient and statistical characteristics for observed and predicted series confirm the reliability of weekly water deficit model for generation of data.

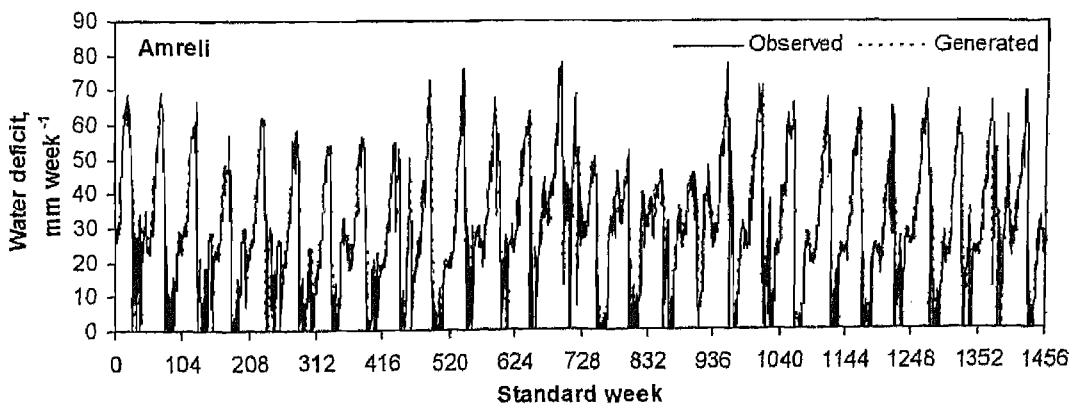
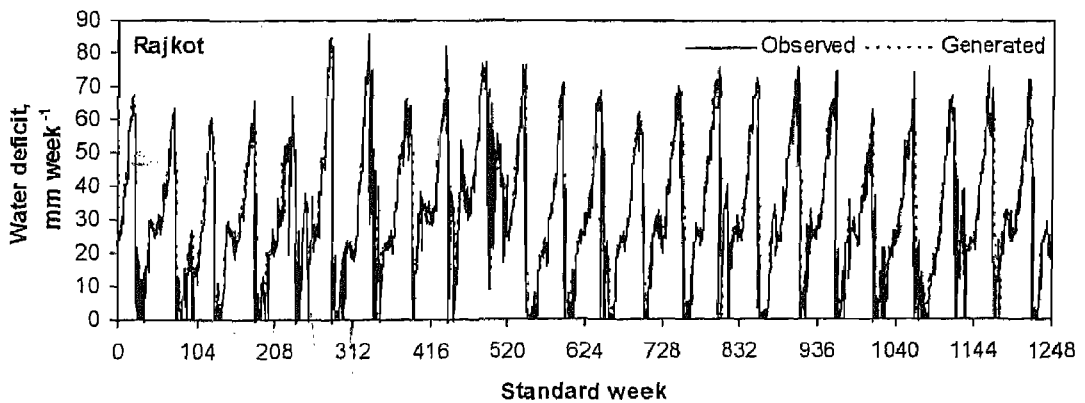
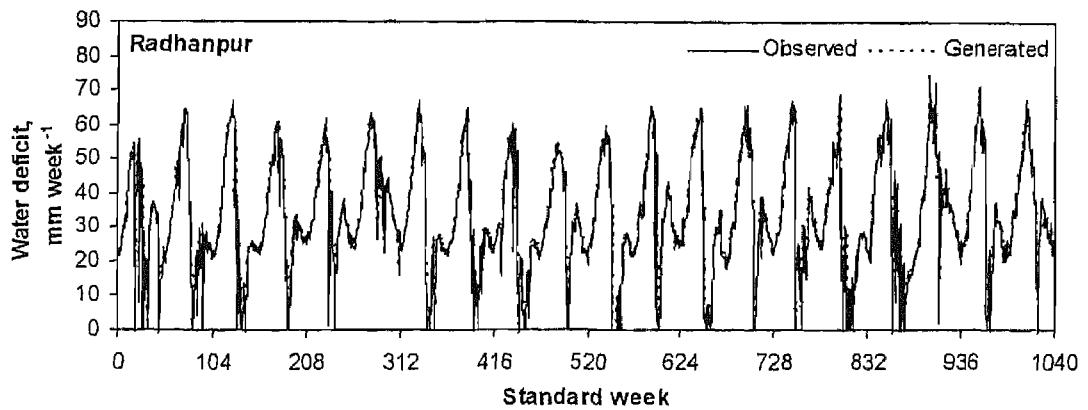
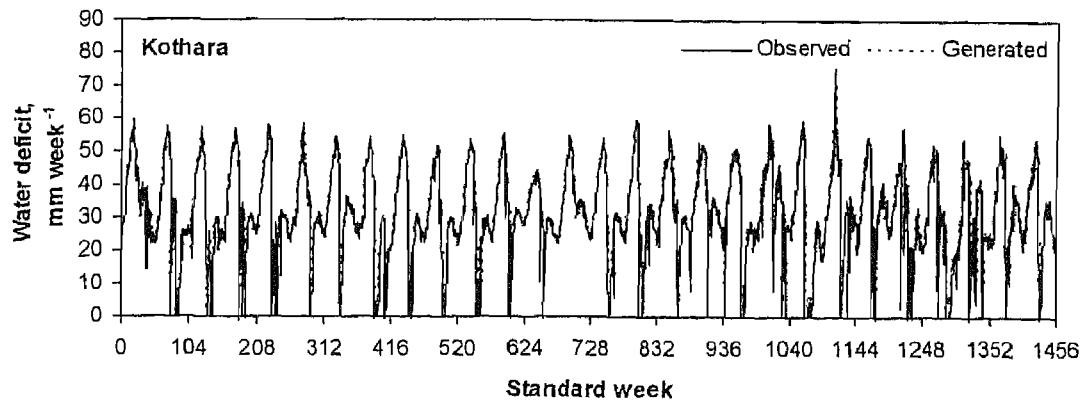


Fig. 4.18a Variation of weekly observed and generated water deficit series for Kothara, Radhanpur, Rajkot and Amreli.

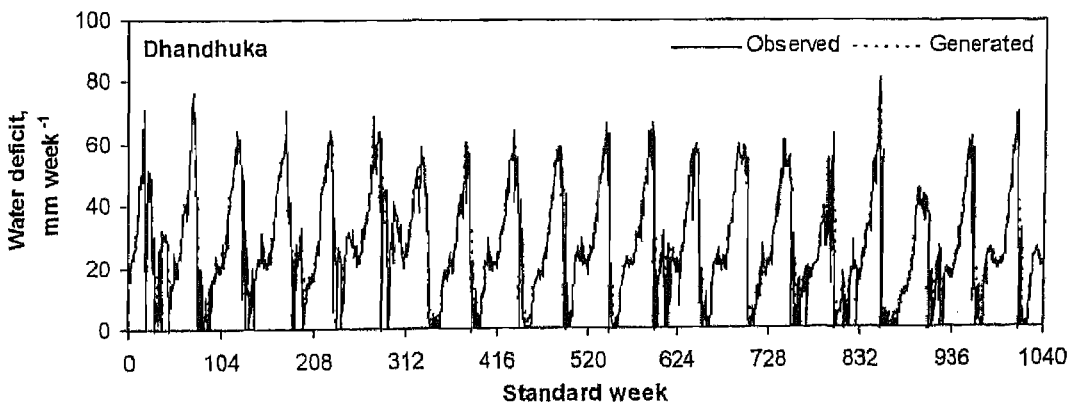
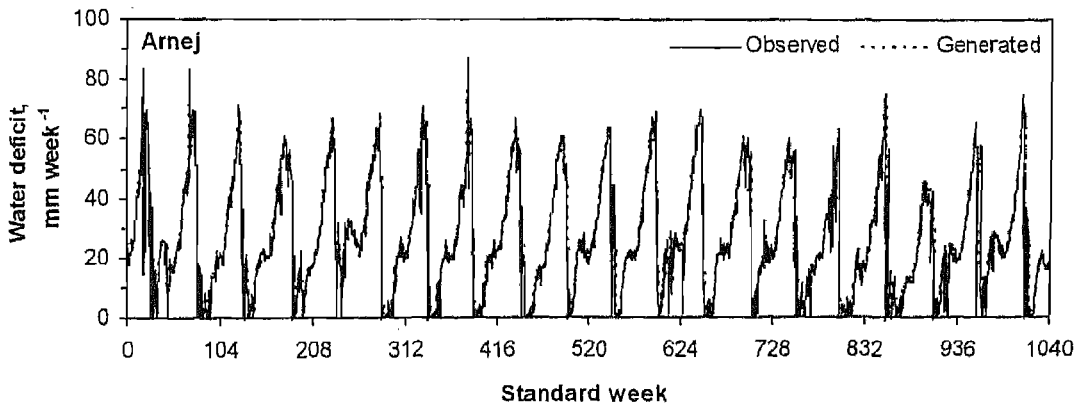
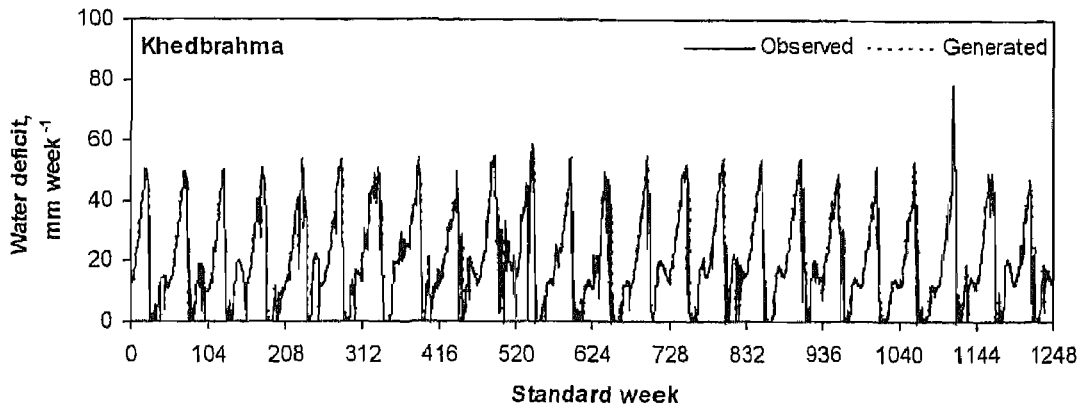
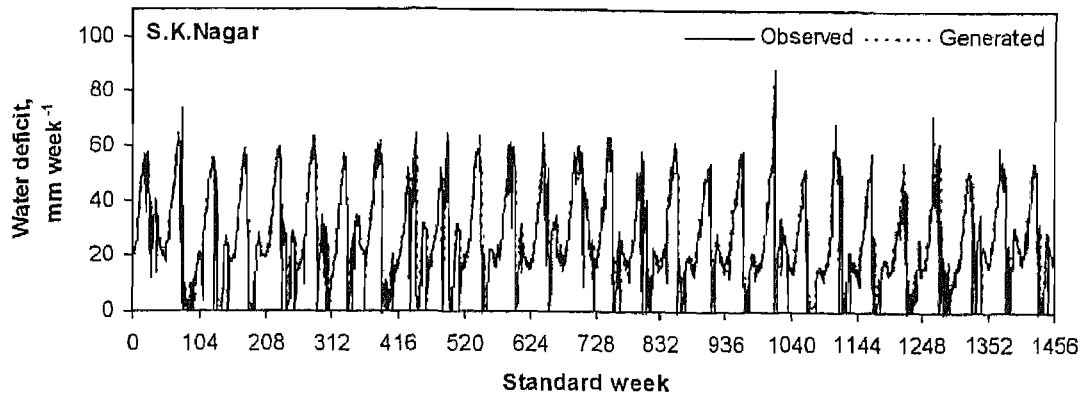


Fig. 4.18b Variation of weekly observed and generated water deficit series for S.K. Nagar, Khedbrahma, Arnej and Dhandhuka

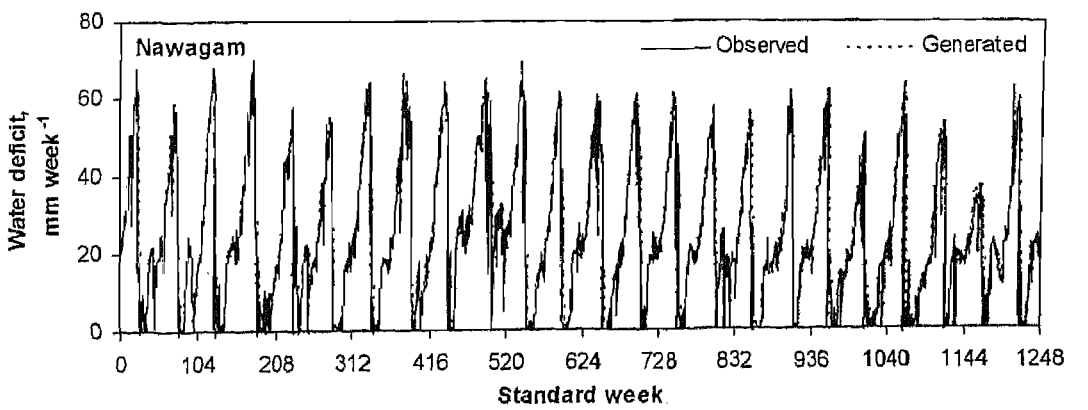
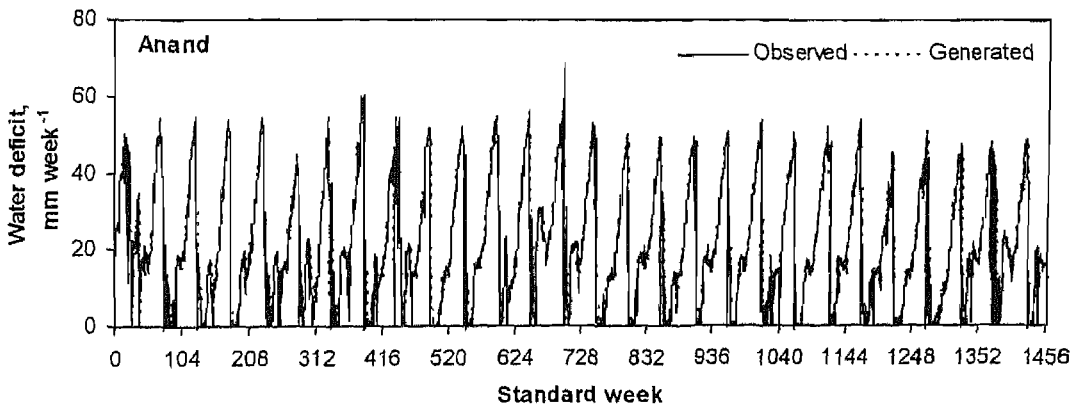
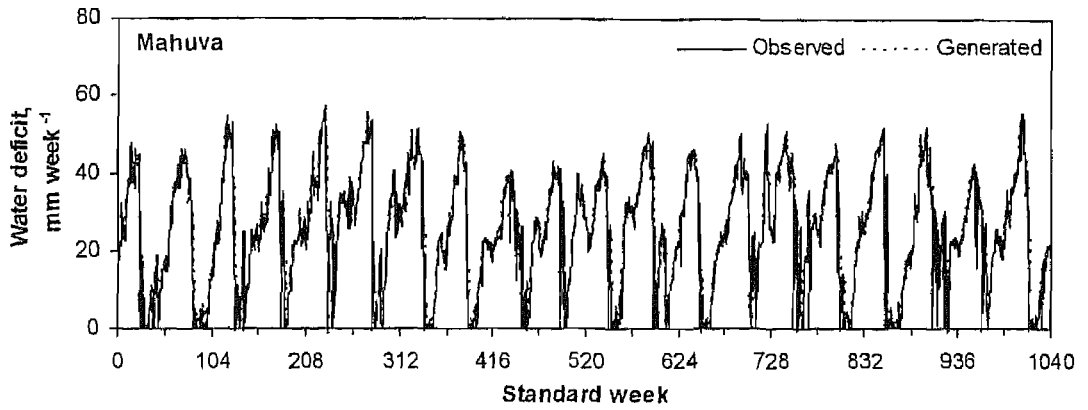
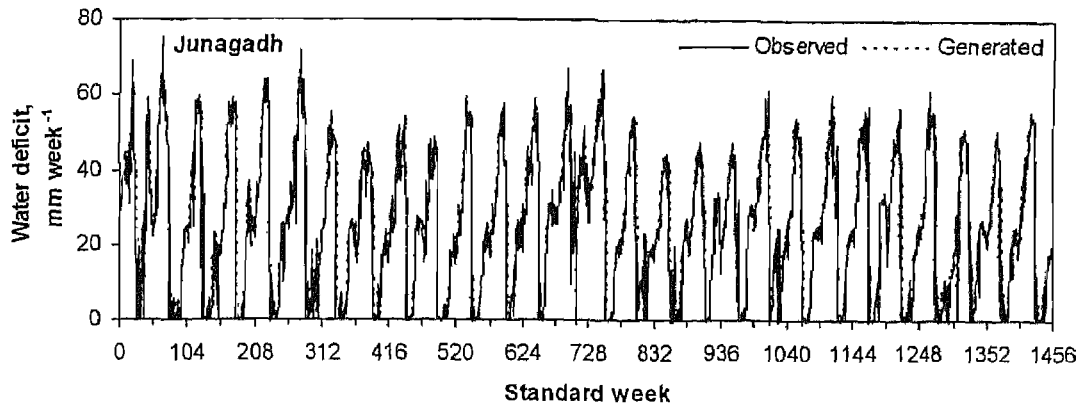


Fig. 4.18c Variation of weekly observed and generated water deficit series for Junagadh, Mahuva, Anand and Nawagam

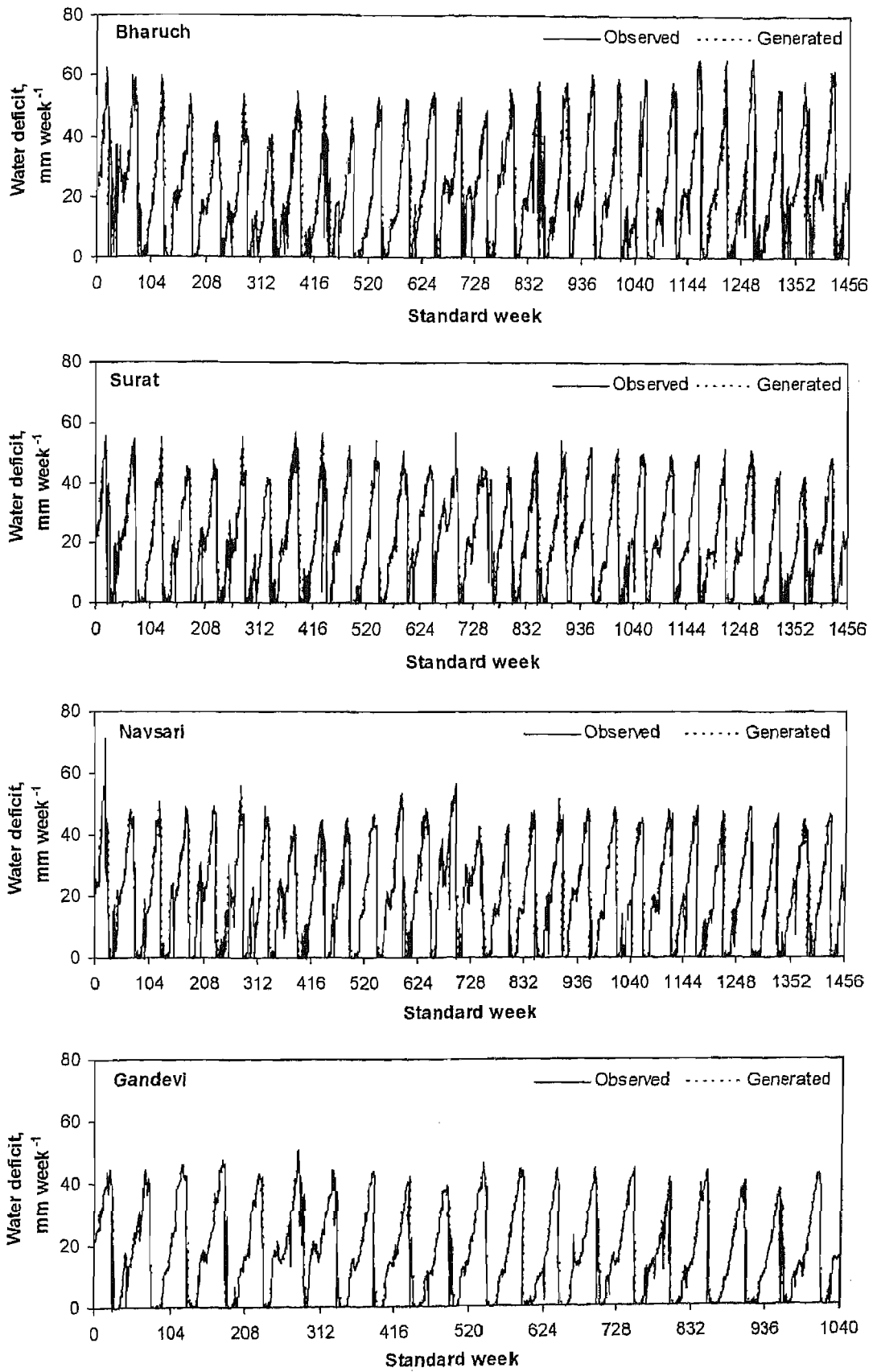


Fig. 4.18d Variation of weekly observed and generated water deficit series for Bharuch, Surat, Navsari, and Gandevi

Table 4.31 Statistical characteristics of observed, generated and residual weekly water deficit series at different stations

Station	Series	Mean, mm	SD, mm	Skewness	Kurtosis	Variance	ISE
Kothara	Observed	31.12	14.15	-0.34	-0.04	200.22	0.0023
	Generated	31.12	12.87	-0.08	-0.40	165.62	
	Residual	0.00	2.71	-1.61	7.82	7.35	
Radhanpur	Observed	32.73	16.93	0.01	-0.52	286.54	0.0031
	Generated	32.73	15.60	0.18	-0.68	243.31	
	Residual	0.00	3.07	-1.51	7.92	9.40	
Rajkot	Observed	30.71	20.53	0.30	-0.66	421.53	0.0029
	Generated	30.71	18.95	0.34	-0.74	358.98	
	Residual	0.00	4.26	-0.95	7.34	18.17	
Amreli	Observed	28.70	18.98	0.19	-0.72	360.13	0.0026
	Generated	28.70	17.73	0.24	-0.79	314.36	
	Residual	0.00	2.85	-0.84	4.32	8.13	
SK Nagar	Observed	26.21	17.17	0.35	-0.64	294.85	0.0033
	Generated	26.23	15.70	0.44	-0.73	246.42	
	Residual	0.00	3.33	-1.11	7.36	11.09	
Khedbrahma	Observed	20.19	15.43	0.58	-0.40	238.05	0.0032
	Generated	20.19	14.63	0.57	-0.53	214.06	
	Residual	0.00	1.97	-0.90	7.09	3.87	
Arnej	Observed	26.28	19.44	0.50	-0.59	378.02	0.0037
	Generated	26.28	18.37	0.49	-0.75	337.51	
	Residual	0.00	3.18	-1.28	8.71	10.10	
Dhandhuka	Observed	26.47	18.34	0.40	-0.63	336.22	0.0044
	Generated	26.47	16.95	0.46	-0.73	287.38	
	Residual	0.00	3.80	-0.73	8.01	14.42	
Junagadh	Observed	24.78	18.42	0.21	-1.00	339.20	0.0025
	Generated	24.78	17.63	0.19	-1.04	310.77	
	Residual	0.00	2.36	-1.01	7.42	5.59	
Mahuva	Observed	24.89	15.20	-0.19	-0.94	230.96	0.0028
	Generated	24.89	14.04	-0.11	-0.99	197.13	
	Residual	0.00	3.33	-1.19	6.71	11.06	
Anand	Observed	20.66	15.83	0.46	-0.78	250.73	0.0038
	Generated	20.66	14.82	0.45	-0.87	219.69	
	Residual	0.00	3.05	-1.38	10.43	9.28	
Nawagam	Observed	23.27	18.02	0.56	-0.58	324.83	0.0042
	Generated	23.27	16.93	0.53	-0.69	286.71	
	Residual	0.00	2.68	-1.29	8.99	7.20	
Bharuch	Observed	21.71	17.49	0.46	-0.84	305.99	0.0029
	Generated	21.71	16.57	0.46	-0.89	274.41	
	Residual	0.00	2.44	-1.20	8.99	5.93	
Surat	Observed	20.50	16.03	0.26	-1.13	256.83	0.0027
	Generated	20.50	15.42	0.26	-1.17	237.74	
	Residual	0.00	1.55	-1.77	9.71	2.41	
Navsari	Observed	19.73	16.12	0.25	-1.17	259.87	0.0026
	Generated	19.73	15.61	0.25	-1.20	243.71	
	Residual	0.00	1.35	-1.49	8.33	1.81	
Gandevi	Observed	16.74	14.55	0.43	-1.07	211.68	0.0023
	Generated	16.74	14.13	0.42	-1.10	199.61	
	Residual	0.00	1.24	-1.65	12.34	1.54	

Table 4.32 Correlation coefficient between observed and generated water deficit series at different stations

Station	Correlation coefficient, r	
	Series	Series mean
Kothara	0.9843	0.9981
Radhanpur	0.9855	0.9992
Rajkot	0.9799	0.9978
Amreli	0.9902	0.9988
SK Nagar	0.9841	0.9983
Khedbrahma	0.9929	0.9987
Arnej	0.9875	0.9994
Dhandhuka	0.9799	0.9993
Junagadh	0.9924	0.9992
Mahuva	0.9772	0.9992
Anand	0.9824	0.9987
Nawagam	0.9902	0.9986
Bharuch	0.9912	0.9993
Surat	0.9959	0.9995
Navsari	0.9969	0.9996
Gandevi	0.9967	0.9994

4.8 GEOSTATISTICAL MODELLING OF WATER DEFICIT

The spatial variability of water deficit during the severe drought year (1987) in different agro-climatic zones of Gujarat was analysed using spatial statistics and estimating water deficit at unrecorded places using geostatistical kriging technique. Observed pattern of the experimental semivariogram was studied and it was fitted to model a suitable trend as recommended in geostatistical modelling. The complete analysis has been carried out using an enhanced geostatistical tool of the ArcGIS 8.0 software. The suitable model fitted was further used to evaluate a krigged estimate of the water deficit at the station using the spatial variability. Isodeficit line maps were prepared for observed and krigged water deficit values for 10 fortnights starting from 23rd standard meteorological week. Comparisons of isodeficit line map of different fortnights indicate the temporal variability of water deficit over Gujarat.

4.8.1 Statistical Parameters

The different statistical parameters of observed fortnightly water deficit data are presented in Table 4.35. Table 4.35 reveals that mean water deficit varies from 18.63 to 41.48 mm in different fortnights. Skewness coefficient and kurtosis values indicate that no fortnight series is normally distributed. Third and ninth fortnight have highest and lowest range. This indicates much difference in zonal water deficit during third fortnight (starting of rainy

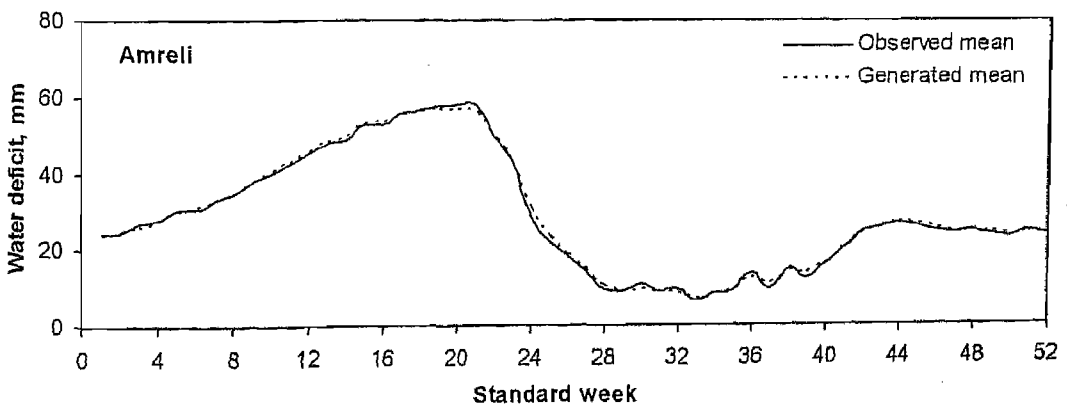
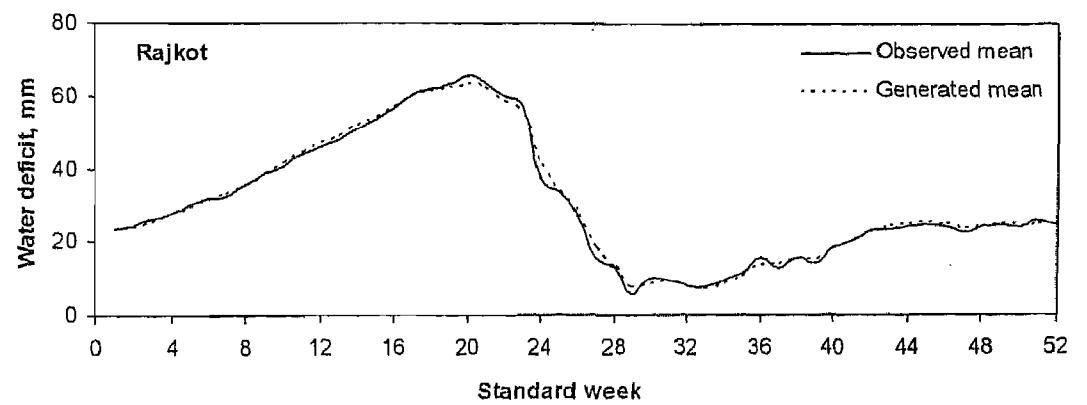
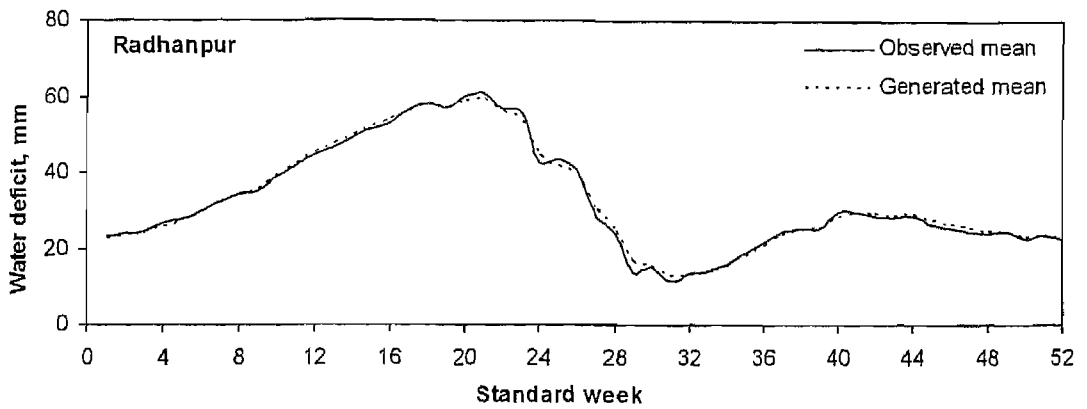
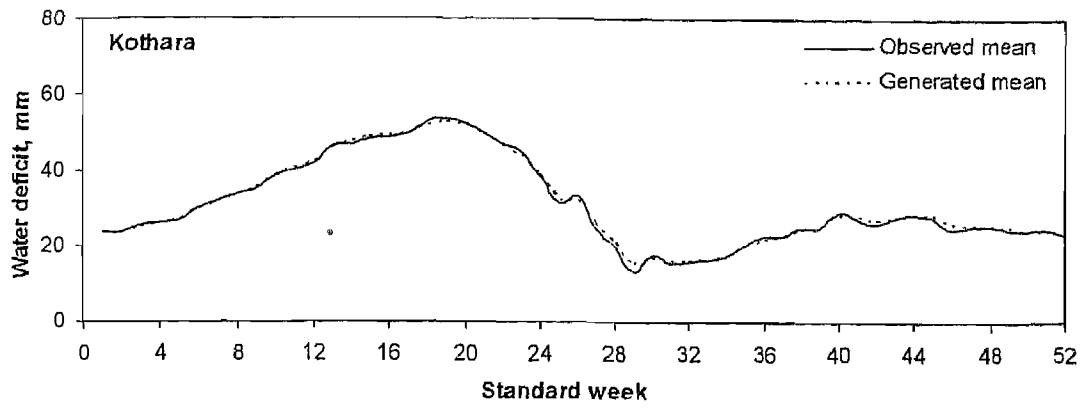


Fig. 4.19a Variation of mean weekly observed and generated water deficit series for Kothara, Radhanpur, Rajkot and Amreli

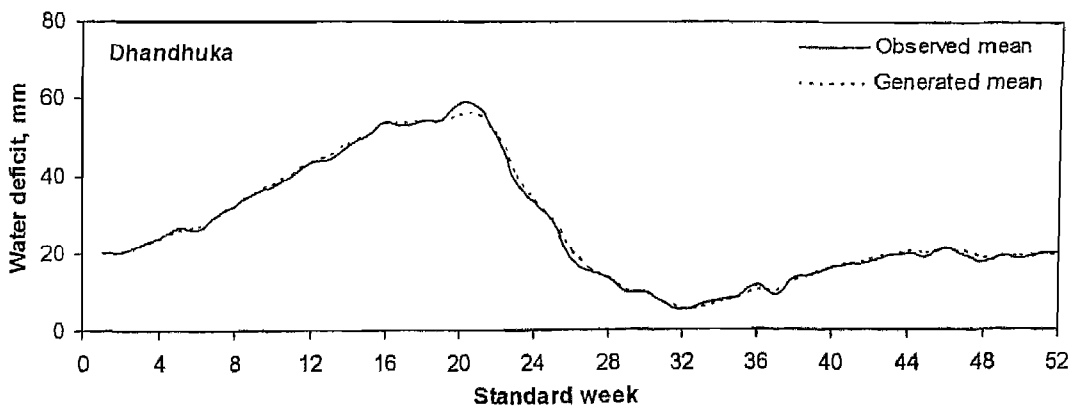
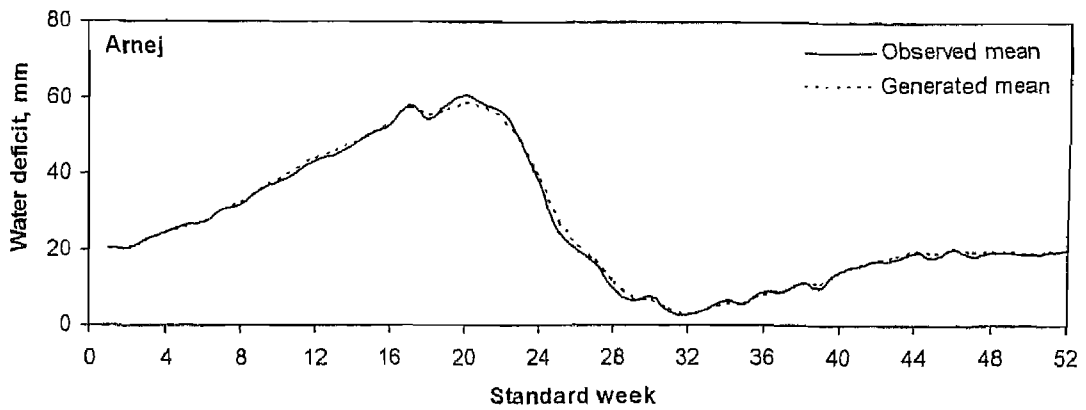
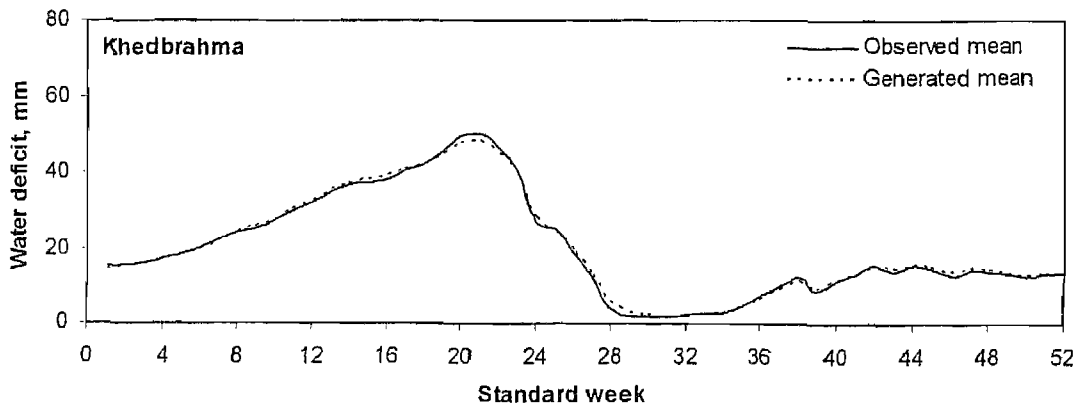
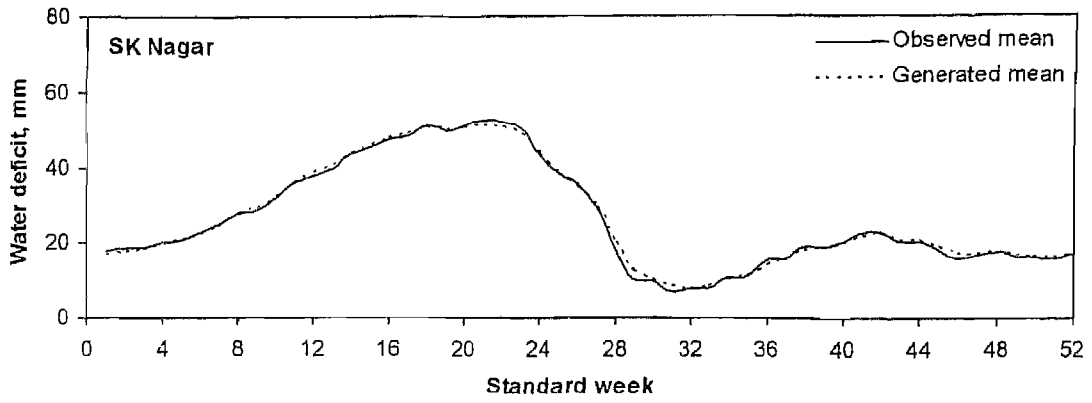


Fig. 4.19b Variation of mean weekly observed and generated water deficit series for S.K. Nagar, Khedbrahma, Arnej and Dhandhuka

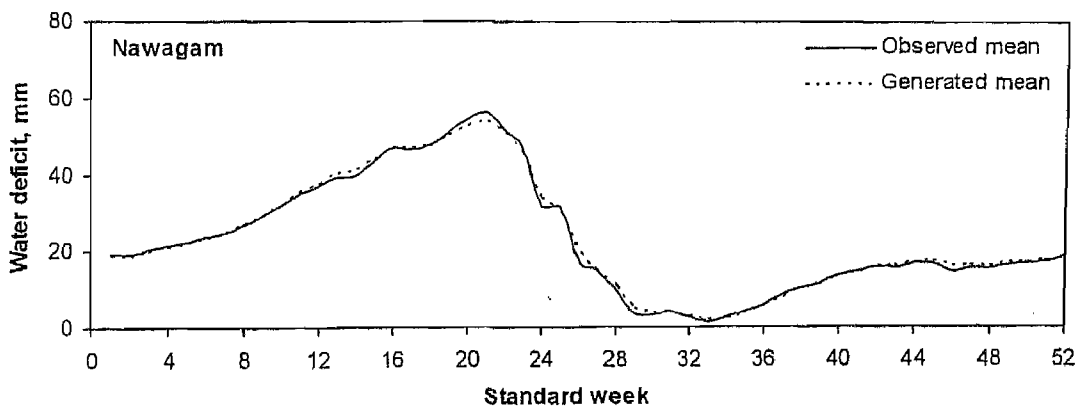
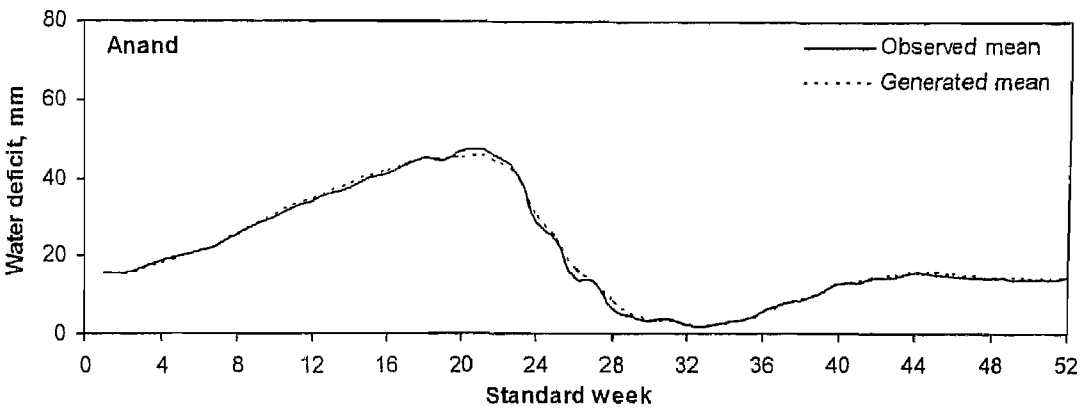
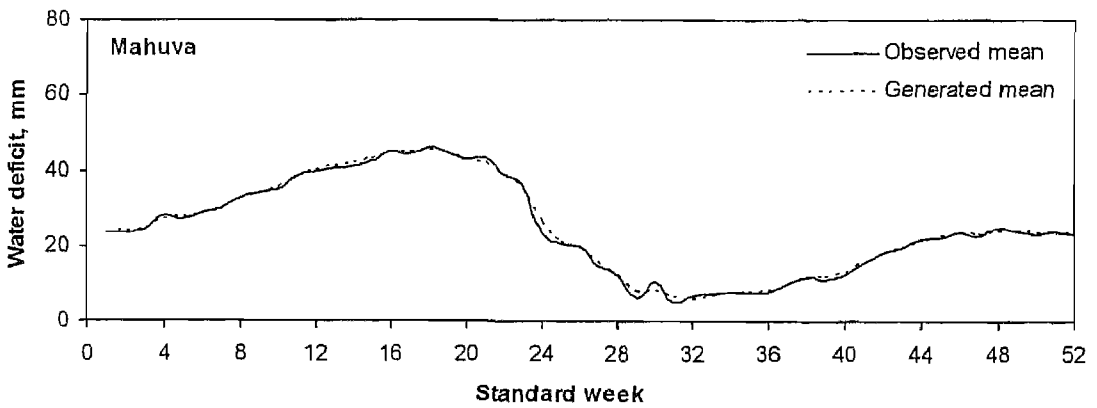
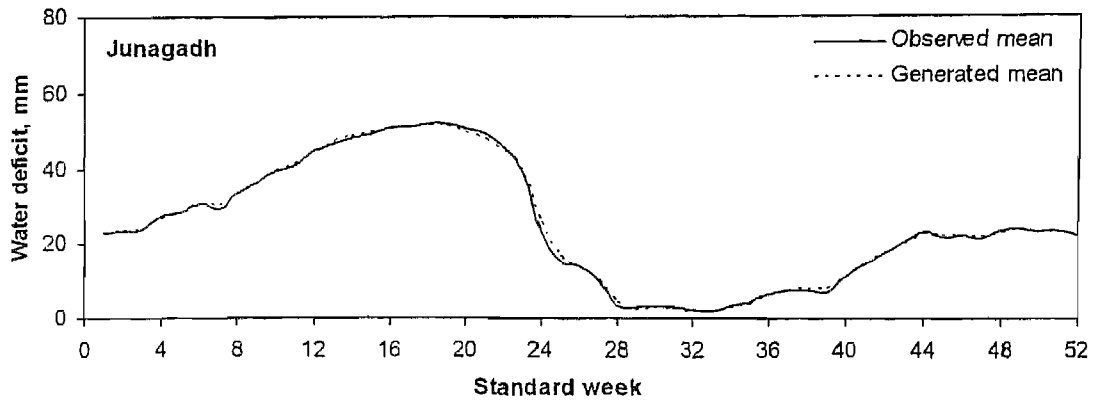


Fig. 4.19c Variation of mean weekly observed and generated water deficit series for Junagadh, Mahuva, Anand and Nawagam

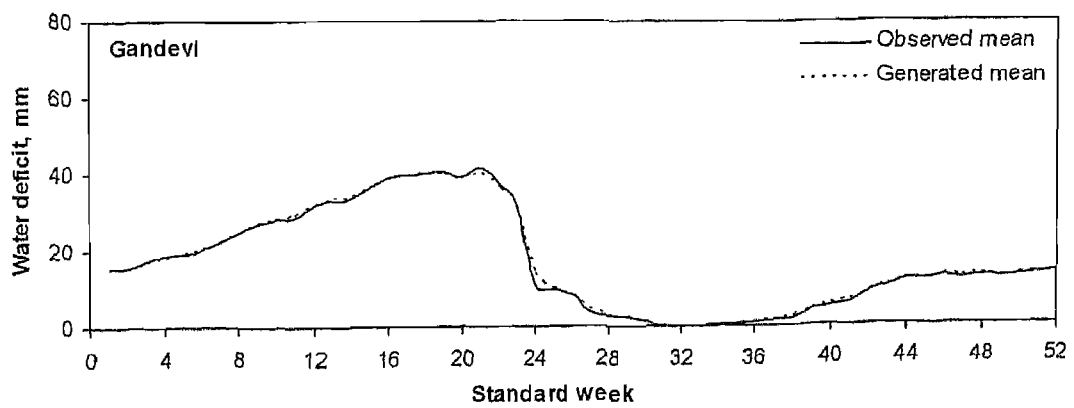
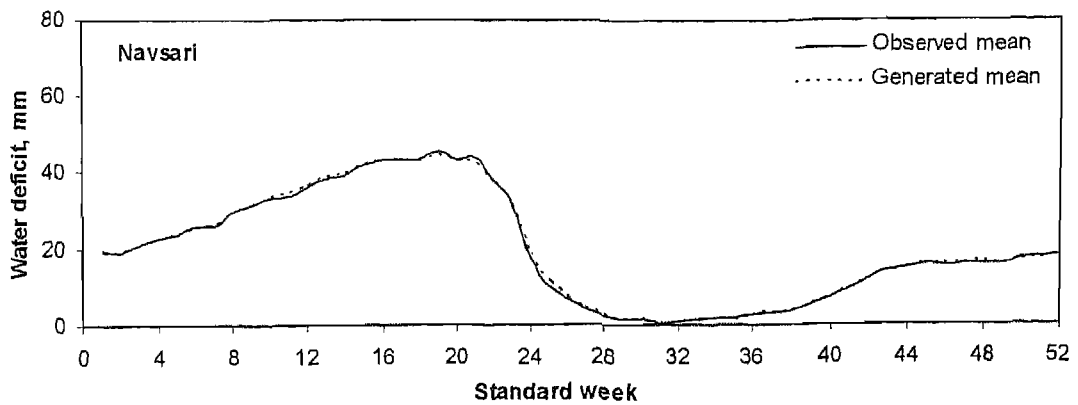
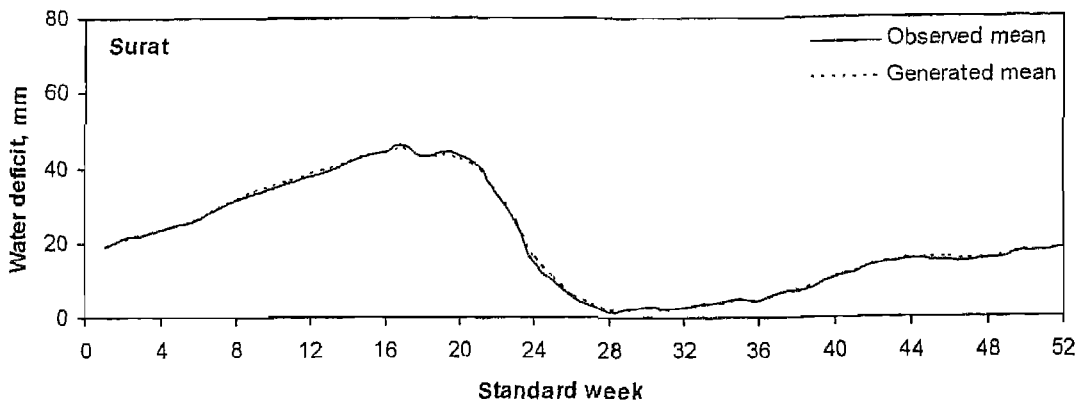
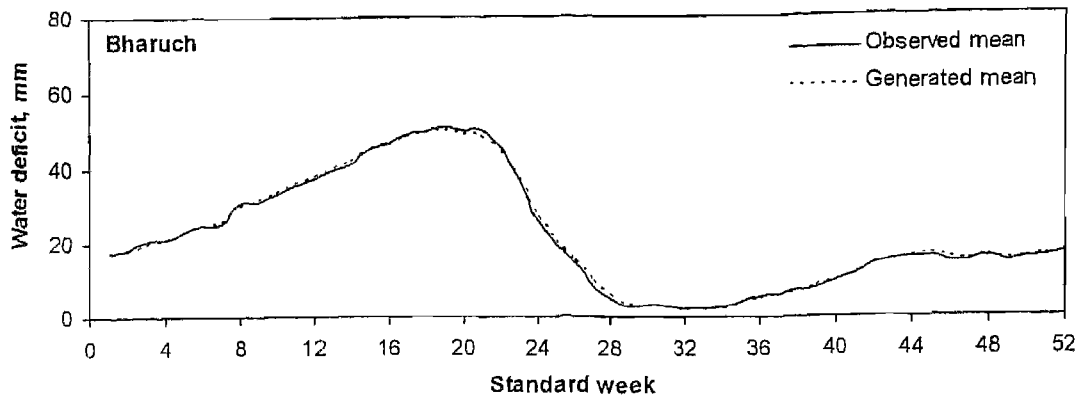


Fig. 4.19d Variation of mean weekly observed and generated water deficit series for Bharuch, Surat, Navsari, and Gandevi

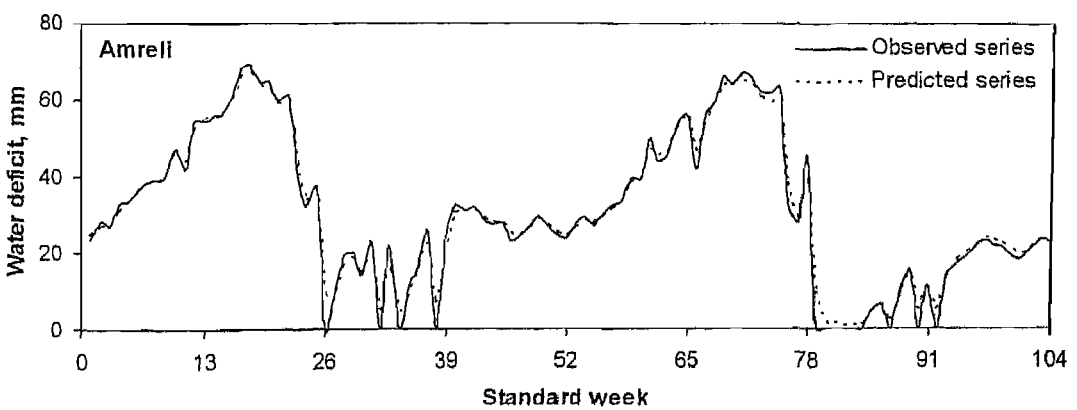
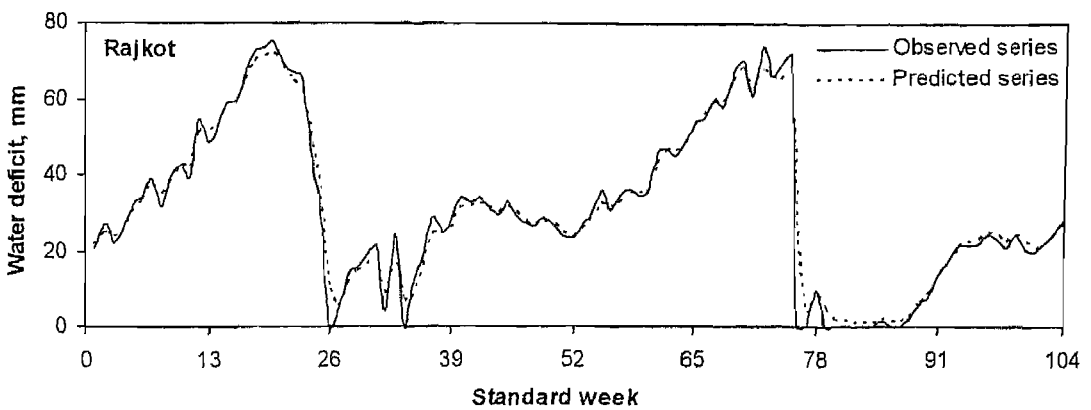
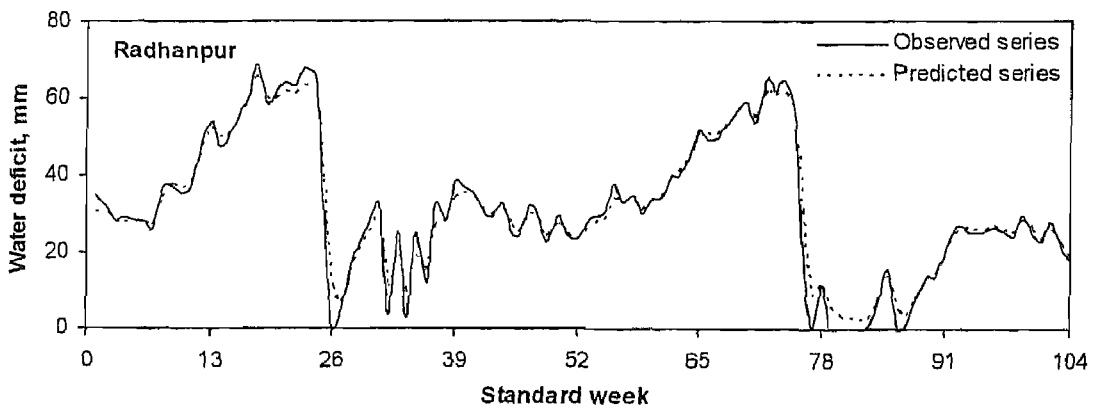
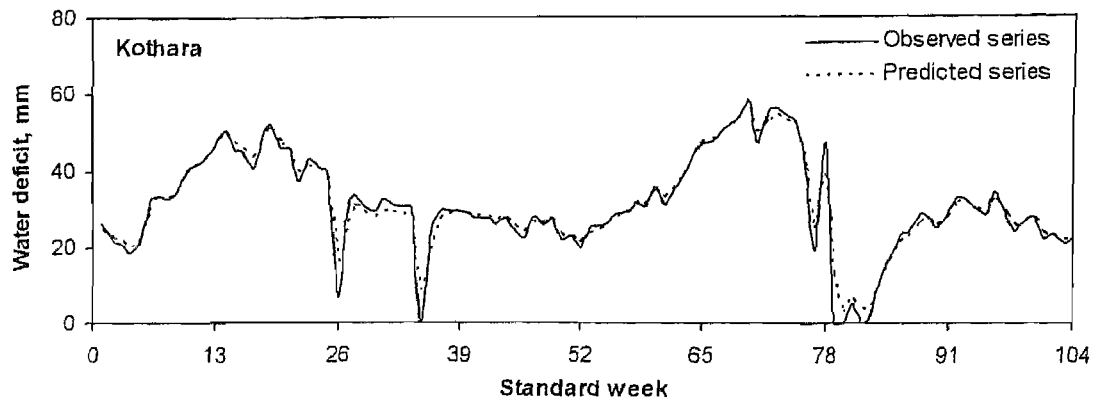


Fig. 4.20a Variation of observed and predicted weekly water deficit series for Kothara, Radhanpur, Rajkot and Amreli

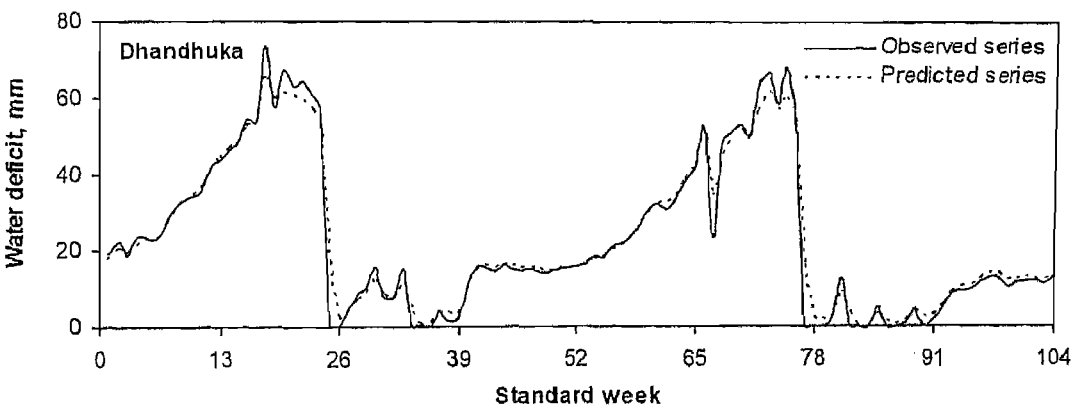
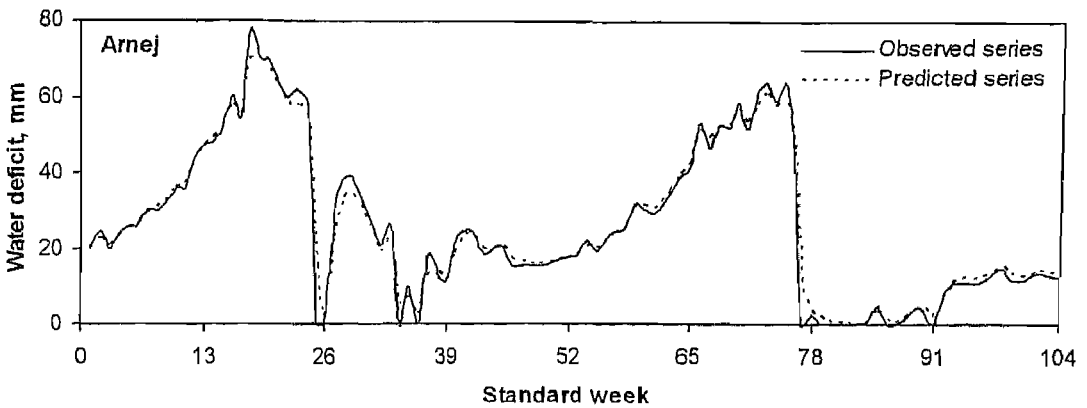
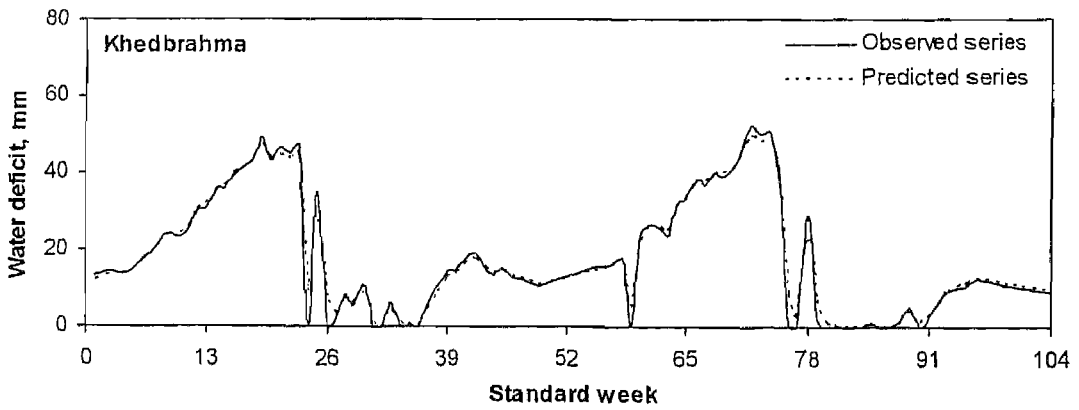
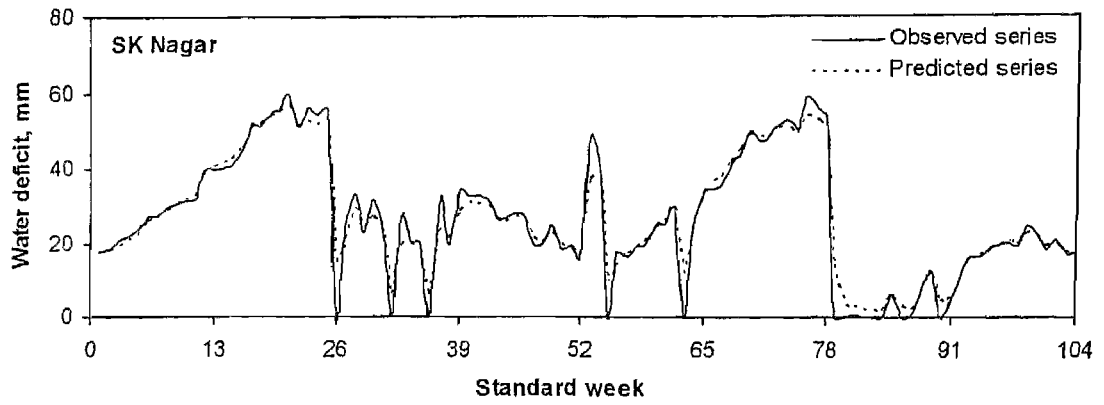


Fig. 4.20b Variation of observed and predicted weekly water deficit series for SK Nagar, Khedbrahma, Arnej and Dhandhuka

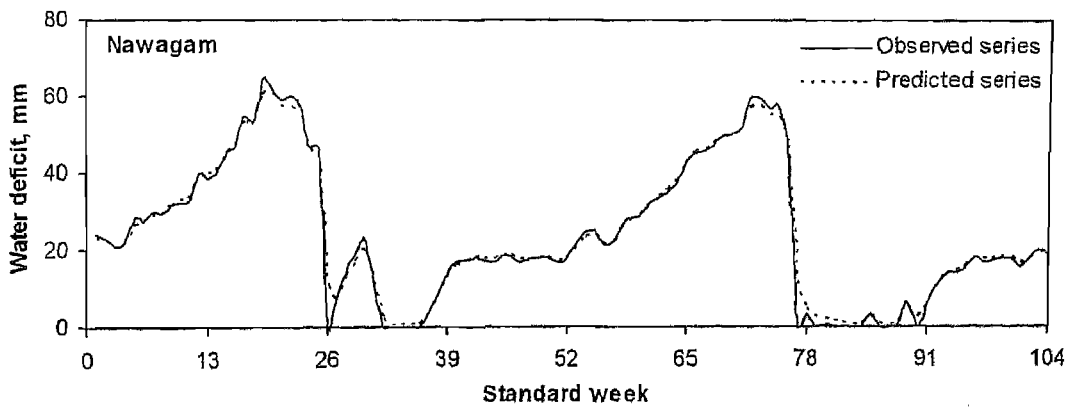
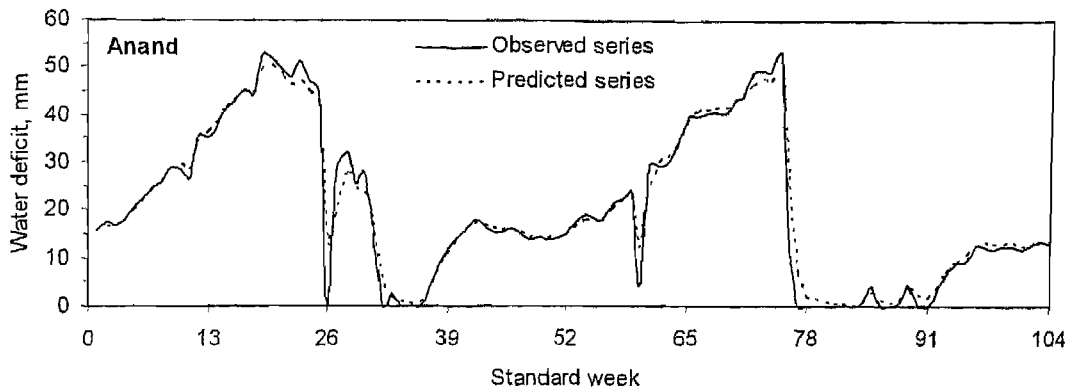
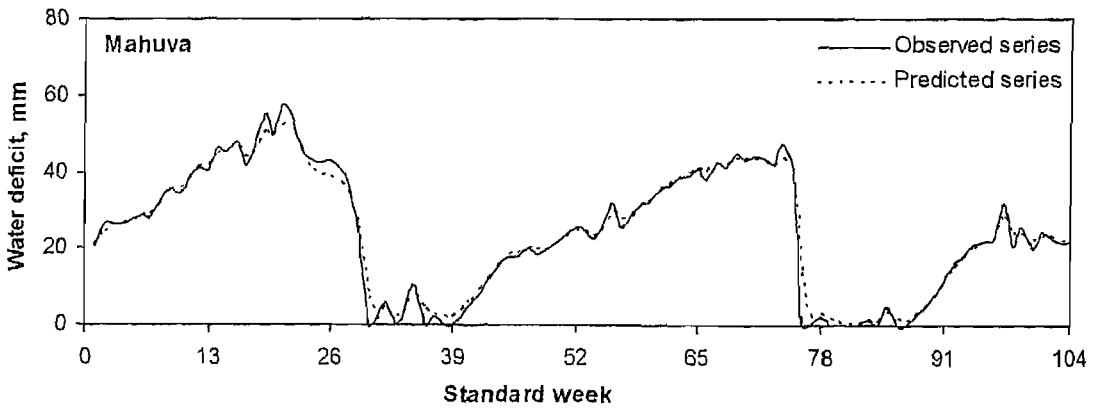
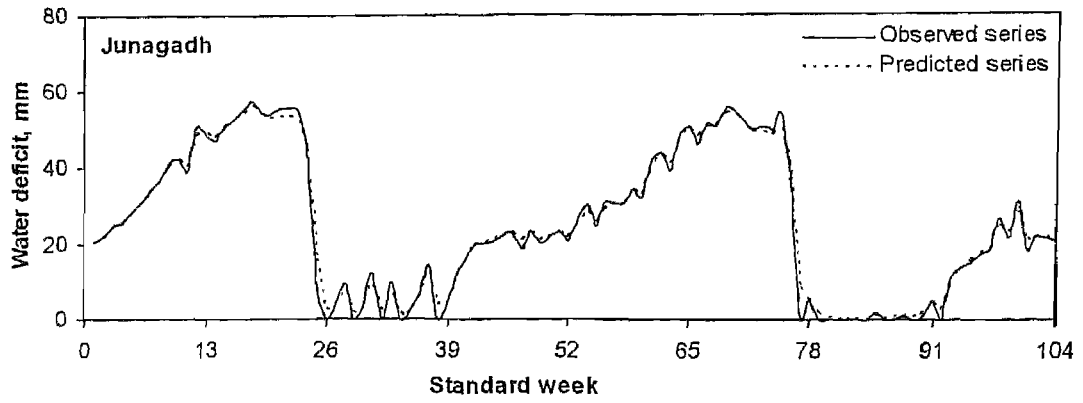


Fig. 4.20c Variation of observed and predicted weekly water deficit series for Junagadh, Mahuva, Anand and Nawagam

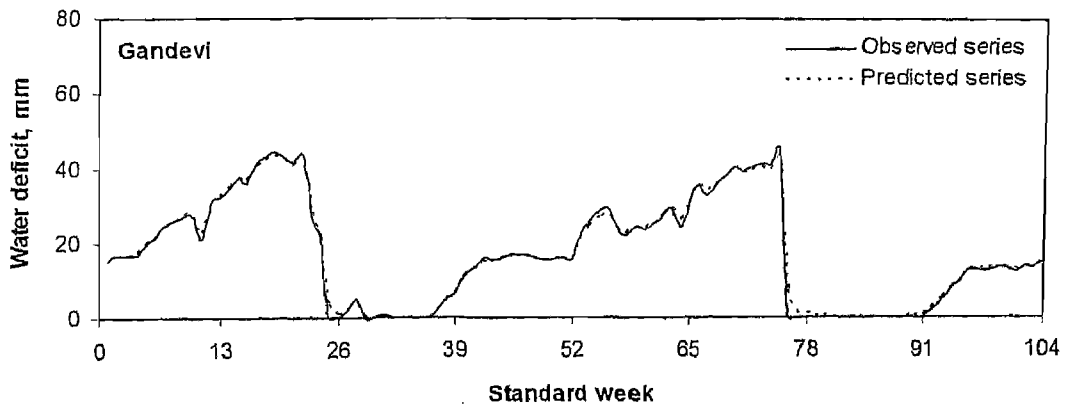
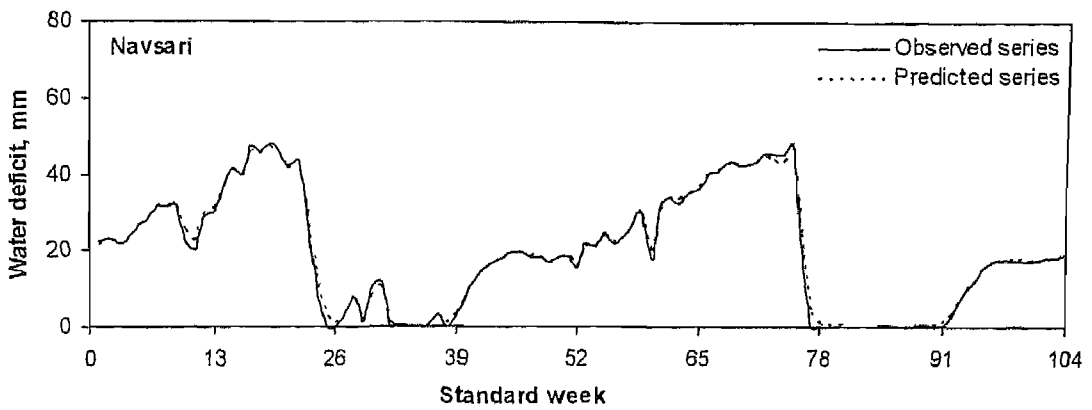
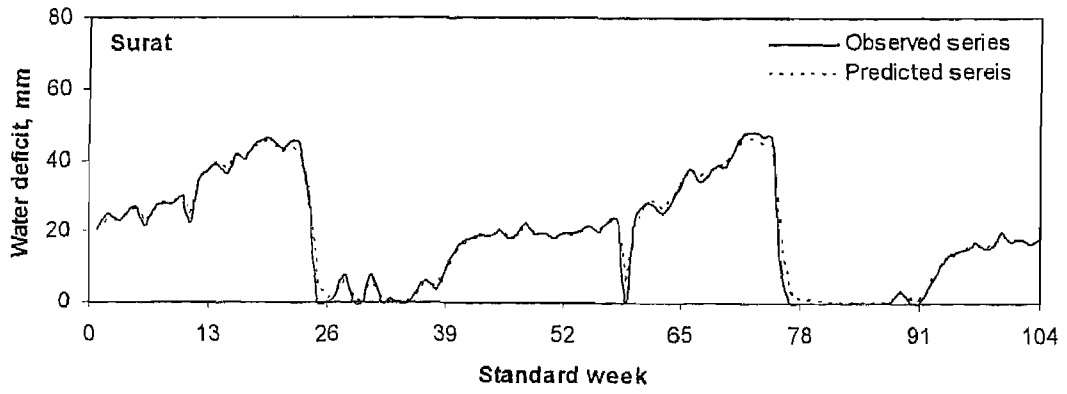
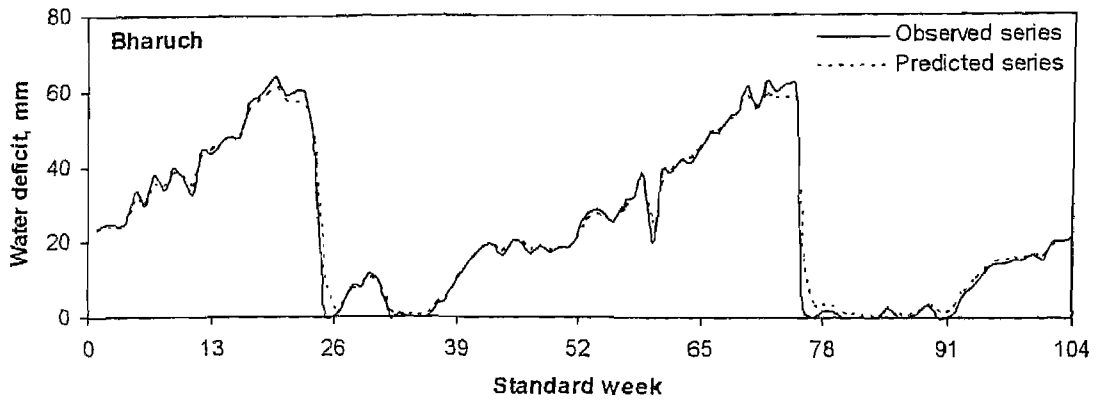


Fig. 4.20d Variation of observed and predicted weekly water deficit series for Bharuch, Surat, Navsari, and Gandevi

Table 4.33 Statistical characteristics of observed, predicted and residual weekly water deficit series at different stations

Station	Series	Mean, mm	SD, mm	Skewness	Kurtosis	Variance	ISE
Kothara	Observed	31.10	12.85	0.17	-0.26	165.14	0.0081
	Predicted	31.10	11.87	0.14	-0.18	140.89	
	Residual	0.00	2.85	-1.73	8.95	6.66	
Radhanpur	Observed	31.48	18.09	0.18	-0.47	327.35	0.0097
	Predicted	31.50	16.76	0.33	-0.62	280.81	
	Residual	-0.01	2.97	-1.14	2.81	8.80	
Rajkot	Observed	31.63	21.50	0.38	-0.66	462.41	0.0074
	Predicted	31.62	20.30	0.42	-0.75	412.18	
	Residual	0.01	3.40	-3.26	20.68	11.58	
Amreli	Observed	30.90	19.98	0.22	-0.81	399.06	0.0079
	Predicted	31.00	18.89	0.30	-0.90	356.89	
	Residual	-0.01	2.53	-1.28	3.88	6.40	
SK Nagar	Observed	26.5	16.82	0.18	-0.73	282.79	0.0134
	Predicted	26.5	15.15	0.37	-0.78	229.45	
	Residual	0.00	3.64	-1.24	6.40	13.27	
Khedbrahma	Observed	17.54	15.12	0.73	-0.58	228.57	0.0126
	Predicted	17.54	14.38	0.77	-0.58	206.78	
	Residual	0.00	2.05	-1.50	8.90	4.22	
Arnej	Observed	26.33	20.39	0.61	-0.58	415.93	0.0109
	Predicted	26.35	19.27	0.62	-0.67	371.43	
	Residual	-0.01	2.95	-1.54	10.82	8.73	
Dhandhuka	Observed	23.18	20.58	0.82	-0.49	423.48	0.0141
	Predicted	23.19	19.13	0.75	-0.73	366.11	
	Residual	-0.01	3.34	-2.31	12.03	11.17	
Junagadh	Observed	25.00	18.98	0.19	-1.27	360.29	0.0069
	Predicted	25.10	18.40	0.19	-1.29	338.49	
	Residual	-0.01	1.78	-2.06	8.60	3.16	
Mahuva	Observed	24.36	16.50	-0.07	-1.14	272.41	0.0084
	Predicted	24.36	15.53	-0.08	-1.20	241.13	
	Residual	0.00	2.27	-2.51	15.36	5.17	
Anand	Observed	20.70	16.23	0.45	-0.93	263.41	0.0122
	Predicted	20.70	15.32	0.46	-0.97	234.76	
	Residual	-0.01	2.59	-1.44	9.75	6.69	
Nawagam	Observed	24.38	18.53	0.48	-0.76	343.31	0.0131
	Predicted	24.39	17.72	0.49	-0.83	313.87	
	Residual	-0.01	1.98	-3.61	20.78	3.94	
Bharuch	Observed	24.20	20.45	0.48	-1.01	418.27	0.0091
	Predicted	24.20	19.38	0.47	-1.06	375.42	
	Residual	-0.01	2.25	-3.06	16.71	5.06	
Surat	Observed	19.3	14.98	0.26	-0.97	224.39	0.0103
	Predicted	19.3	14.56	0.25	-1.04	211.90	
	Residual	-0.01	1.32	-2.11	7.47	1.73	
Navsari	Observed	19.7	15.39	0.25	-1.06	236.82	0.0097
	Predicted	19.7	15.07	0.23	-1.12	227.10	
	Residual	-0.01	0.99	-1.12	3.35	0.98	
Gandevi	Observed	17.38	14.30	0.31	-1.07	204.55	0.0060
	Predicted	17.40	13.96	0.29	-1.12	194.76	
	Residual	-0.02	1.07	-3.37	21.65	1.15	

Table 4.34 Correlation coefficient between observed and predicted water deficit series at different stations

Station	Correlation coefficient, r	
	Series	Series mean
Kothara	0.9813	0.9932
Radhanpur	0.9884	0.9914
Rajkot	0.9884	0.9918
Amreli	0.9930	0.9964
SK Nagar	0.9794	0.9870
Khedbrahma	0.9916	0.9946
Arnej	0.9905	0.9916
Dhandhuka	0.9885	0.9900
Junagadh	0.9960	0.9966
Mahuva	0.9918	0.9956
Anand	0.9882	0.9930
Nawagam	0.9950	0.9974
Bharuch	0.9951	0.9967
Surat	0.9964	0.9973
Navsari	0.9981	0.9985
Gandevi	0.9974	0.9984

Table 4.35 Statistical analysis of fortnightly water deficit data for 1987 over Gujarat

Fortnight	F ₁	F ₂	F ₃	F ₄	F ₅	F ₆	F ₇	F ₈	F ₉	F ₁₀
Mean, mm fortnight ⁻¹	41.48	30.06	22.96	22.88	24.15	18.63	24.88	29.48	30.85	30.48
S.D., mm fortnight ⁻¹	13.53	17.52	19.40	15.88	17.19	20.38	13.87	11.77	10.94	10.75
Variance	183.16	306.99	377.42	252.23	295.83	415.45	192.52	138.71	119.89	115.72
Skewness	-0.58	-0.74	0.19	0.03	0.29	0.79	-0.01	0.31	0.53	1.22
Kurtosis	2.62	2.24	1.74	1.90	1.99	2.04	1.78	2.11	2.37	4.26
Maximum, mm fortnight ⁻¹	58.07	54.51	57.32	50.98	54.30	54.44	48.97	52.68	53.25	59.78
Minimum, mm fortnight ⁻¹	11.21	0.00	0.00	0.10	0.00	0.00	3.67	12.55	16.93	18.70
Range	46.86	54.51	57.32	50.88	54.32	54.44	45.30	40.13	36.32	41.08
Count	17	17	17	17	17	17	17	17	17	17

season) compared to ninth fortnight (end of rainy season). The non-consistency and variability of each fortnightly series is due to change of climatic factors affecting evapotranspiration process over the study area.

4.8.2 Semivariograms

The variability of water deficit estimates between any two locations can be assessed using semivariogram, a graphical representation of semivariance and lag distance. Computation of semivariance and covariance was evaluated for data spaced on irregular grid.

Values of semivariance show jumps and drops because of regional changes in climate throughout the kharif season over the study area. Computed values of semivariance at different lags were used by the software programme for generating the best fit model for each fortnight. The parameters of the fitted model such as nugget, sill, range and structure of the water deficit data are given in Table 4.36.

Table 4.36 Variogram characteristics of fitted Gaussian model for fortnightly water deficit for 1987

Fortnight	Nugget	Sill	Range
1	35.26	194.86	0.92
2	208.23	511.07	3.79
3	230.06	491.51	2.26
4	152.19	355.41	2.56
5	75.77	427.19	1.99
6	88.41	1289.72	4.89
7	5.49	284.54	1.83
8	0.00	188.14	1.59
9	5.91	148.96	1.39
10	21.98	135.75	1.30

Experimental semivariograms of different fortnights reveal that it is directionless and structured isotropic in all fortnights. Since no anisotropy in water deficit series is observed, directional variogram is same in east-west and north-south direction. Hence only one variogram is sufficient. The model variograms for different fortnights are shown in Figures 4.21a to 4.21c.

4.8.3 Kriging Estimates of the Water Deficit Model

Based on the model fitted using the semivariograms, the krigged parameters were estimated for each fortnight of the study area. Krigged estimates for the stations were computed by the package ArcGIS, using point kriging technique.

4.8.4 Isodeficit Line Map of Observed and Krigged Estimates of Water Deficit Data

The isodeficit line map of the observed and krigged estimates of fortnightly water deficit during 1987 kharif season over Gujarat were generated using geographic information system software and have been plotted for 2.5 mm interval. The isodeficit line map of observed and krigged water deficit values are shown in the Figures 4.22a to 4.22j.

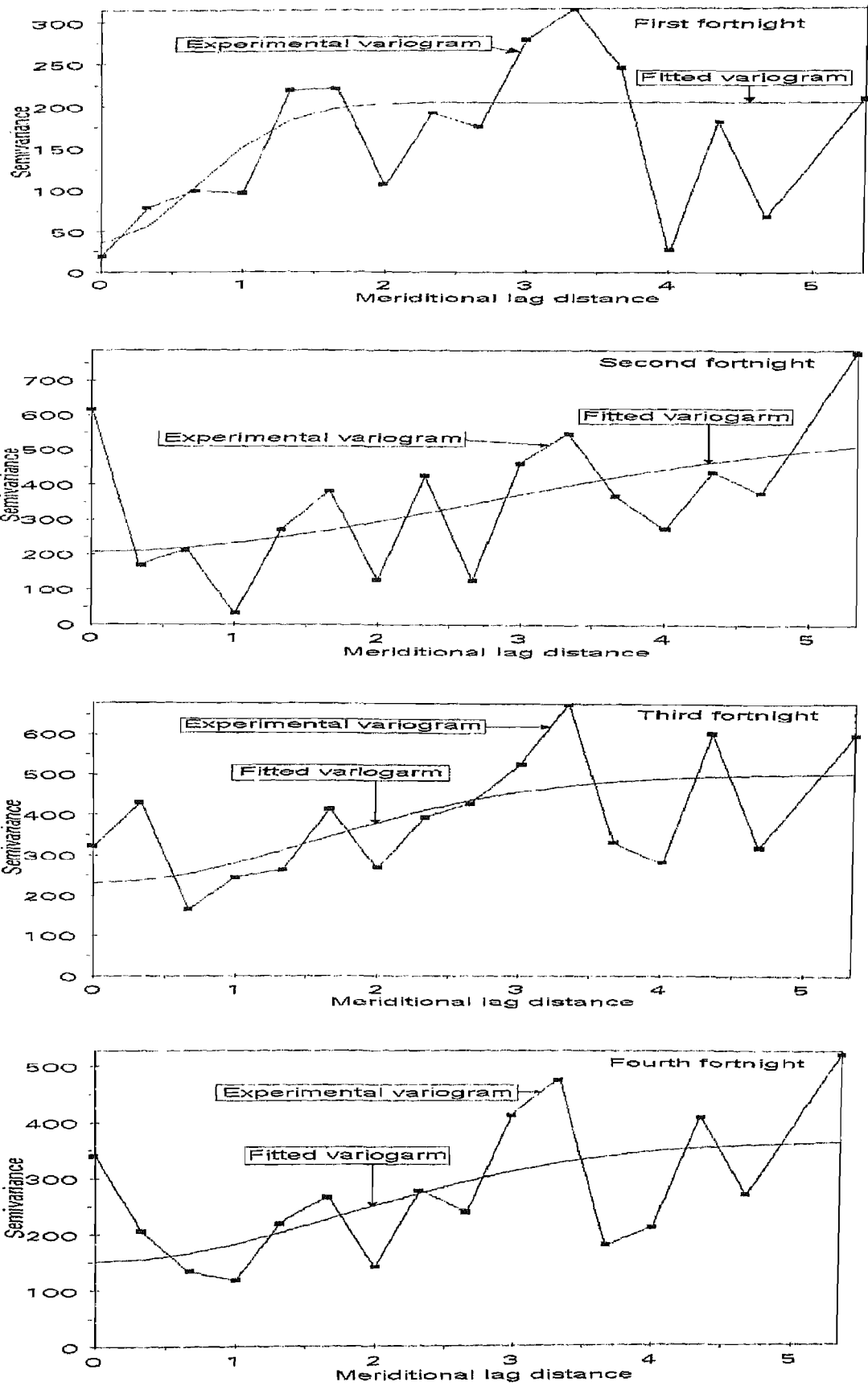


Fig. 4.21a Variogram model fitting for First, Second, Third and Fourth fortnight

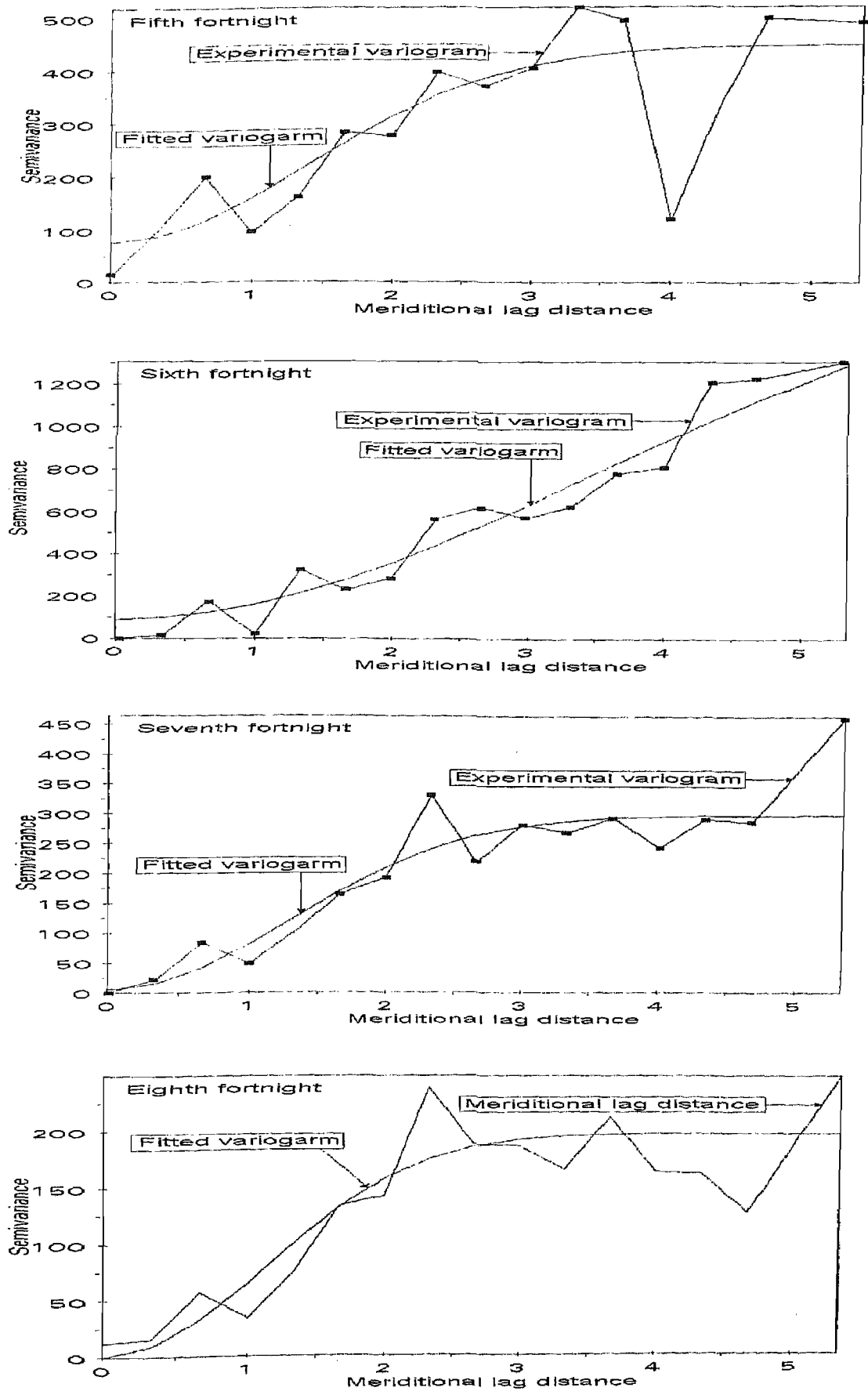


Fig. 4.21b Variogram model fitting for Fifth, Sixth, Seventh and Eighth fortnight

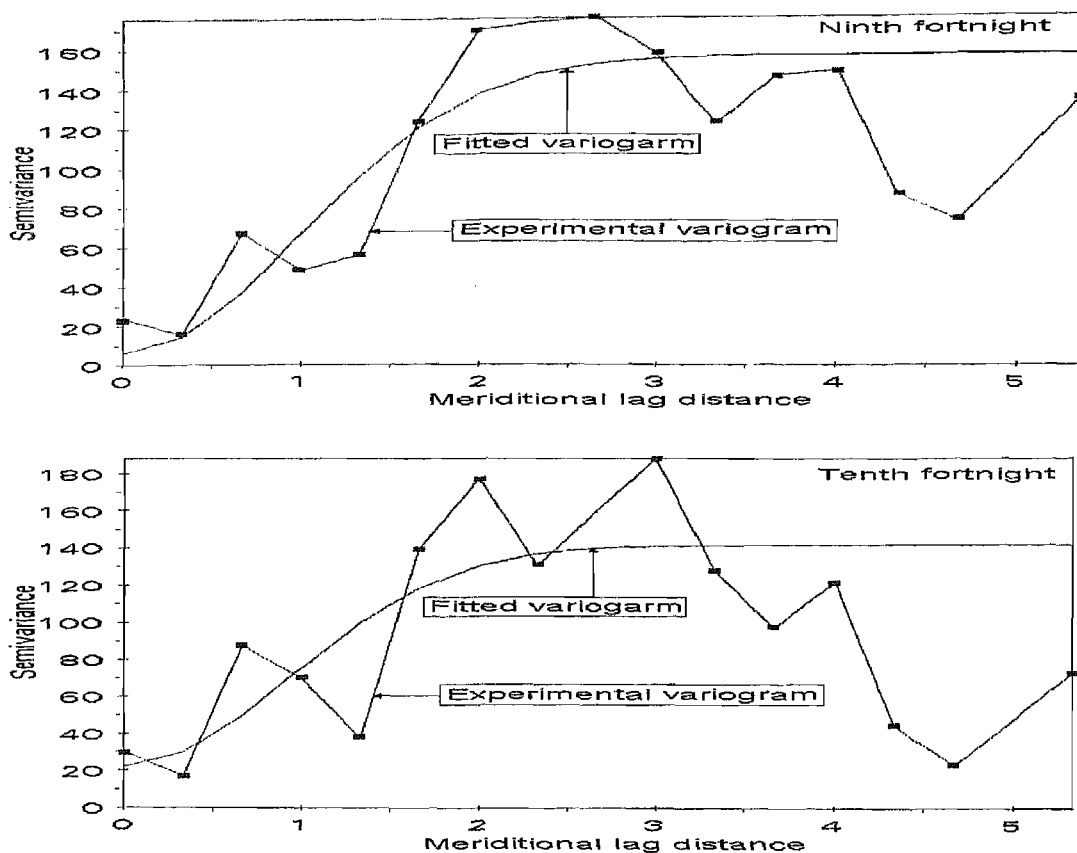


Fig. 4.21c Variogram model fitting for Ninth and Tenth fortnight

Comparison of observed and krigged isodeficit line maps as shown in Figures 4.22a to 4.22j for different fortnights indicate the spatial structure of measured and krigged water deficit over Gujarat. Spatial structure of fortnightly water deficit in krigged isodeficit line maps indicates the effect of krigged water deficit at unrecorded places by way of isolated locations of differing water deficits. However, water deficit iso-lines in observed and krigged maps of different fortnights indicate a slight variation of deficit magnitudes keeping the spatial trend almost similar to observed one. Hence, the spatial and temporal variation of water deficit during 1987 drought is studied using both the maps simultaneously.

4.8.5 Spread of 1987 Drought over Gujarat

Droughts usually do not descend all of sudden without warning, but they are usually the result of culmination of a set of a weather sequences that require extended periods of time to develop. The results of drought evaluation in Section 4.4.1 indicate that in Gujarat, often some part or the other experiences localized drought. However, in some years the whole state experiences drought conditions. Studies revealed that even in such years the drought intensity and its time of occurrence varied from zone to zone. In order to project a pattern of drought spread over Gujarat, one case study is presented, pertaining to the severe drought condition that prevailed over the state during the year 1987.

Spatial and temporal variability of water deficit during the kharif season of 1987 drought year is visualized from Figures 4.22a to 4.22j. Water deficit iso-lines for the first fortnight (23rd and 24th smw) shows the peak observed and predicted deficit values prior to onset of monsoon. Figures 4.22b and 4.22c indicate the water deficit status during starting of the monsoon season over Gujarat. Water deficit iso-lines in Figures 4.22b and 4.22c show direction of movement of monsoon over the state, which clearly indicates that monsoon begins from south Gujarat and advances in north-east, north and north-west direction. Water deficit contours on north Gujarat, north-west (Kutch) and Saurashtra regions in Figures 4.22b and 4.22c indicate inadequate monsoon rains during the normal sowing weeks (25th to 27th smw). High water deficit condition existing during 3rd fortnight (Figure 4.22c) over the parts of the state, reduced in 4th fortnight (Figure 4.22d) due to advancement of monsoon rains. However, the water deficiency in scarcity zone (Saurashtra, Kutch and North Gujarat) remained pronounced compared to other parts, where moisture status was favourable for crop growth.

Figure 4.22e indicates the beginning of the drought from Radhanpur and Rajkot region in 5th fortnight, which intensified from large to severe over the scarcity zone covering North Gujarat, Kutch and North to central Saurashtra in 6th and 7th fortnights (Figures 4.22f and 4.22g). Large to severe drought condition was further intensified in rest part of the state during 8th, 9th and 10th fortnights and continued in all agro-climatic zones of Gujarat.

The results of spatial and temporal variability of water deficit during a severe drought year clearly indicate that the occurrence and spread of drought in Gujarat State has a general tendency to originate in the water deficient region, spreads in different directions of similar deficient regions and then dissipates. The analysis thus, brings out two important facts, that the effect of drought is more discernible and occurs early in regions receiving lower rainfall and secondly, that they have an origin and follow a pattern of spread and decay. This type of analysis could be useful to pinpoint the origin and the gradual spread of drought into various regions of the state and would provide advance information to crop planners/administrators to mitigate the ill effects of such severe drought.

4.9 CROP PLANNING UNDER DIFFERENT AGRO-CLIMATIC ZONES OF GUJARAT

The selection of crops and cropping pattern for rainfed region depends on the quantum and distribution pattern of rainfall during crop growing season. It becomes essential to plan cropping sequences such that the critical crop stages escape the continuous severe dry spells safely or if not possible then to select suitable drought resistant crops. Such an analysis not only helps in identifying the risk involved in the production of a specific crop/variety in a given region but also enables to achieve sustainability of crop production. Among different

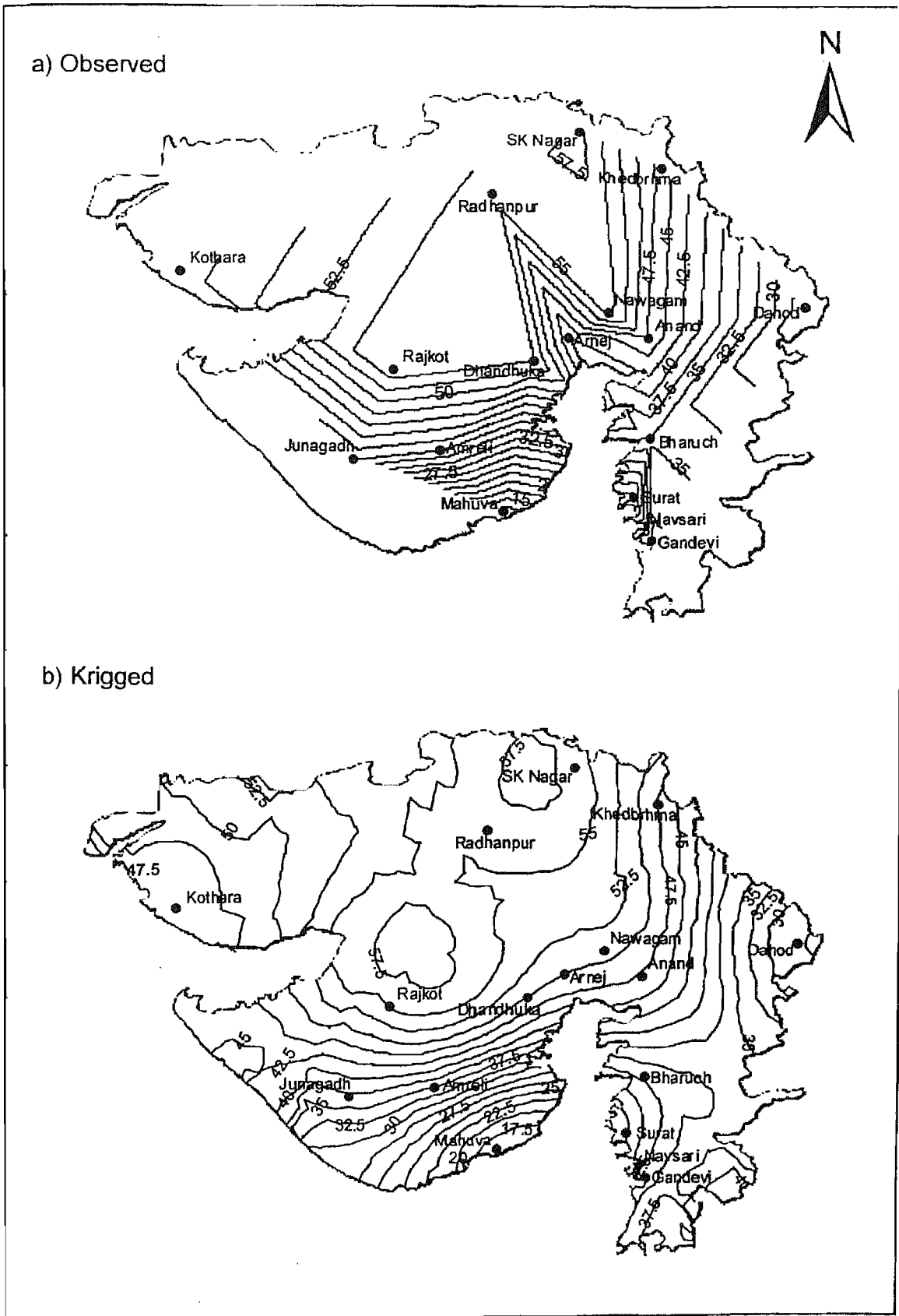
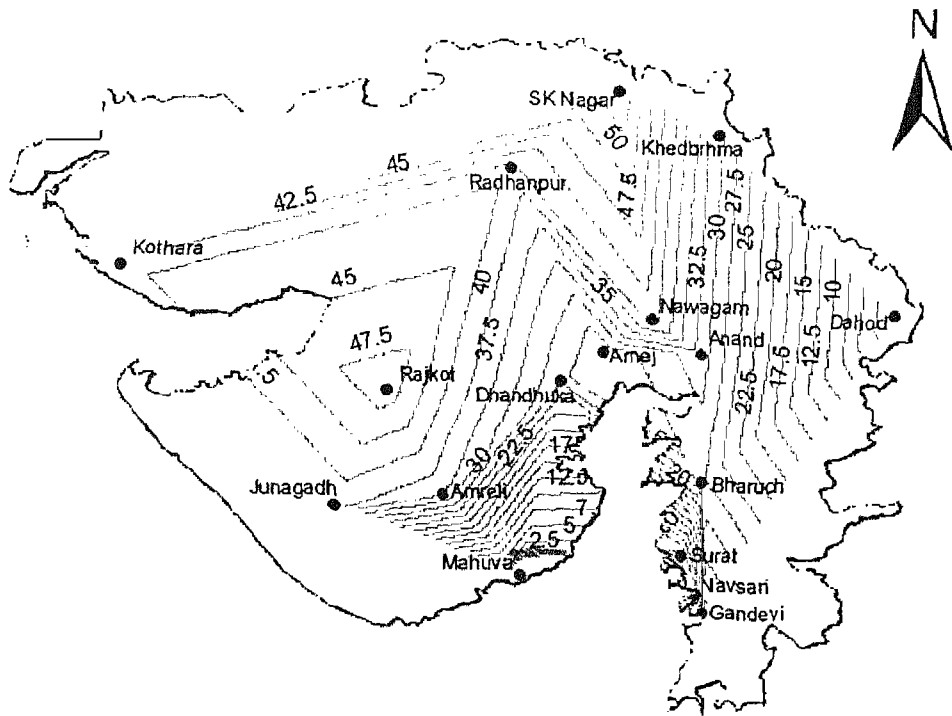


Fig. 4.22a Observed and krigged water deficit (mm) during 1st fortnight of 1987 drought year over Gujarat

a) Observed



b) Krigged

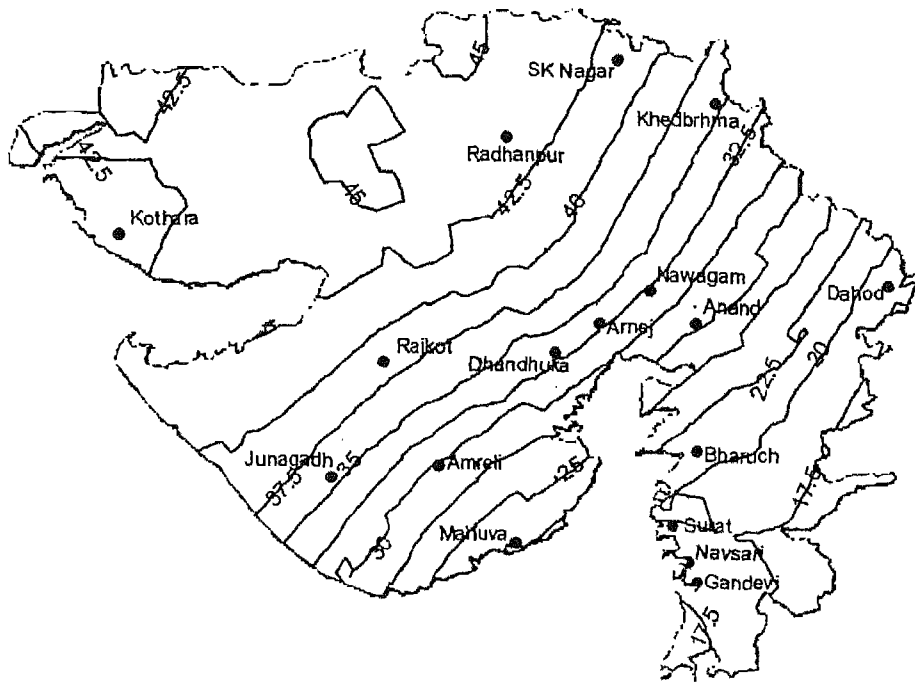
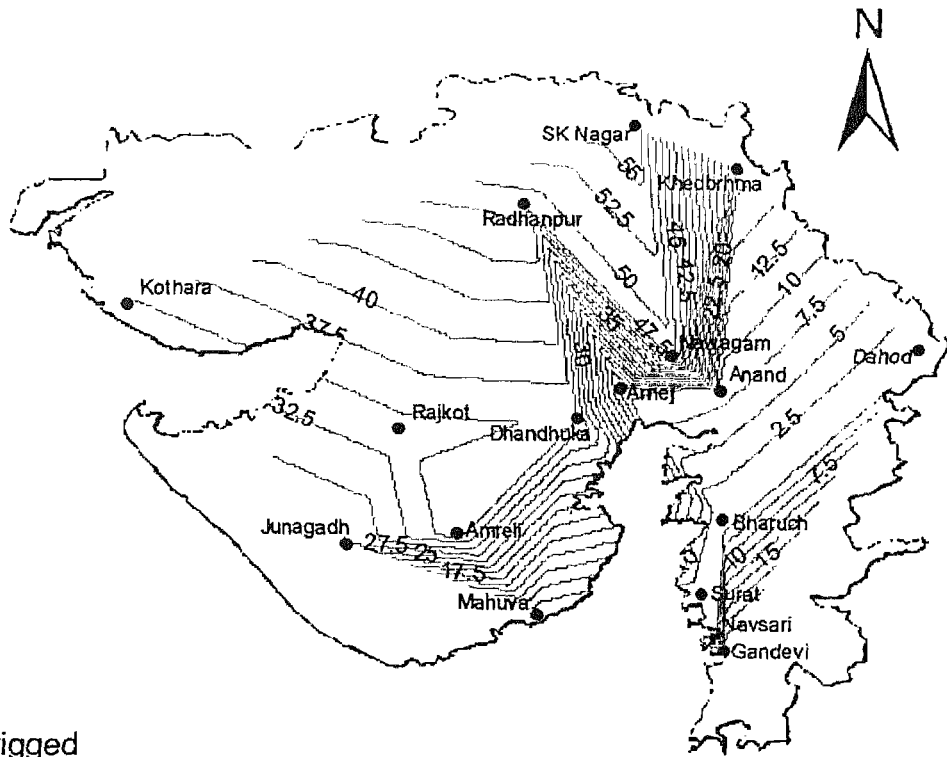


Fig. 4.22b Observed and krigged water deficit (mm) during 2nd fortnight of 1987 drought year over Gujarat

a) Observed



b) Krigged

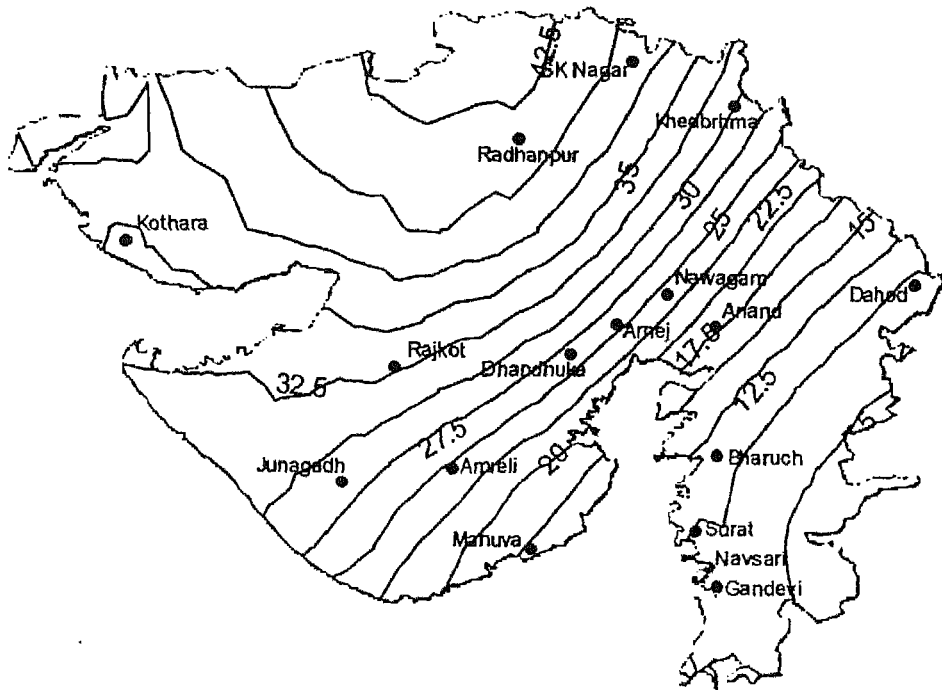


Fig. 4. 22c Observed and krigged water deficit (mm) during 3rd fortnight of 1987 drought year over Gujarat

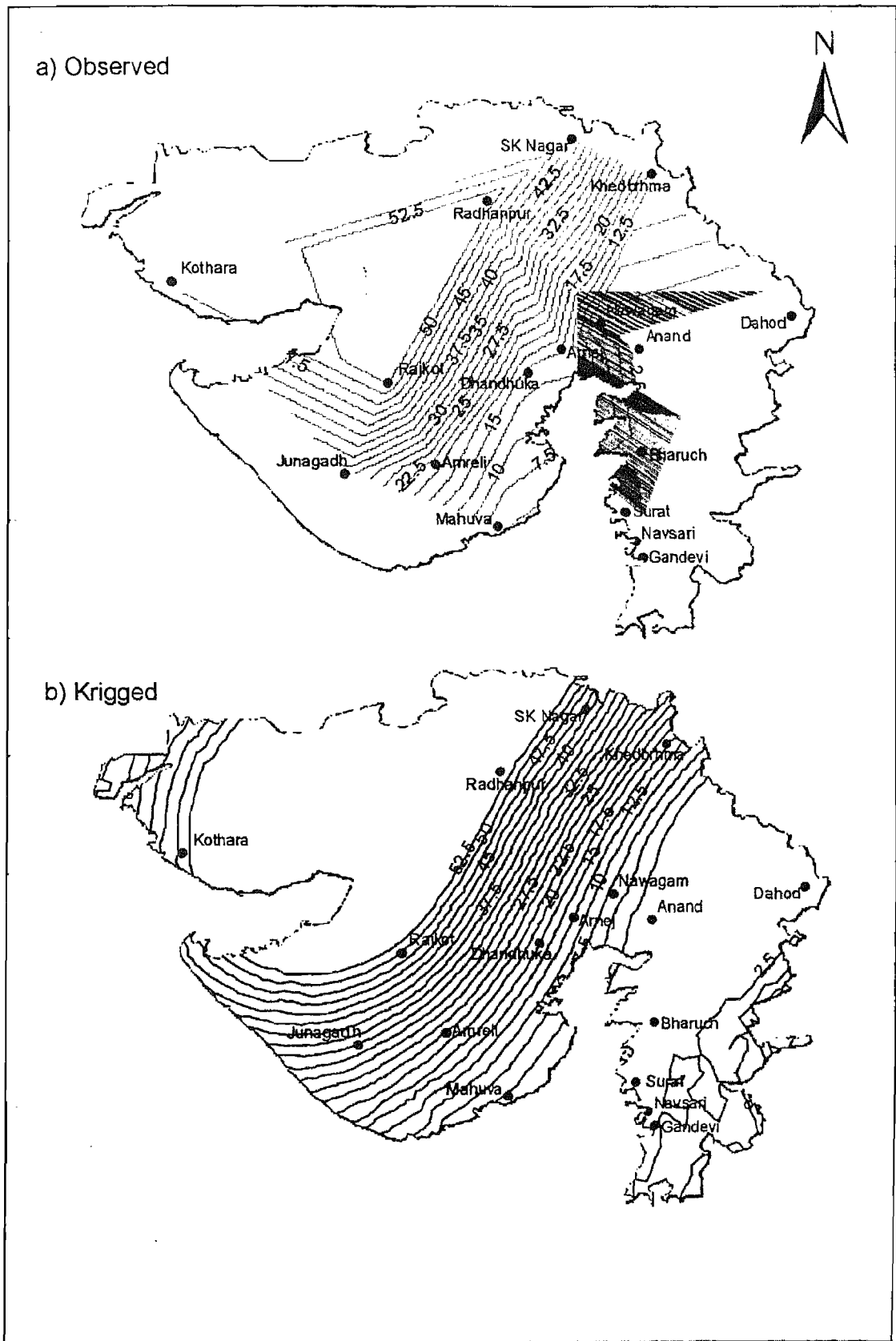


Fig. 4.22f Observed and krigged water deficit (mm) during 6th fortnight of 1987 drought year over Gujarat

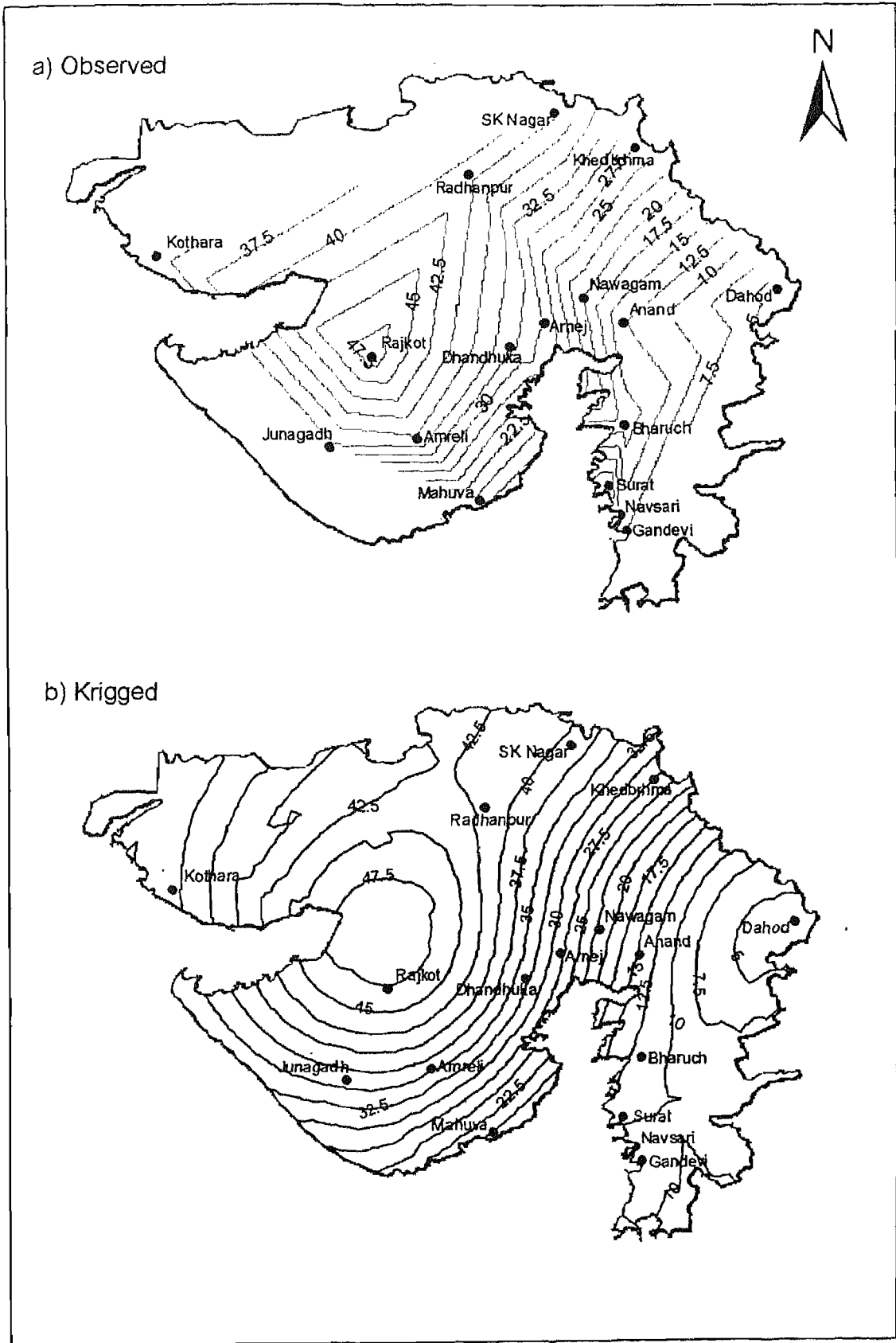


Fig. 4. 22g Observed and krigged water deficit (mm) during 7th fortnight of 1987 drought year over Gujarat

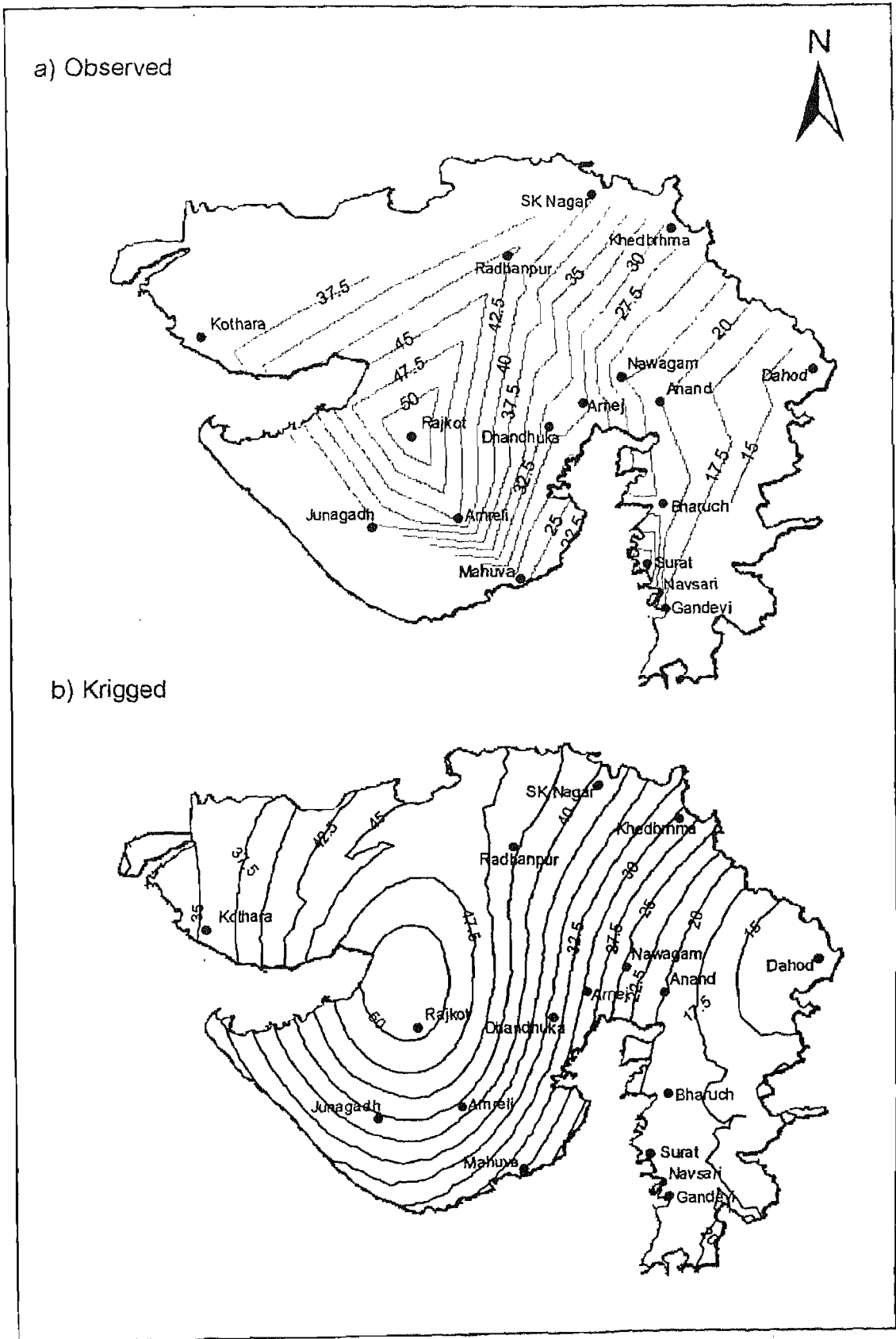


Fig. 4.22h Observed and krigged water deficit (mm) during 8th fortnight of 1987 drought year over Gujarat

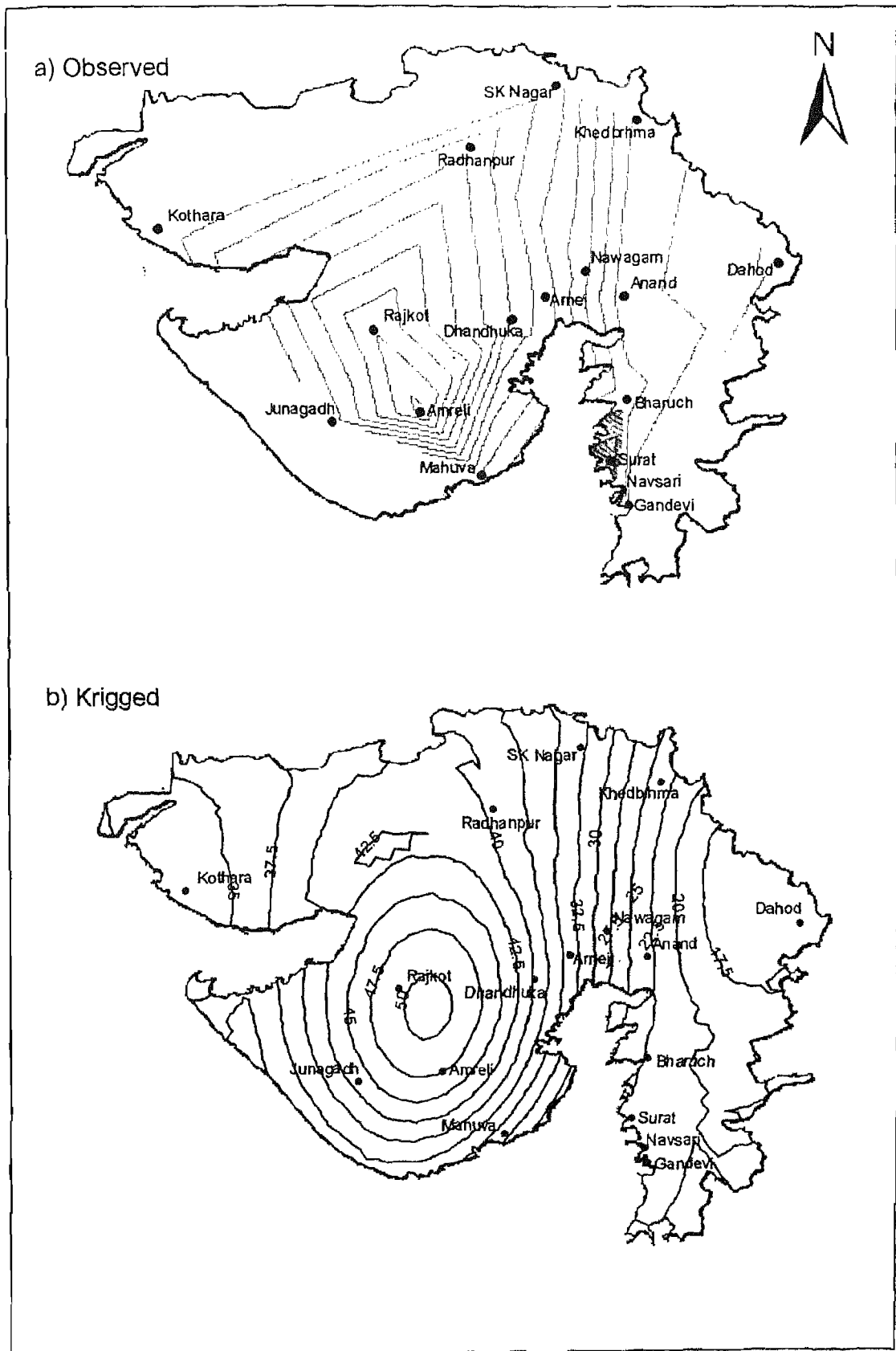


Fig. 4. 22i Observed and krigged water deficit (mm) during 9th fortnight of 1987 drought year over Gujarat

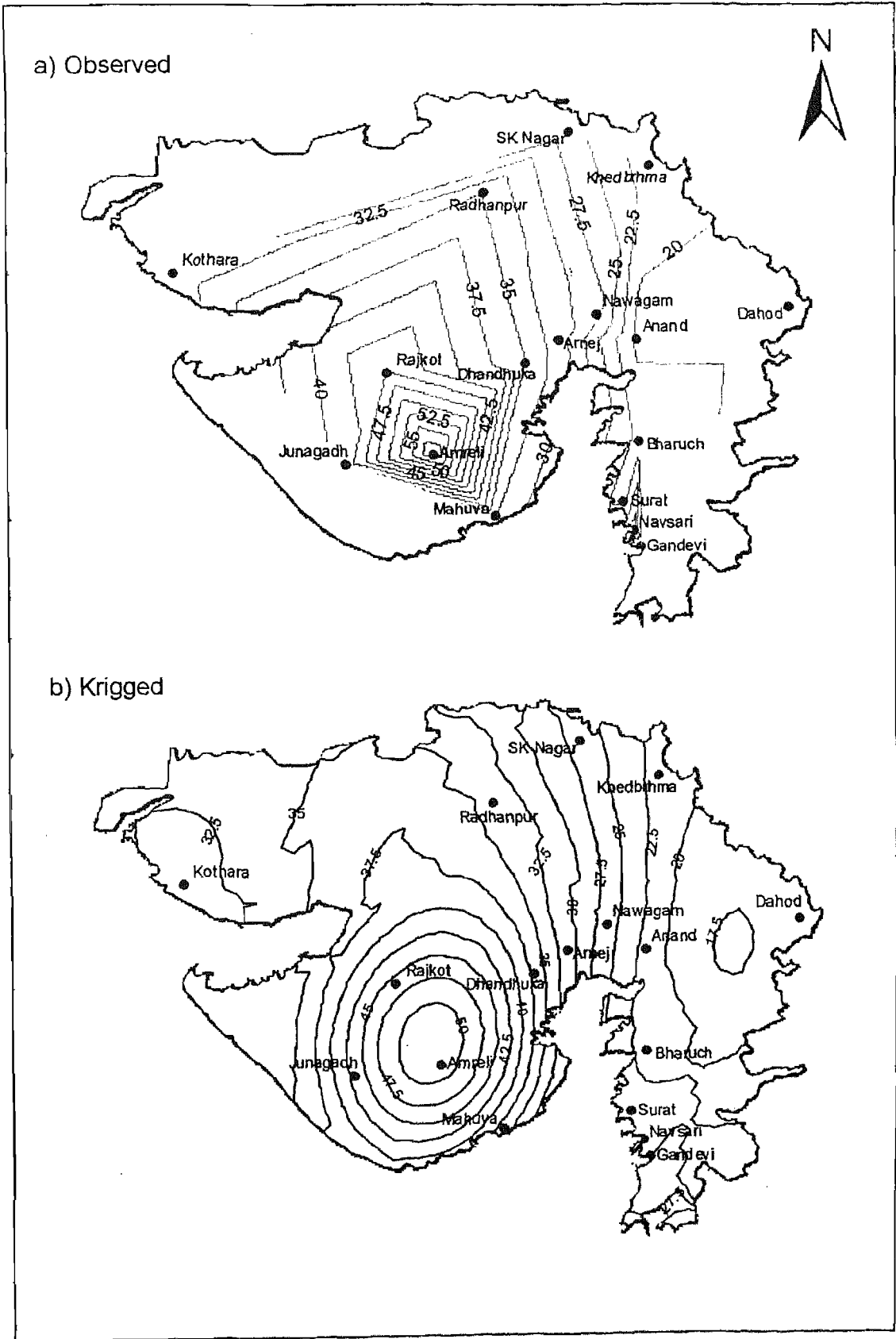


Fig. 4. 22j Observed and krigged water deficit (mm) during 10th fortnight of 1987 drought year over Gujarat

crop growth stages, flowering and grain filling periods are known to be critical (grand growth period) as far as root zone moisture is concerned (Salter and Goode, 1967). Using the results of dry spell analysis, crop planning for different agro-climatic zone is done as under:

4.9.1 Length of Growing Season

The length of growing season is computed as per Section 3.13 for different years at the selected stations. Length of growing season for different stations at 70 per cent probability of annual rainfall is obtained from Figures 4.23a to 4.23d and presented in Table 4.37.

It is observed from Figures 4.23a to 4.23d that the length of growing season (LGS) show an increasing trend with increasing annual rainfall at all the stations. Length of growing season in general varied from a minimum of 0 to 10 weeks to the maximum of 17 to 26 weeks at different stations during the study period. The LGS at 70 per cent probability at Kothara, Radhanpur, Rajkot and Amreli (Figure 4.23a) with annual rainfall of 185 mm, 225 mm, 225 mm and 375 mm was observed to be 9, 10, 11 and 13 weeks, respectively. Similarly, the LGS at 70 per cent probability at Bharuch, Surat, Navsari and Gandevi (Figure 4.23d) with annual rainfall of 615 mm, 825 mm, 1135 mm and 1215 mm was observed to be 14, 14, 15 and 15 weeks, respectively. The length of growing season for rest of the stations were observed between 12 to 14 weeks with an annual rainfall from 330 to 585 mm. Starting week of growing season was decided based on the onset of effective monsoon. Table 4.37 indicates that in south Gujarat, LGS starts two to three week earlier than that of north, north-west and Saurashtra region of the Gujarat.

4.9.2 Choice of Crops and Cropping Systems

The choice of crops and cropping systems in a region depends on the length of growing season, rainfall distribution and soil type and depth. Selected rainfed crops and cropping systems under different agro-climatic zones are presented in Table 4.38. It is seen from Table 4.38 that mono-cropping is possible in almost all the zones of the state. Double cropping is possible in South, Central and part of North Gujarat considering availability of irrigation water, soil depth and available water holding capacities. When long duration kharif crops like castor, cotton, pigeon pea, paddy, etc. are grown then only mono-cropping system is possible. Double cropping system is possible in deep soils with fair moisture holding capacities alongwith short duration kharif crops. For north-western (SK Nagar, Radhanpur and Kothara), South-western (Amreli, Rajkot and Junagadh) and Bhal and coastal (Arnej, Dhandhuka and Maluva) scarcity zones of the state, mono-cropping system based drought resistant crops are possible.

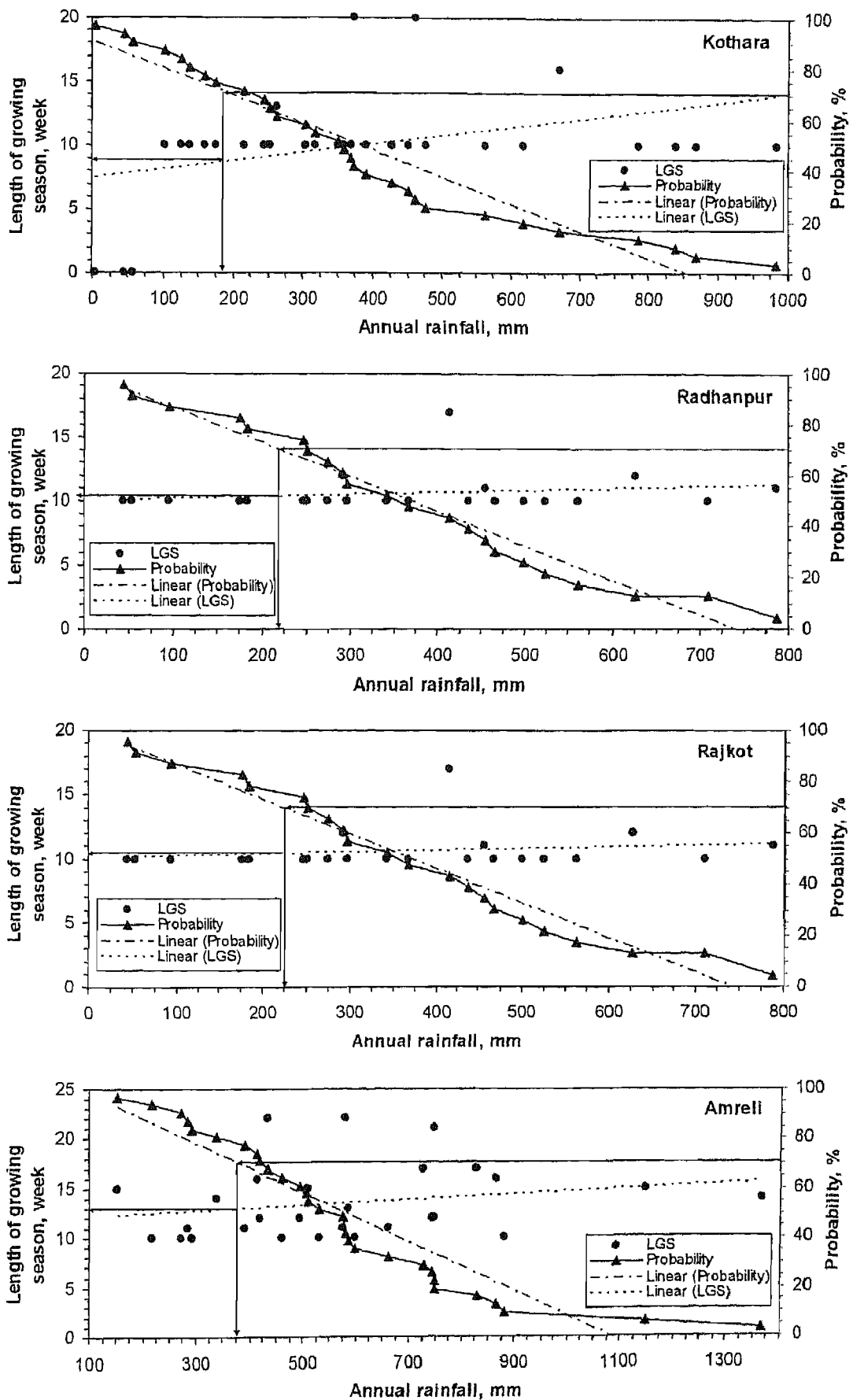


Fig. 4.23a Length of growing season at Kothara, Radhanpur, Rajkot and Amreli

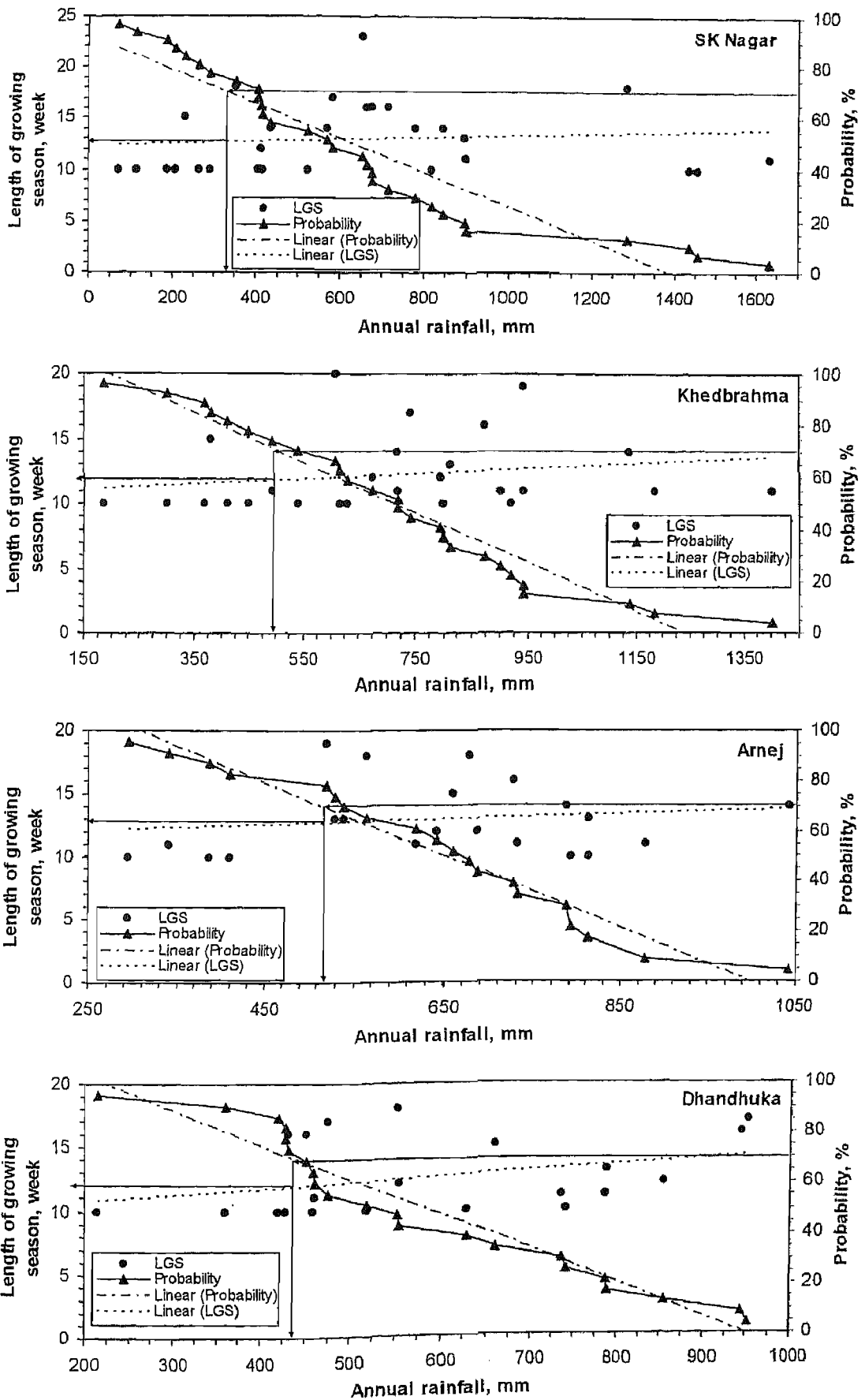


Fig. 4.23b Length of growing season at SK Nagar, Khedbrahma, Arnej and Dhandhuka

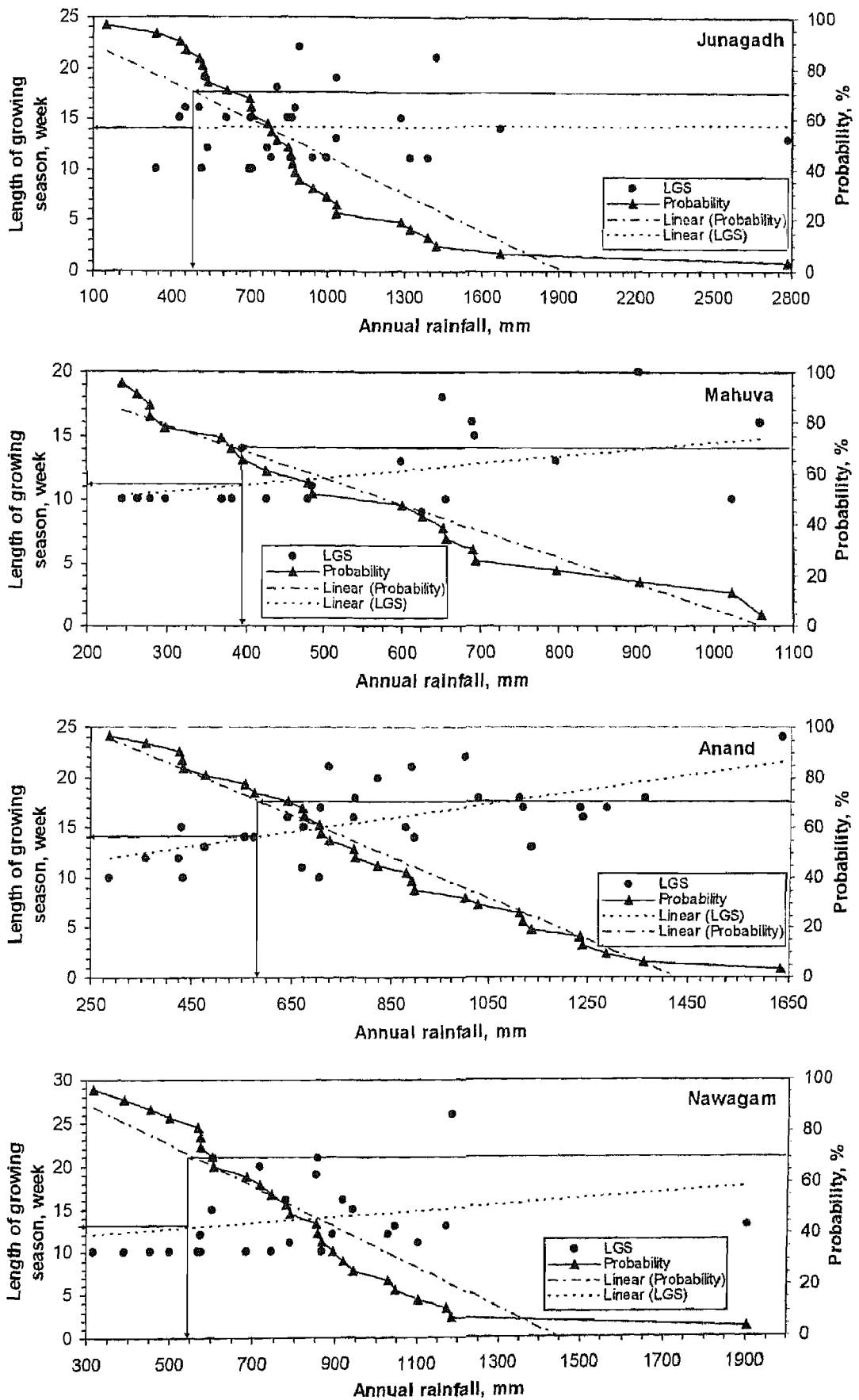


Fig. 4.23c Length of growing season at Junagadh, Mahuva, Anand and Nawagam

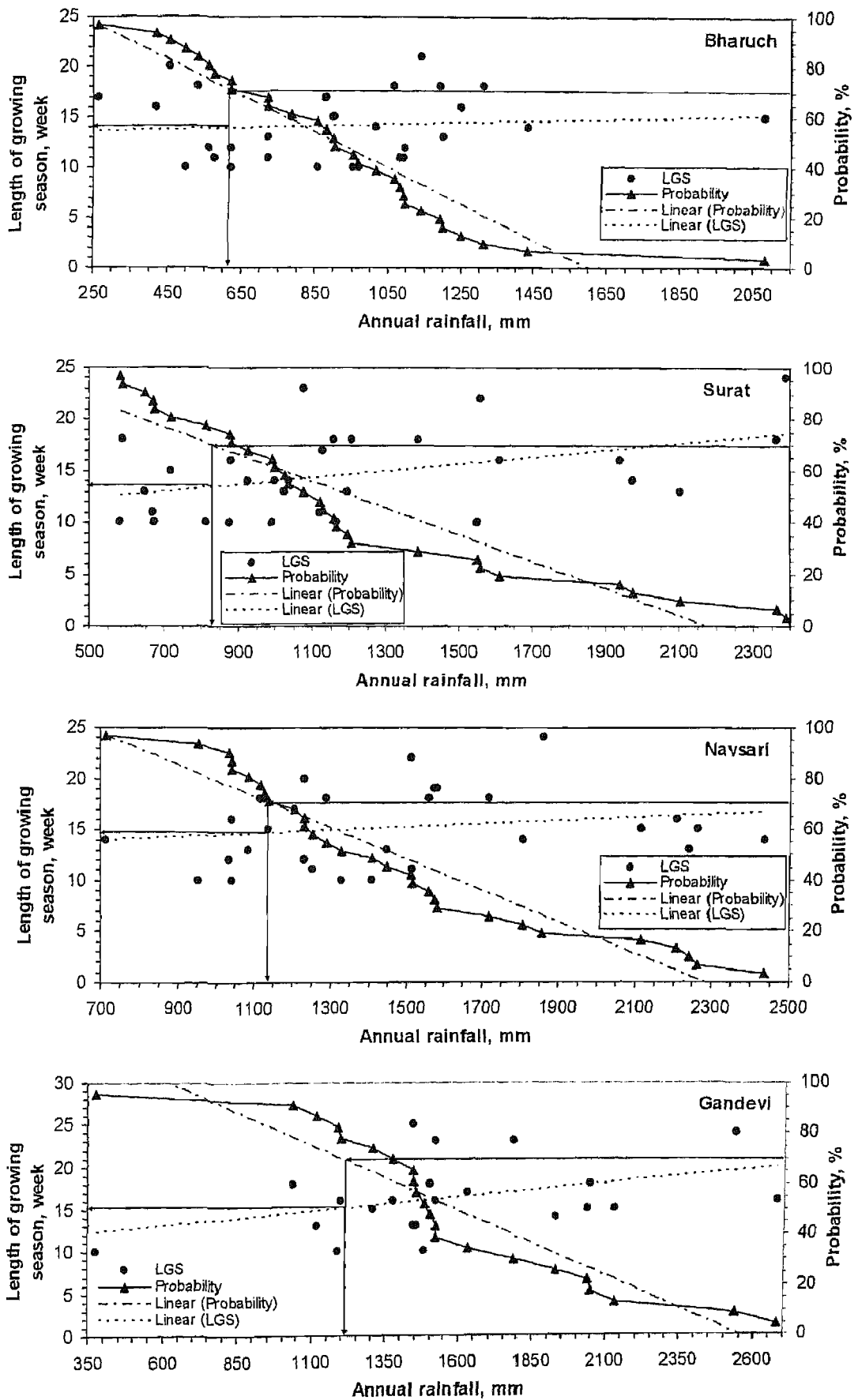


Fig. 4.23d Length of growing season at Bharuch, Surat, Navasari and Gandevi

Table 4.37 Length of growing season under different agro-climatic zones of Gujarat

Station	Starting week	Ending week	Duration, week
Kothara	28	36	9(63)
Radhanpur	28	37	10(70)
Rajkot	27	37	11(77)
Amreli	27	39	13(91)
SK Nagar	27	39	13(91)
Khedbrahma	27	38	12(84)
Arnej	26	38	13(91)
Dhandhuka	26	37	12(84)
Junagadh	26	39	14(98)
Mahuva	27	37	11(77)
Anand	26	39	14(98)
Nawagam	26	38	13(91)
Bharuch	25	38	14(98)
Surat	25	38	14(98)
Navsari	25	39	15(105)
Gandevi	25	39	15(105)

Figures in parenthesis indicate number of days.

Table 4.38 Length of growing season (LGS) and soil characteristics based suitable rainfed cropping system for Gujarat

Zone	Station	LGS(day) at 70% probability	Standard meteorological weeks of 2 week dry spell at probability of		Cropping system	Major kharif crops
			25 -50%	> 50%		
South Gujarat (Heavy rainfall)	Gandevi	105	25,38-39	23, 40-45	Mono/ Double	Paddy, Sugarcane, Sorghum and Hill millet
	Navsari	105	24-25,34, 37-39	23, 40-45	Mono/ Double	Paddy, Sugarcane, Sorghum and Cotton
South Gujarat	Surat	98	24-26,34-38	23, 39-45	Mono/ Double	Paddy, Sugarcane, Sorghum and Cotton
	Bharuch	98	24-27,30,35-38	23, 39-45	Mono/ Double	Pigeon pea, Sorghum, Cotton, Ground nut and Castor
Middle Gujarat	Anand	98	24-26, 35-36	23, 37-45	Mono/ Double	Ground nut, Pigeon pea, Sorghum, Cotton, Castor, Maize and Pearl millet
	Nawagam	91	25, 27-28,32,35	23-24, 36-45	Mono/ Double	Paddy, Ground nut, Sorghum, Cotton, and Pearl millet
North Gujarat	SK Nagar	91	27-28,30,32-33,35	23-26,34, 36-45	Mono/ Double	Castor, Pearl millet, Sorghum and Pulses
	Khedbrahma	84	24-26, 33-34	23, 35-45	Mono/ Double	Castor, Cotton, Pigeon pea, Maize, Sorghum, Pearl millet and Pulses
North-West Gujarat	Radhanpur	70	29-30	23-28, 31-45	Mono	Castor, Cotton, Pearl millet and Pulses
	Kothari	63	29-30	23-28, 31-45	Mono	Ground nut, Pearl millet and Pulses
Saurashtra	Rajkot	77	24-26,28,31-34	23, 35-45	Mono	Castor, Pearl millet, Sorghum, Ground nut and Pulses
	Amreli	91	25-27,29-34	23-24, 36-38, 40-45	Mono	Cotton, Pearl millet, Sorghum, Ground nut and Pulses
South Saurashtra	Junagadh	98	24-27,32,34,38-39	23, 35-37, 40-45	Mono/ Double	Ground nut, Castor, Cotton, Pearl millet, Sorghum and Pulses
	Mahuva	77	24-25,27-28,30,36	23,26, 33,35,37-45	Mono/ Double	Ground nut, Castor, Cotton, Pearl millet, Sorghum and Pulses
Bhal and Coastal	Arnej	91	24-28,30,32-34,36	23,35,37-45	Mono	Cotton, Ground nut, Castor, Pearl millet, Sorghum and Pulses
	Dhandhuka	84	25,28-37	23-24, 38-45	Mono	Cotton, Ground nut, Castor, Pearl millet, Sorghum and Pulses

V - SUMMARY AND CONCLUSIONS

Rainfed agriculture predominates the large part of the country in general and Gujarat in particular. In these areas with no assured irrigation facilities, complex soil-water-atmospheric exchange aggravates water supply to plants as a result of precipitation deficiency. Prolonged water deficit leads to drought, which is primarily influenced by climatic evapotranspiration process. Drought studies in a systematic manner are very few and have been done only in last few decades, generally in the countries with availability of long term hydrological and meteorological records. The precise knowledge of onset and termination of effective monsoon, dry and wet spells, magnitude of water deficit, water surplus and their spatial and temporal behaviour over the years in quantitative terms are not available and posing difficulty in analysis of drought.

Keeping this in view, the study on "Modelling of Drought Under Different Agro-climatic Zones of Gujarat" was undertaken with the objectives: (i) to analyse the rainfall pattern and estimate dry spells, (ii) to estimate the moisture status on the basis of water balance, (iii) to evaluate droughts and estimate frequencies of water deficit, (iv) to predict water deficit using artificial neural networks, (v) to develop and validate appropriate stochastic model of water deficit, (vi) to study spatial and temporal variability of water deficit using geostatistical model, and (vii) to plan suitable cropping pattern on the basis of drought analysis.

The climatic data of rainfall, air temperature, relative humidity, wind velocity and bright sunshine hours for a period of 30 years (1974 to 2003) for Kothara, Amreli, SK Nagar, Junagadh, Anand, Bharuch, Surat, and Navsari; for 26 years (1978-2003) for Rajkot, Khedbrahma and Nawagam and for 22 years for Radhanpur, Arnej, Dhandhuka, Mahuva, and Gandevi, respectively, were collected from Meteorological Observatories of the respective Agricultural Research Stations of the Gujarat Agricultural University. Soil data were obtained from a joint publication of the Gujarat Agricultural University, Navsari and National Bureau of Soil Survey and Land Use Planning, Regional Centre, Udaipur.

The rainfall data were analysed for annual, seasonal and weekly pattern and onset and withdrawal of rainy season. Initial and conditional probabilities of dry and wet spell were determined by Markov-Chain process. Weekly reference evapotranspiration values were estimated by Penman-Monteith equation. Water balance components were determined by Thornthwaite and Mather book keeping technique. The drought is characterized considering aridity index (I_a) anomalies estimated on weekly and annual basis by determining its intensity and duration. Extreme weekly water deficit data during kharif season was analysed using various distributions to find out the best probability distribution for each zone. Water deficit data were also analysed to develop and validate appropriate Artificial Neural Network

models and stochastic models. Geostatistical approach was used to study the drought spread by producing contour maps to understand spatial and temporal variability of water deficit over the region. Suitable crops and cropping systems were suggested based on the results obtained in the study. The results of the study are summarized as follows:

Results of rainfall analysis of different agro-climatic zones indicated that average annual rainfall varied from 368.74 mm at Radhanpur to 1580.53 mm at Gandevi with coefficient of variation of 54.94 and 32.25 per cent, respectively. Mean seasonal rainfall received from June to September ranged between 337.68 mm at Kothara to 1541.33 mm at Gandevi. Maximum and minimum mean weekly rainfall during monsoon season ranged from 6.91 to 197.55 mm and 2.10 mm to 42.48 mm, respectively in different agro-climatic zones.

Onset of effective monsoon under normal condition is expected by 25th standard meteorological week (smw) in south Gujarat i.e. Gandevi, Navsari, Surat and Bharuch with a probability of 43.5, 38.7, 41.9 and 38.7 per cent; by 26th smw at Arnej, Junagadh, Anand and Nawagam with a probability of 60.9, 58.1, 45.2 and 40.7 percent; by 27th smw at Rajkot, Amreli, SK Nagar, Khedbrahma, Dhandhuka and Mahuva with a probability of 51.8, 54.8, 41.9, 48.1, 65.2 and 52.2 percent and by 28th smw at Kothara and Radhanpur with a probability of 29.0 and 34.8 percent, respectively. Similarly, withdrawal of monsoon is expected in 36th smw at Kothara and Radhanpur with 54.8 and 56.6 percent probability; in 38th smw at Rajkot, Khedbrahma, Arnej and Mahuva with 51.8, 48.1, 43.5 and 47.9 percent probability; in 39th smw at Amreli, SK Nagar, Dhandhuka, Junagadh, Anand, Nawagam, Bharuch, Surat and Gandevi with 41.9, 51.6, 52.2, 41.9, 58.1, 55.5, 51.6, 48.4 and 43.5 percent probability and in 40th smw at Navsari with 45.2 percent probability, respectively. Results of dry spell analysis indicated that mid season droughts are likely to occur with 26 to 50 percent probabilities at Junagadh, Anand, Nawagam, Bharuch, Surat and Navsari; with 51 to 75 per cent probability at Rajkot, Amreli, SK Nagar, Khedbrahma, Arnej, Dhandhuka and Mahuva, and < 25 per cent probability at Gandevi. Kothara and Radhanpur experienced mid season droughts on regular basis with high probability. The possibilities of late season droughts during maturity period are high (> 50%) at all the stations except Gandevi, where it is 25 percent.

The mean annual reference evapotranspiration in different zones was found to vary from 1437.31 mm with CV of 5.10 percent at Gandevi to 2026.55 mm with CV of 9.05 percent at Rajkot. Whereas, seasonal reference evapotranspiration values at Kothara, Radhanpur, Rajkot, Amreli, SK Nagar, Khedbrahma, Arnej, Dhandhuka, Junagadh, Mahuva, Anand, Nawagam, Bharuch, Surat, Navsari, and Gandevi were found to be 631.46 mm, 693.89 mm, 655.59 mm, 598.51 mm, 658.17 mm, 510.28 mm, 641.65 mm, 634.17 mm, 114.08 mm, 557.97 mm, 563.52 mm, 584.50 mm, 548.70 mm, 530.51 mm, 429.36 mm and 68.97 mm, respectively. The result of annual moisture status in different zones indicated that

high water deficit prevailed during driest year followed by normal and wettest year. The weekly water deficit during active crop growing period at Kothara, Radhanpur, Rajkot and Amreli varies from 13.73 to 25.44 mm, 12.08 to 24.94 mm, 5.80 to 16.02 and 6.84 to 14.00 mm; at SK Nagar, Khedbrahma, Arnej and Dhandhuka varies from 7.16 to 18.30 mm, 1.76 to 11.81 mm, 4.24 to 11.91 mm and 5.28 to 12.79 mm; at Junagadh, Mahuva, Anand and Nawagam varies from 2.16 to 7.47 mm, 4.74 to 13.01 mm, 1.95 to 8.35 mm and 1.56 to 10.09 mm and at Bharuch, Surat, Navsari and Gandevi varies between 2.08 to 6.82 mm, 0.80 to 5.98 mm, 0.86 to 3.31 mm and 0.08 to 2.62 mm, respectively. The results for different agro-climatic zones indicate that under normal condition, moisture status at all the stations situated in half of the eastern part of the state (Khedbrahma, Anand, Nawagam, Bharuch, Surat, Navsari and Gandevi) is sufficient for satisfactory growth of rainfed crops, whereas, all the stations located in the other half (western part, includes SK Nagar, Arnej, Dhandhuka, Mahuva, Junagadh, Radhanpur and Kothara) experienced moisture deficit during the crop growth period. Climatic shift study at station under consideration indicated that Kothara and Radhanpur (North-West Gujarat) were found to be predominantly in arid climate, Bharuch, Surat, Navsari and Gandevi (South Gujarat) in humid (dry sub-humid to humid) climate and rest of the stations in semi-arid climatic condition. Results of surplus water availability in different agro-climatic zones clearly indicated that there are chances of getting excess water in rainy season in all the zones, which can be effectively harvested and used in water deficit periods.

Drought evaluation study revealed that total drought years vary from 9 to 15 during the study period in different zones, indicating the frequency of one drought year in every two to three years. Analysis of drought years indicated that drought does not occur simultaneously in all the agro-climatic zones but usually occur sporadically all over the state. However, during some years, all the zones experienced droughts of varying intensity. The results indicated that droughts are common not only in arid and semi-arid climate but equally occur even with higher frequency in dry sub-humid climate also. The cumulative deviation values of the drought year in different agro-climatic zones in general indicate that different category droughts of varying durations prevail simultaneously all over the state. Chi-square test of best fit frequency distributions indicated that log Pearson type-III distribution was the best probability model for predicting weekly maximum water deficit during crop growing season at all the stations except Dhandhuka, Junagadh, Mahuva, Nawagam and Surat, where Weibull (maxima) distribution and at Kothara Gumbel distribution fitted best.

Artificial Neural Networks technique was used for estimation of weekly water deficit for the selected agro-climatic zones. It was observed that the ANN predicted water deficit (DEF_{ANN}) and observed water deficit (DEF) shows similar trend for all the weeks for different stations. Highly significant values of correlation coefficient of the regression analysis for

different stations indicated that the network has accurately estimated the water deficit and the provided 7-4-1 architecture is adequate for the network. The trained network, validated for the year 2003 shown that the ANN has predicted water deficit reasonably accurate for all the stations.

Stochastic models for the selected stations were developed for weekly water deficit series by using data set vary from 20 to 28 years. Turning point test and Kendall's rank correlation test indicated that the annual time series of the water deficit was trend free. One of two, three or four harmonics were found to be significant in weekly water deficit series for different stations. Periodic component was modeled by Fourier series. The developed autoregressive stochastic models for weekly water deficit are expressed as under:

Kothara

$$(DEF)_W = 31.12 - 2.85\text{Cos}(2\pi t/p) + 11.64\text{Sin}(2\pi t/p) - 5.08\text{Cos}(4\pi t/p) \\ + 7.62\text{Sin}(4\pi t/p) + 0.77\text{Cos}(6\pi t/p) + 2.59\text{Sin}(6\pi t/p) \\ + 0.646S_{t-1} + 0.196S_{t-2} + a_t$$

Radhanpur

$$(DEF)_W = 32.73 - 5.60\text{Cos}(2\pi t/p) + 13.93\text{Sin}(2\pi t/p) - 4.48\text{Cos}(4\pi t/p) \\ - 10.38\text{Sin}(4\pi t/p) - 0.07\text{Cos}(6\pi t/p) + 4.58\text{Sin}(6\pi t/p) \\ + 0.652S_{t-1} + 0.200S_{t-2} + a_t$$

Rajkot

$$(DEF)_W = 30.71 - 2.49\text{Cos}(2\pi t/p) + 19.22\text{Sin}(2\pi t/p) - 4.59\text{Cos}(4\pi t/p) \\ - 11.99\text{Sin}(4\pi t/p) + 2.06\text{Cos}(6\pi t/p) + 4.05\text{Sin}(6\pi t/p) \\ - 2.51\text{Cos}(8\pi t/p) + 1.67\text{Sin}(8\pi t/p) + 0.605S_{t-1} + 0.256S_{t-2} + a_t$$

Amreli

$$(DEF)_W = 28.74 - 0.50\text{Cos}(2\pi t/p) + 17.73\text{Sin}(2\pi t/p) - 5.75\text{Cos}(4\pi t/p) \\ - 10.26\text{Sin}(4\pi t/p) + 1.97\text{Cos}(6\pi t/p) + 2.08\text{Sin}(6\pi t/p) - 2.84\text{Cos}(8\pi t/p) \\ + 0.22\text{Sin}(8\pi t/p) + 0.691S_{t-1} + 0.172S_{t-2} + 0.008S_{t-3} + a_t$$

SK Nagar

$$(DEF)_W = 26.23 - 6.4\text{Cos}(2\pi t/p) + 14.23\text{Sin}(2\pi t/p) - 3.63\text{Cos}(4\pi t/p) \\ - 9.54\text{Sin}(4\pi t/p) - 0.28\text{Cos}(6\pi t/p) + 4.52\text{Sin}(6\pi t/p) + 1.1\text{Cos}(8\pi t/p) \\ - 1.49\text{Sin}(8\pi t/p) + 0.643S_{t-1} + 0.197S_{t-2} + a_t$$

Khedbrahma

$$(DEF)_W = 20.19 - 2.95\text{Cos}(2\pi t/p) + 14.89\text{Sin}(2\pi t/p) - 3.85\text{Cos}(4\pi t/p) \\ - 9.45\text{Sin}(4\pi t/p) + 1.12\text{Cos}(6\pi t/p) + 4.41\text{Sin}(6\pi t/p) - 1.45\text{Cos}(8\pi t/p) \\ - 1.76\text{Sin}(8\pi t/p) + 0.726S_{t-1} + 0.143S_{t-2} + a_t$$

Arnej

$$(DEF)_W = 26.28 - 2.78\text{Cos}(2\pi t/p) + 19.79\text{Sin}(2\pi t/p) - 4.42\text{Cos}(4\pi t/p) \\ - 11.15\text{Sin}(4\pi t/p) + 1.68\text{Cos}(6\pi t/p) + 3.55\text{Sin}(6\pi t/p) - 2.04\text{Cos}(8\pi t/p) \\ - 1.31\text{Sin}(8\pi t/p) + 0.656S_{t-1} + 0.223S_{t-2} + a_t$$

Dhandhuka

$$(DEF)_W = 26.47 - 2.57\text{Cos}(2\pi t/p) + 17.95\text{Sin}(2\pi t/p) - 5.04\text{Cos}(4\pi t/p) \\ - 9.79\text{Sin}(4\pi t/p) + 1.70\text{Cos}(6\pi t/p) + 2.65\text{Sin}(6\pi t/p) \\ + 0.608S_{t-1} + 0.246S_{t-2} + a_t$$

Junagadh

$$\begin{aligned}(\text{DEF})_w = & 24.78 - 2.88\text{Cos}(2\pi t/p) + 18.95\text{Sin}(2\pi t/p) - 5.46\text{Cos}(4\pi t/p) \\ & - 9.80\text{Sin}(4\pi t/p) + 1.93\text{Cos}(6\pi t/p) + 1.23\text{Sin}(6\pi t/p) - 2.35\text{Cos}(8\pi t/p) \\ & - 0.52\text{Sin}(8\pi t/p) + 0.701S_{t-1} + 0.20S_{t-2} + a_t\end{aligned}$$

Mahuva

$$\begin{aligned}(\text{DEF})_w = & 24.89 + 1.92\text{Cos}(2\pi t/p) + 14.97\text{Sin}(2\pi t/p) - 3.12\text{Cos}(4\pi t/p) \\ & - 7.53\text{Sin}(4\pi t/p) + 0.583S_{t-1} + 0.287S_{t-2} + a_t\end{aligned}$$

Anand

$$\begin{aligned}(\text{DEF})_w = & 20.66 - 2.27\text{Cos}(2\pi t/p) + 15.73\text{Sin}(2\pi t/p) - 4.13\text{Cos}(4\pi t/p) \\ & - 9.12\text{Sin}(4\pi t/p) + 0.98\text{Cos}(6\pi t/p) + 3.39\text{Sin}(6\pi t/p) - 1.34\text{Cos}(8\pi t/p) \\ & - 1.14\text{Sin}(8\pi t/p) + 0.617S_{t-1} + 0.253S_{t-2} + a_t\end{aligned}$$

Nawagam

$$\begin{aligned}(\text{DEF})_w = & 23.27 - 2.91\text{Cos}(2\pi t/p) + 17.36\text{Sin}(2\pi t/p) - 3.23\text{Cos}(4\pi t/p) \\ & - 10.65\text{Sin}(4\pi t/p) + 1.36\text{Cos}(6\pi t/p) + 4.40\text{Sin}(6\pi t/p) - 1.03\text{Cos}(8\pi t/p) \\ & - 1.47\text{Sin}(8\pi t/p) + 0.690S_{t-1} + 0.180S_{t-2} + a_t\end{aligned}$$

Bharuch

$$\begin{aligned}(\text{DEF})_w = & 21.71 - 0.765\text{Cos}(2\pi t/p) + 18.02\text{Sin}(2\pi t/p) - 4.93\text{Cos}(4\pi t/p) \\ & - 9.07\text{Sin}(4\pi t/p) + 2.09\text{Cos}(6\pi t/p) + 2.79\text{Sin}(6\pi t/p) - 2.31\text{Cos}(8\pi t/p) \\ & - 0.40\text{Sin}(8\pi t/p) + 0.701S_{t-1} + 0.175S_{t-2} + a_t\end{aligned}$$

Surat

$$\begin{aligned}(\text{DEF})_w = & 20.50 + 1.03\text{Cos}(2\pi t/p) + 17.14\text{Sin}(2\pi t/p) - 4.656\text{Cos}(4\pi t/p) \\ & - 7.69\text{Sin}(4\pi t/p) + 2.16\text{Cos}(6\pi t/p) + 2.12\text{Sin}(6\pi t/p) - 2.25\text{Cos}(8\pi t/p) \\ & - 0.67\text{Sin}(8\pi t/p) + 0.769S_{t-1} + 0.127S_{t-2} + a_t\end{aligned}$$

Navsari

$$\begin{aligned}(\text{DEF})_w = & 19.73 + 2.39\text{Cos}(2\pi t/p) + 17.42\text{Sin}(2\pi t/p) - 4.75\text{Cos}(4\pi t/p) \\ & - 7.84\text{Sin}(4\pi t/p) + 2.29\text{Cos}(6\pi t/p) + 1.61\text{Sin}(6\pi t/p) - 2.64\text{Cos}(8\pi t/p) \\ & - 0.09\text{Sin}(8\pi t/p) + 0.791S_{t-1} + 0.113S_{t-2} + a_t\end{aligned}$$

Gandevi

$$\begin{aligned}(\text{DEF})_w = & 16.74 + 0.499\text{Cos}(2\pi t/p) + 16.244\text{Sin}(2\pi t/p) - 3.873\text{Cos}(4\pi t/p) \\ & - 7.464\text{Sin}(4\pi t/p) + 2.07\text{Cos}(6\pi t/p) + 1.70\text{Sin}(6\pi t/p) - 2.557\text{Cos}(8\pi t/p) \\ & - 0.135\text{Sin}(8\pi t/p) + 0.782S_{t-1} + 0.123S_{t-2} + a_t\end{aligned}$$

Highly significant values of correlation coefficient between observed and predicted weekly water deficit series (0.9794 to 0.9981) for two years ahead (2002 and 2003) indicated the adequacy of developed stochastic models for different agro-climatic zones.

Spatial and temporal variability of water deficit (drought pattern) during 1987, the severe most drought year, was studied using geostatistical modelling technique. Fortnightly water deficits of 17 meteorological stations that represent as point samples were interpolated applying kriging technique to generate estimates for non-sampled points. Applying variogram, the spatial structure of fortnightly water deficits were analysed and then modified for use in kriging to produce point-kriging estimates. These estimates have been used to produce water deficit maps for different fortnights over Gujarat to study spatial and temporal

variability of drought. The results indicated that the occurrence and spread of drought has a general tendency to originate in the water deficit region, spreads in different directions of similar deficient regions and then dissipates.

Results of crop planning study indicated that at 70 per cent probable rainfall, longest length of growing season of 15 weeks was observed at Navsari and Gandevi, followed by Surat, Bharuch, Anand and Junagadh (14 weeks, each), Nawagam, Arnej, SK Nagar and Amreli (13 weeks, each), Dhandhuka and Khedbrahma (12 weeks, each) and for Rajkot 11 weeks, respectively. The lowest value of 10 and 9 weeks were observed for Radhanpur and Kothara, respectively. The length of growing season showed an increasing trend with increase in annual rainfall at the selected stations.

Mono-cropping as well as double cropping system was found to be suitable in the different agro-climatic zones of Gujarat, mainly due to large variability in soils and climate. Selected short duration crops like pearl millet, pulses, ground nut, sorghum or fodder can successfully be grown in different zones. The long duration kharif crops such as castor, cotton, paddy and pigeon pea, etc. experience intermittent water stress for short duration during grand growth period, which can be avoided by making arrangement for supplementary or protective irrigation by harvesting of surplus water.

Following conclusions are drawn from the results of this study:

- (i) Annual, seasonal and weekly rainfall analysis of sixteen stations representing different agro-climatic zones indicated that the mean values of rainfall at Kothara and Radhanpur are lowest with higher values of coefficient of variation, which highlights the extremely erratic rainfall distribution making it a scarcity zone compared to others.
- (ii) Effective monsoon onsets in 25th to 28th smw and terminates in 36th to 40th smw in different agro-climatic zones.
- (iii) Dry spell analysis indicated that mid season droughts are likely to occur with 26 to 50 per cent probability at Junagadh, Anand, Nawagam, Bharuch, Surat and Navsari; with 51 to 75 per cent probability at Rajkot, Amreli, SK Nagar, Khedbrahma, Arnej, Dhandhuka and Mahuva, and < 25 per cent probability at Gandevi. Kothara and Radhanpur experienced mid season droughts on regular basis with high probability. The possibilities of late season droughts during maturity period are high (> 50%) at all the stations except Gandevi, where it is 25 percent.
- (iv) Comparison of seasonal rainfall with seasonal reference evapotranspiration (ET₀) indicated that normal evaporative demand of crops grown in rainy season is fulfilled at all the stations except Kothara, Radhanpur, Rajkot, Amreli, SK Nagar, Arnej, Dhandhuka and Mahuva.

- (v) Under normal condition, moisture status at all the stations situated in half of the eastern part of the state (Khedbrahma, Anand, Nawagam, Bharuch, Surat, Navsari and Gandevi) is sufficient for satisfactory growth of rainfed crops, whereas, all the stations located in the other half (western part, includes SK Nagar, Arnej, Dhandhuka, Mahuva, Junagadh, Radhanpur and Kothara) experienced moisture deficit during the crop growth period. However, the distribution of weekly rainfall, which is highly erratic and uncertain, results in moisture stress of various categories in different agro-climatic zones, producing intermittent droughty conditions.
- (vi) Climatic shift study revealed that Kothara and Radhanpur (North-west Gujarat) were found to be predominantly in arid climate, Bharuch, Surat, Navsari and Gandevi (South Gujarat) in humid (dry sub-humid to humid) climate and rest of the stations in semi-arid climatic condition.
- (vii) Surplus water availability in different agro-climatic zones clearly indicated that there are chances of getting excess water in rainy season in all the zones, which can be effectively harvested and used in water deficit periods.
- (viii) Drought evaluation study indicated a frequency of one drought year in every two to three years. Droughts are common not only in arid and semi-arid climate but equally occur in dry sub-humid climate also. Drought analysis also indicated that different category droughts of varying durations prevail simultaneously in different agro-climatic zones.
- (ix) Frequency analysis of weekly maximum water deficit during crop growing season inferred that log Pearson type-III probability distribution is the best at all the stations except Dhandhuka, Junagadh, Mahuva, Nawagam and Surat, where Weibull (maxima) distribution and at Kothara Gumbel distribution fitted best.
- (x) Artificial Neural Networks used for estimation of weekly water deficits are found to be accurate as seen from the highly significant values of correlation coefficient between observed and generated, and observed and predicted water deficit for different stations.
- (xi) Developed autoregressive stochastic models are found to be adequate for forecasting the weekly water deficit as seen from the highly significant values of correlation coefficient between observed and generated and observed and predicted water deficit series.
- (xii) Spatial and temporal variability of water deficit during the drought year (1987), using geostatistical modelling technique, indicated that the occurrence and spread of drought has a tendency to originate in the water deficit region, spreads in different directions of similar deficient regions and then dissipates.

- (xiii) Mono-cropping as well as double cropping systems are possible in all the agro-climatic zones of Gujarat except hot arid and part of semi-arid areas. Short duration rainfed kharif crops can be successfully grown in all the agro-climatic zones. Long duration kharif crops experience intermittent water stress for short period during their critical growth stages. However, sustainable production can be maintained by providing protective irrigation through harvesting of surplus water during rainy period.

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ABSTRACT

Modelling of drought is one of the most important aspects in the rainfed farming. The present study was undertaken to model drought in different agro-climatic zones of Gujarat, by analysing rainfall and estimating dry spells and water deficits, determining suitable frequency distributions for extreme weekly water deficit, developing and validating appropriate artificial neural networks and stochastic models, studying drought spread using geostatistical modelling and suggesting suitable crop planning. Weekly meteorological data for 22 to 30 years (upto 2003) and soil data for sixteen stations (representing eight agro-climatic zones), namely Kothara, Radhanpur, Rajkot, Amreli, SK Nagar, Khedbrahma, Arnej, Dhandhuka, Junagadh, Mahuva, Anand, Nawagam, Bharuch, Surat, Navsari and Gandevi were collected. Meteorological and soil data for Dahod were also included for geostatistical analysis.

Weekly rainfall data were analysed for onset and withdrawal of rainy season and determination of dry spells. Results of rainfall analysis of different agro-climatic zones indicated that average annual rainfall varied from 368.74 mm at Radhanpur to 1580.53 mm at Gandevi with coefficient of variation of 54.94 and 32.25 per cent, respectively. Mean seasonal rainfall received from June to September ranged between 337.68 mm at Kothara to 1541.33 mm at Gandevi. Maximum and minimum mean weekly rainfall during monsoon season ranged from 46.91 to 197.55 mm and 2.10 mm to 42.48 mm, respectively in different agro-climatic zones. Annual, seasonal and weekly rainfall analysis of different agro-climatic zones indicated that the coefficient of variation at Kothara is highest, signifying extremely erratic rainfall distribution compared to other stations. Effective monsoon onsets from 25th to 28th week and terminates from 36th to 40th week in different agro-climatic zones of the state. Dry spell analysis indicated that mid season droughts are likely to occur with 26 to 50 per cent probability at Junagadh, Anand, Nawagam, Bharuch, Surat and Navsari; with 51 to 75 per cent probability at Rajkot, Amreli, SK Nagar, Khedbrahma, Arnej, Dhandhuka and Mahuva, and < 25 per cent probability at Gandevi. Kothara and Radhanpur experienced mid season droughts on regular basis with high probability. The possibilities of late season droughts during maturity period are high (> 50% probability) at all the stations except Gandevi (< 25 % probability).

Under normal condition, moisture status at all the stations situated in half of the eastern part of the state is sufficient for satisfactory growth of rainfed crops, whereas, all the stations located in the other half (western part) experienced moisture deficit during the crop growth period. Drought evaluation study indicated a frequency of one drought year in every two to three years. The analysis also indicated that drought does not occur simultaneously in all the agro-climatic zones but usually occur sporadically all over the state. However, during

some years, all the zones experienced droughts of varying intensity. The results indicated that droughts are common not only in arid and semi-arid climate but equally occur even with higher frequency in dry sub-humid climate also.

Weekly reference evapotranspiration and water balance components were also determined. Frequency analysis of weekly maximum water deficit during crop growing season indicated that Gumbel distribution fitted best at Kothara; Weibull (maxima) distribution at Dhandhuka, Junagadh, Mahuva, Nawagam and Surat and log Pearson type-III is the best probability distribution at rest of the stations.

The artificial neural network (ANN) generated water deficit and observed water deficit have indicated similar trend for all the weeks for different stations. Highly significant values of correlation coefficient of the regression analysis for different stations indicated that the network has accurately estimated the water deficit and the provided 7-4-1 architecture is adequate for the network. The trained network model during validation has predicted water deficit reasonably accurate for all the stations.

Developed stochastic models were found to be adequate for forecasting the weekly water deficit for two years ahead (2002 and 2003) as seen from the highly significant values of correlation coefficient between observed and predicted series. Spatial and temporal variability of water deficit during 1987 drought year using geostatistical modelling technique indicated that the occurrence and spread of drought has a tendency to originate in the water deficit region, spreads in the direction of similar deficient regions and then dissipates.

Mono-cropping as well as double cropping systems are possible in all the agro-climatic zones of Gujarat (except hot arid and part of semi-arid areas), mainly due to presence of heavy soils. Short duration rainfed kharif crops can be successfully grown in different zones. Long duration kharif crops experience water stress for short period during their critical growth stages. However, sustainable production can be maintained by providing protective irrigation through harvesting of surplus water during rainy season.

अनुक्षेपण

बारानी खेती में अनावृष्टि का प्रतिरूपण एक अत्यन्त महत्वपूर्ण पहलू है। गुजरात के विभिन्न कृषि-जलवायुवीय क्षेत्रों में अनावृष्टि का प्रतिरूपण करने हेतु यह अध्ययन किया गया, जिसमें वर्षा का विश्लेषण एवं शुष्क दौरों तथा जल हास का आकलन, अधिकतम साप्ताहिक जल हास योग्य आवर्तन-वर्गीकरण का निश्चितीकरण, उपयुक्त कृत्रिम तन्त्रिका तंत्र तथा प्रसभाव्य प्रतिरूपों का विकास एवं प्रमाणिकरण, भूसांख्यिकीय प्रतिरूपण के सहारे सूखे के विस्तार का अध्ययन और योग्य फसलों का चयन समाविष्ट है। इस अध्ययन हेतु राज्य के कुल आठ कृषि-जलवायुवीय क्षेत्रों का प्रतिनिधित्व करने वाले सोलह केंद्रों, कोठारा, राधनपुर, राजकोट, अमरेली, एसके नगर, खेडब्रह्मा, अरनेज, धन्धुका, जूनागढ़, महुवा, आणन्द, नवागाम, भरुच, सूरत, नवसारी एवं गणदेवी के 22 से 30 वर्ष तक के साप्ताहिक मौसमी आंकड़े एवम् मृदा सम्बन्धित जानकारी एकत्रित की गई है। भूसांख्यिकीय विश्लेषण हेतु दाहोद केंद्र की मौसमी एवम् मृदा सम्बन्धित जानकारी का भी समावेश किया गया है।

साप्ताहिक वर्षा के आंकड़ों के विश्लेषण से वर्षा ऋतु के प्रारम्भ तथा समाप्ति और शुष्क दौरों का निश्चितीकरण किया गया। विभिन्न कृषि-जलवायुवीय क्षेत्रों के वार्षिक वर्षा विश्लेषण के परिणाम दर्शाते हैं कि औसत वार्षिक वर्षा तथा विचरण गुणांक का राधनपुर से गणदेवी तक क्रमशः 368.74 से 1580.53 मिमी तक और 54.94 से 32.35 प्रतिशत तक परिवर्तन हो रहा है। जून से सितम्बर तक औसत ऋतुनिष्ठ वर्षा कोठारा में 337.68 मिमी से गणदेवी में 1541.33 मिमी तक रही। विभिन्न कृषि-जलवायुवीय क्षेत्रों में महत्तम तथा न्यूनतम औसत साप्ताहिक वर्षा क्रमशः 46.91 से 197.55 मिमी तथा 21.0 से 42.48 मिमी के मध्य रही। विभिन्न कृषि-जलवायुवीय क्षेत्रों के वार्षिक, ऋतुनिष्ठ और साप्ताहिक वर्षा के आंकड़ों के विश्लेषण से संकेत मिलता है कि कोठारा का विचरण गुणांक सर्वाधिक है जो अन्य स्थानों की तुलना में वर्षा की अधिकतम-अनिश्चितता दर्शाता है।

राज्य के विभिन्न कृषि-जलवायुवीय क्षेत्रों में प्रभावी मानसून का प्रारम्भ 25 से 28वें सप्ताह में, जबकि समाप्ति 36 से 40वें सप्ताह में होती है। शुष्क दौरों का विश्लेषण सूचित करता है कि जूनागढ़, आणन्द, नवागाम, भरुच, सूरत, व नवसारी में 26 से 50 प्रतिशत तक; राजकोट, अमरेली, एसके नगर, खेडब्रह्मा, अरनेज, धन्धुका एवं महुवा में 51 से 75 प्रतिशत तक तथा गणदेवी में 25 प्रतिशत से कम प्राययिकता सहित मध्य-ऋतु शुष्क रह सकती है। कोठारा एवं राधनपुर में मध्य-ऋतु सूखे की सम्भावना नियमित रूप से अधिक प्राययिकता के साथ रहती है। परिपक्वता के समय विलम्ब से आने वाले सूखे की संभावना गणदेवी (< 25 प्रतिशत प्राययिकता) को छोड़कर शेष सभी स्थानों पर अत्याधिक (> 50% प्राययिकता) आंकी गई।

सामान्य परिस्थिति में राज्य के पूर्वी अर्धविस्तार में स्थित सभी केंद्रों पर मृदा नमी की अवस्था बारानी फसलों के लिये संतोषजनक पाई गई, जबकि शेष पश्चिमी अर्धविस्तार में स्थित केंद्रों पर यह कम पाई गई। अनावृष्टि मूल्यांकन अध्ययन के अनुसार प्रत्येक दो से तीन वर्ष में एक बार अनावृष्टि

का आवर्तन होता है। विश्लेषण से यह भी विदित हुआ कि विभिन्न कृषि-जलवायुवीय क्षेत्रों में अनावृष्टि का प्रभाव एक साथ न होकर सामान्यतः पूरे राज्य में छुट-पुट रूप से घटित होता है। तथापि, कुछ वर्षों में सभी क्षेत्रों में विविध अवधि एवं तीव्रता की अनावृष्टि का प्रभाव हो रहा है। परिणाम दर्शाते हैं कि अनावृष्टि केवल शुष्क एवं अर्धशुष्क जलवायु में ही निहित न होकर समान रूप से अथवा अधिक आवर्तन के साथ शुष्क अर्ध-नम जलवायु वाले क्षेत्रों में भी घटित हो रही है।

साप्ताहिक निर्देश वाष्पन-वाष्पोत्सर्जन तथा जल संतुलन भागों का निश्चितीकरण भी किया गया। फसल उत्पादन काल में साप्ताहिक अधिकतम जल ह्रास के आवर्तन विश्लेषण से ज्ञात होता है कि कोटारा के लिये गुम्बेल, धन्धुका, जूनागढ, महुवा, नवागाम व सूरत के लिये विबुल (अधिकतम) तथा शेष सभी स्थानों के लिये लॉग पियर्सन टाईप-III बंटन समुचित पाया गया।

विभिन्न केन्द्रों के लिये कृत्रिम तंत्रिका-तंत्र द्वारा जनित श्रेणी और निरीक्षण श्रेणी से प्राप्त साप्ताहिक जल ह्रास समान रूझान वाला पाया गया। पश्चगति विश्लेषण के उच्च सह सम्बन्ध गुणांक दर्शाते हैं कि तंत्रों द्वारा किया गया जल ह्रास आकलन उचित है तथा शिल्प 7-4-1 सभी केन्द्रों के लिये पर्याप्त है। प्रमाणीकरण के समय प्रशिक्षित तंत्र प्रतिरूप द्वारा किया गया जल ह्रास का आकलन सभी केन्द्रों के लिये न्यायसंगत पाया गया।

प्रागुत श्रेणी एवं निरीक्षण श्रेणी के अति सार्थक सहसम्बन्ध दर्शाते हैं कि यहां विकसित प्रसंभाव्य प्रतिरूपणों से, साप्ताहिक जल ह्रास के दो अग्रिम वर्ष (2002 और 2003) पूर्वानुमान हेतु योग्य पाये गये। भूसांख्यिकीय प्रतिरूपण कौशल से वर्ष 1987 में रही अनावृष्टि तथा उसके विस्तार का अध्ययन सूचित करता है कि अनावृष्टि अल्पजल क्षेत्र में उत्पन्न होकर, उसी प्रकार के अल्पजल क्षेत्रों की दिशा में अग्रसर होते हुए समाप्त हो जाती है।

गुजरात के शुष्क एवं कुछ अर्धशुष्क क्षेत्रों के कुछ भागों को छोड़ कर सभी कृषि-जलवायुवीय क्षेत्रों में भारी मृदा के कारण एकल फसलीय क्रम के साथ-साथ द्विफसलीय व्यवस्था सम्भव हो सकती है। कम अवधि वाली बारानी खरीफ फसलें विभिन्न क्षेत्रों में सफलतापूर्वक उत्पन्न की जा सकती हैं। दीर्घ अवधि वाली खरीफ फसलों में उनके क्रान्तिक विकास अवस्था में कम समय के लिये नमी ह्रास संभव हो सकता है। तथापि, वर्षा ऋतु में संग्रहित अतिरिक्त जल से रक्षित सिंचाई द्वारा शास्वत उत्पादन प्राप्त किया जा सकता है।

Appendix A: Standard meteorological weeks

Week No.	Dates		Week No.	Dates	
1	January	1-7	27	July	2-8
2	..	8-14	28	..	9-15
3	..	15-21	29	..	16-22
4	..	22-28	30	..	23-29
5	..	29- Feb. 4	31	..	30- Aug. 5
6	February	5-11	32	August	6-12
7	..	12-18	33	..	13-19
8	..	19-25	34	..	20-26
9	..	26- Mar. 4	35	..	27- Sept. 2
10	March	5-11	36	September	3-9
11	..	12-18	37	..	10-16
12	..	19-25	38	..	17-23
13	..	26- Apr. 1	39	..	24-30
14	April	2-8	40	October	1-7
15	..	9-15	41	..	8-14
16	..	16-22	42	..	15-21
17	..	23-29	43	..	22-28
18	..	30- May 6	44	..	29 Nov. 4
19	May	7-13	45	November	5-11
20	..	14-20	46	..	12-18
21	..	21-27	47	..	19-25
22	..	28- Jun.3	48	..	26- Dec. 2
23	June	4-10	49	December	3-9
24	..	11-17	50	..	10-16
25	..	18-24	51	..	17-23
26	..	25- Jul.1	52	..	24-31

Appendix B 1: Weekly mean rainfall and coefficient of variation at the selected stations

Week	Kothara		Radhanpur		Rajkot		Amreli	
	Rainfall, mm	CV, %	Rainfall, mm	CV, %	Rainfall, mm	CV, %	Rainfall, mm	CV, %
1	0.60	488.57	0.00	0.00	0.35	353.37	0.15	547.72
2	0.00	0.00	0.00	0.00	0.21	437.89	0.31	406.36
3	0.17	385.36	0.18	469.04	0.00	0.00	0.29	398.76
4	0.27	547.72	0.00	0.00	0.00	0.00	0.00	0.00
5	1.36	384.93	0.02	469.04	0.16	509.90	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.30	314.68	0.00	0.00
8	0.38	491.47	0.00	0.00	0.05	386.82	0.00	0.00
9	0.00	0.00	0.59	469.04	0.00	0.00	0.00	0.00
10	0.02	547.72	0.00	0.00	0.08	509.90	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	469.04	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00	0.07	509.90	0.30	522.84
15	0.10	547.72	0.57	469.04	0.34	317.25	0.07	547.72
16	0.00	0.00	0.11	469.04	0.00	0.00	0.70	281.61
17	0.00	0.00	0.00	0.00	0.00	0.00	0.05	547.72
18	1.64	547.72	0.00	0.00	0.07	509.90	0.80	444.56
19	0.33	547.72	5.29	396.60	1.43	468.83	0.30	547.72
20	0.00	0.00	0.00	0.00	0.00	0.00	1.23	397.62
21	7.87	547.72	0.00	0.00	0.97	357.15	1.07	314.80
22	0.93	416.33	2.20	312.60	7.04	315.44	5.73	264.70
23	1.57	391.57	0.48	442.02	3.90	259.60	13.30	246.99
24	10.69	327.47	11.17	195.84	17.60	123.87	24.47	187.37
25	18.48	285.91	18.28	282.09	41.28	155.85	45.85	199.19
26	14.26	362.18	4.45	181.38	43.46	155.74	39.15	207.41
27	21.52	220.81	22.72	167.07	33.51	103.18	32.84	148.98
28	31.19	193.28	38.70	231.07	49.48	157.87	46.91	133.81
29	52.59	225.01	50.94	143.03	61.64	135.28	40.64	124.46
30	32.44	182.64	38.23	163.46	43.31	107.89	41.17	149.36
31	34.48	270.49	25.98	135.30	34.54	153.54	27.60	141.31
32	34.49	260.33	20.17	172.77	60.09	248.83	29.20	162.27
33	18.43	169.03	13.98	147.69	21.79	144.49	25.96	145.29
34	9.24	242.56	38.49	232.78	22.88	143.24	23.46	127.72
35	14.66	239.59	19.57	237.54	20.04	171.07	38.82	121.17
36	19.83	304.59	6.15	311.01	9.91	227.48	16.69	239.47
37	13.31	256.87	19.54	278.87	24.70	279.53	22.54	156.45
38	2.10	334.00	7.00	310.68	16.33	166.20	20.65	171.16
39	3.04	231.64	4.20	190.40	17.35	153.66	29.38	152.62
40	5.37	537.26	1.92	297.50	8.72	223.36	12.60	143.97
41	3.47	381.77	2.49	432.87	4.12	246.70	4.77	250.35
42	2.71	300.31	9.82	436.13	6.15	435.26	2.83	299.42
43	7.63	525.89	0.06	469.04	1.42	309.68	2.68	399.39
44	5.17	547.72	0.00	0.00	2.40	368.65	2.42	528.52
45	7.07	537.13	4.85	469.04	4.56	509.90	13.41	517.18
46	2.03	451.20	0.18	469.04	1.17	482.74	4.81	349.82
47	0.00	0.00	0.00	0.00	3.59	429.84	2.16	383.66
48	0.00	0.00	0.00	0.00	0.13	509.90	3.00	463.86
49	0.00	0.00	0.00	0.00	0.10	509.90	0.00	0.00
50	0.00	0.00	0.38	424.60	0.18	509.90	0.08	547.72
51	0.00	0.00	0.00	0.00	0.14	509.90	0.03	547.72
52	0.07	547.72	0.00	0.00	0.00	0.00	0.00	0.00

Appendix B 2: Weekly mean rainfall and coefficient of variation at the selected stations

Week	S.K.Nagar		Khedbrahma		Arnej		Dhandhuka	
	Rainfall, mm	CV, %	Rainfall, mm	CV, %	Rainfall, mm	CV, %	Rainfall, mm	CV, %
1	0.00	0.00	0.31	509.90	0.00	0.000	0.00	0.00
2	0.38	353.43	0.05	353.27	1.23	374.165	0.80	317.76
3	3.23	493.75	0.05	509.90	0.00	0.000	0.00	0.00
4	0.00	0.00	0.10	509.90	0.00	0.000	0.00	0.00
5	0.74	413.69	0.08	509.90	0.00	0.000	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00
7	0.79	366.50	1.08	456.36	0.00	0.000	0.11	469.04
8	0.00	0.00	0.32	294.13	0.00	0.000	0.00	0.00
9	0.45	423.75	0.70	509.90	0.00	0.000	0.27	469.04
10	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00
11	1.75	547.72	0.00	0.00	0.00	0.000	0.00	0.00
12	0.01	547.72	0.19	509.90	0.50	469.042	0.00	0.00
13	0.00	0.00	0.00	0.00	0.03	469.042	0.32	469.04
14	0.23	547.72	0.00	0.00	1.48	327.065	0.45	469.04
15	0.00	0.00	0.28	509.90	0.32	469.042	1.18	359.60
16	0.58	314.51	1.86	509.90	0.70	462.700	0.69	469.04
17	2.53	380.56	0.92	509.90	0.85	458.585	2.19	250.82
18	0.59	339.22	1.88	249.51	2.29	333.025	1.50	400.72
19	5.08	376.33	1.23	276.67	0.75	469.042	5.66	384.51
20	1.53	547.72	0.00	0.00	0.80	289.862	0.00	0.00
21	1.30	268.54	0.70	403.47	5.90	380.577	1.82	382.42
22	2.68	255.27	3.63	293.59	5.17	337.358	11.38	311.23
23	6.19	278.17	4.52	197.47	7.18	237.468	16.92	164.33
24	14.01	180.83	19.27	118.94	17.25	150.183	14.67	176.65
25	16.25	219.80	22.56	169.60	65.37	129.004	46.22	139.28
26	35.12	230.22	48.75	184.15	31.55	134.018	51.66	131.03
27	29.64	221.89	55.47	127.69	39.05	125.219	34.05	126.22
28	73.37	159.89	59.93	100.73	47.79	132.297	39.21	135.91
29	49.52	111.53	58.65	116.73	56.62	128.369	27.28	125.56
30	68.80	160.88	66.08	85.32	40.81	122.994	48.00	124.24
31	44.42	142.72	89.58	107.50	58.52	118.233	36.60	119.58
32	43.16	140.30	42.73	115.63	35.36	116.026	32.99	128.57
33	44.29	144.45	46.42	154.70	29.68	144.225	21.07	168.84
34	34.05	242.84	42.63	125.09	40.67	155.309	33.64	126.55
35	29.64	132.85	38.72	157.32	26.45	119.319	22.21	122.61
36	36.90	302.57	31.61	254.01	36.81	178.475	26.49	191.87
37	18.60	177.24	17.28	223.68	17.19	144.470	13.77	148.66
38	16.42	261.25	12.07	268.22	12.26	151.920	25.05	211.58
39	5.75	201.18	21.97	159.71	13.11	134.321	11.91	207.57
40	11.34	353.34	6.10	224.90	9.26	280.739	21.80	389.48
41	2.21	352.40	2.82	233.53	11.50	325.433	19.12	315.93
42	8.37	422.69	0.38	459.70	3.33	343.218	4.58	299.93
43	3.83	395.51	3.79	312.89	2.45	343.717	2.05	427.40
44	1.72	547.72	0.00	0.00	0.00	0.000	0.00	0.00
45	3.93	377.14	2.58	497.41	4.73	469.042	7.27	469.04
46	5.84	291.73	2.12	332.23	0.00	0.000	0.00	0.00
47	3.11	467.96	1.48	403.90	0.12	469.042	0.00	0.00
48	0.01	547.72	0.12	509.90	0.38	469.042	1.41	469.04
49	0.15	547.72	0.35	509.90	0.35	469.042	0.00	0.00
50	0.70	484.39	1.10	384.76	0.00	0.000	0.00	0.00
51	0.83	547.72	0.90	509.90	0.00	0.000	0.00	0.00
52	0.14	473.28	0.20	509.90	0.00	0.000	0.00	0.00

Appendix B 3: Weekly mean rainfall and coefficient of variation at the selected stations

Week	Junagadh		Mahuva		Anand		Nawagam	
	Rainfall, mm	CV, %	Rainfall, mm	CV, %	Rainfall, mm	CV, %	Rainfall, mm	CV, %
1	0.00	0.00	0.00	0.00	0.03	547.72	0.16	509.90
2	0.31	337.25	0.43	398.38	1.09	379.72	0.47	410.81
3	0.47	416.33	0.47	327.86	0.38	450.93	0.25	353.32
4	0.00	0.00	0.00	0.00	0.00	0.00	0.35	373.93
5	0.06	547.72	0.00	0.00	0.00	0.00	0.35	509.90
6	0.01	547.72	0.00	0.00	0.21	504.63	0.00	509.90
7	1.25	510.71	0.00	0.00	0.19	491.47	0.39	378.90
8	0.18	547.72	0.00	0.00	0.90	474.28	0.00	0.00
9	0.00	0.00	0.06	469.04	0.04	547.72	0.00	0.00
10	0.00	0.00	0.00	0.00	0.09	442.15	0.15	509.90
11	0.20	547.72	0.00	0.00	0.04	547.72	0.00	0.00
12	0.00	0.00	0.00	0.00	0.31	480.50	0.19	509.90
13	0.00	0.00	0.00	0.00	0.00	0.00	1.05	509.90
14	0.03	547.72	0.00	0.00	0.36	547.72	0.50	509.90
15	0.61	547.72	0.00	0.00	0.27	547.72	0.43	456.36
16	0.00	0.00	0.00	0.00	0.53	365.92	0.11	386.82
17	0.22	491.86	0.00	0.00	0.37	332.77	1.20	329.50
18	0.00	0.00	0.05	469.04	0.23	523.28	0.87	415.02
19	0.00	0.00	0.60	469.04	1.78	521.78	0.88	426.97
20	1.18	539.80	0.68	469.04	2.19	547.72	1.18	353.30
21	0.47	363.54	0.00	0.00	1.80	399.67	0.80	419.52
22	3.38	284.42	7.33	398.36	6.15	356.14	5.26	309.41
23	12.89	215.50	4.67	259.80	19.04	375.37	7.30	224.88
24	47.32	160.95	20.31	142.39	15.65	150.37	20.20	140.87
25	102.33	253.06	35.90	157.82	38.24	148.61	39.44	177.42
26	64.42	203.68	18.78	183.65	59.73	139.61	44.65	134.62
27	63.02	151.49	27.70	117.51	40.93	117.73	48.14	105.81
28	82.82	125.42	40.79	158.39	68.10	116.72	74.13	172.51
29	98.75	132.82	57.86	169.88	64.23	105.41	75.18	114.75
30	57.96	125.92	46.00	137.54	72.80	102.60	69.42	109.35
31	52.17	149.37	49.80	142.86	64.97	106.26	83.93	112.02
32	60.34	155.18	26.56	86.11	71.71	114.42	43.02	113.73
33	47.18	170.06	19.50	140.09	51.74	117.80	57.23	122.86
34	20.29	105.18	36.04	138.68	64.48	139.66	58.44	150.23
35	28.71	130.75	28.92	146.54	44.66	151.22	42.10	159.73
36	26.00	157.82	39.29	114.38	41.11	151.66	46.06	234.54
37	24.59	199.48	14.18	162.47	22.55	173.93	21.13	181.82
38	25.33	176.31	25.80	181.27	17.30	187.86	13.85	219.66
39	19.69	119.58	33.22	201.80	12.30	198.06	14.77	207.44
40	16.70	192.00	6.16	170.39	3.63	316.94	7.86	351.39
41	7.15	242.50	5.10	315.56	9.68	389.11	4.68	294.93
42	6.08	284.49	6.11	245.16	4.72	277.65	4.09	402.11
43	6.34	303.01	8.31	241.81	3.57	344.92	1.98	447.61
44	2.76	481.12	8.58	434.70	3.27	511.04	3.01	509.90
45	4.22	394.28	3.51	273.46	2.39	448.79	4.00	509.90
46	1.17	380.89	0.12	469.04	3.81	416.88	7.20	341.11
47	3.46	363.93	1.52	446.07	7.97	367.31	1.38	344.45
48	0.00	0.00	0.00	0.00	1.99	426.74	1.83	392.78
49	0.00	0.00	0.00	0.00	0.58	501.36	0.66	509.90
50	0.01	547.72	0.00	0.00	0.28	547.72	0.61	509.90
51	0.14	547.72	0.00	0.00	0.55	547.72	0.00	0.00
52	0.38	499.93	0.00	0.00	0.14	547.72	0.00	0.00

Appendix B 4: Weekly mean rainfall and coefficient of variation at the selected stations

Week	Bharuch		Surat		Navsari		Gandevi	
	Rainfall, mm	CV, %	Rainfall, mm	CV, %	Rainfall, mm	CV, %	Rainfall, mm	CV, %
1	0.44	547.72	0.00	0.00	0.42	447.98	0.40	358.57
2	1.20	340.64	0.72	412.60	1.56	342.04	0.66	469.04
3	0.23	384.70	0.27	547.70	2.35	504.65	0.24	371.72
4	0.00	0.00	0.00	0.00	0.35	526.35	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.07	547.70	0.07	547.72	0.00	0.00
7	0.91	471.82	1.90	528.20	0.55	441.12	0.00	0.00
8	0.43	547.72	0.08	547.70	0.40	547.72	0.00	0.00
9	0.00	0.00	0.07	547.70	0.61	491.90	0.00	0.00
10	0.02	547.72	0.00	0.00	0.00	0.00	0.00	0.00
11	0.05	547.72	0.33	547.70	0.00	0.00	0.11	469.04
12	0.00	0.00	0.00	0.00	0.15	547.72	0.52	335.77
13	0.00	0.00	0.00	0.00	0.06	547.72	0.00	0.00
14	0.25	547.72	0.00	0.00	0.04	547.72	0.83	469.04
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.02	547.72	0.00	0.00	0.01	547.72	0.00	469.04
17	0.08	547.72	0.00	0.00	0.00	0.00	0.00	0.00
18	0.06	547.72	0.00	0.00	0.37	547.72	0.35	469.04
19	1.03	547.72	1.55	411.40	0.38	443.66	0.45	469.04
20	1.44	547.72	0.13	547.70	0.03	547.72	2.05	469.04
21	0.07	547.72	2.59	547.70	0.82	536.37	0.13	337.89
22	7.43	304.10	6.78	319.20	9.22	271.29	5.27	348.17
23	29.03	367.23	43.42	410.20	17.48	258.88	8.41	250.14
24	30.83	132.43	46.48	188.20	71.48	172.16	76.75	153.31
25	44.56	169.03	130.51	141.10	121.85	133.28	127.80	142.33
26	89.19	142.80	86.17	132.80	94.04	113.57	98.31	136.30
27	45.36	111.39	90.67	110.30	121.03	118.90	123.23	128.10
28	68.53	109.16	108.19	97.40	110.17	109.61	143.31	113.39
29	90.36	133.63	137.00	117.30	150.00	92.71	197.55	76.34
30	53.40	152.55	119.15	176.50	128.07	121.11	127.85	118.82
31	51.85	156.81	70.68	142.70	94.42	129.87	107.18	121.85
32	63.92	121.14	76.47	122.30	100.29	112.69	96.86	91.85
33	45.81	123.45	42.65	107.90	61.61	127.18	100.29	121.19
34	51.92	111.04	41.15	121.30	49.01	127.52	59.66	93.88
35	41.33	122.37	38.52	123.10	64.88	125.56	65.33	124.71
36	43.96	163.76	42.99	235.20	80.71	144.98	49.30	107.74
37	36.10	175.80	24.70	173.00	39.62	137.99	55.56	108.90
38	29.96	157.08	24.37	151.00	33.31	122.55	42.48	131.46
39	33.30	193.27	26.96	205.30	38.84	168.76	51.92	155.72
40	11.52	277.86	16.83	216.70	21.44	176.45	9.54	191.35
41	5.79	259.41	11.79	244.20	18.18	268.25	18.13	226.41
42	1.46	289.21	4.79	301.60	7.62	278.01	1.97	237.52
43	1.61	294.71	0.70	324.60	5.96	286.80	2.64	360.70
44	6.48	378.27	2.30	427.60	6.93	314.65	0.66	469.04
45	0.82	547.72	1.36	363.80	2.76	395.57	2.39	434.80
46	8.58	330.98	4.01	473.20	3.93	436.23	0.54	469.04
47	4.67	359.20	3.77	369.80	3.99	309.61	1.48	469.04
48	0.10	547.72	2.41	387.30	0.93	493.74	0.07	469.04
49	1.81	486.95	0.00	0.00	1.22	399.85	0.00	0.00
50	0.30	547.72	0.00	0.00	0.18	547.72	0.00	0.00
51	0.53	547.72	0.00	0.00	0.50	547.72	0.00	0.00
52	0.20	547.72	0.00	0.00	0.13	547.72	0.32	469.04

Appendix C 1: Normal weekly water balance at Kothara (1974-03)

(AWC = 100 mm)

Week	Rainfall, mm	ET ₀ , mm	AET, mm	Deficit, mm	Surplus, mm	I _a , %	I _{ma} , %
1	0.60	24.49	0.83	23.66	0.00	96.30	3.71
2	0.00	24.12	0.22	23.90	0.00	99.04	0.97
3	0.17	25.89	0.36	25.53	0.00	98.60	1.40
4	0.27	26.39	0.42	25.97	0.00	98.52	1.49
5	1.36	28.17	1.43	26.74	0.00	94.47	5.53
6	0.00	30.50	0.12	30.38	0.00	99.62	0.39
7	0.00	31.89	0.09	31.81	0.00	99.72	0.28
8	0.38	34.30	0.45	33.85	0.00	98.71	1.29
9	0.00	34.77	0.05	34.72	0.00	99.87	0.15
10	0.02	38.39	0.06	38.33	0.00	99.86	0.15
11	0.00	40.05	0.03	40.03	0.00	99.94	0.06
12	0.00	41.63	0.02	41.61	0.00	99.96	0.04
13	0.00	46.24	0.01	46.23	0.00	99.98	0.03
14	0.00	46.99	0.01	46.98	0.00	99.99	0.02
15	0.10	47.92	0.10	47.81	0.00	99.77	0.24
16	0.00	48.24	0.00	48.24	0.00	100.00	0.01
17	0.00	49.21	0.00	49.21	0.00	100.00	0.00
18	1.64	54.13	1.64	52.49	0.00	96.84	3.17
19	0.33	53.74	0.33	53.41	0.00	99.27	0.73
20	0.00	52.17	0.00	52.17	0.00	100.00	0.00
21	7.87	50.98	1.28	49.70	3.25	96.67	3.33
22	0.93	49.19	2.07	47.12	0.00	95.32	4.68
23	1.57	47.29	2.23	45.06	0.00	94.32	5.68
24	10.69	42.94	4.59	38.35	0.52	88.24	11.76
25	18.48	42.60	11.32	31.28	4.69	72.34	27.66
26	14.26	41.02	8.00	33.02	8.02	79.02	20.98
27	21.52	33.65	9.09	24.57	6.40	71.08	28.92
28	31.19	32.98	13.27	19.71	12.29	57.80	42.20
29	52.59	30.99	17.26	13.73	22.61	41.81	58.20
30	32.44	30.96	13.30	17.66	15.98	53.13	46.87
31	34.48	31.01	15.27	15.74	15.36	47.43	52.57
32	34.49	32.27	15.79	16.48	20.11	48.08	51.92
33	18.43	31.03	14.05	16.98	3.48	51.13	48.87
34	9.24	31.69	13.54	18.15	0.08	55.36	44.64
35	14.66	33.12	12.96	20.16	3.99	58.03	41.96
36	19.83	33.18	10.17	23.00	12.29	66.24	33.76
37	13.31	34.01	10.62	23.39	5.21	66.31	33.69
38	2.10	34.52	9.08	25.44	0.00	71.56	28.44
39	3.04	33.55	8.22	25.33	0.00	74.29	25.71
40	5.37	34.65	5.20	29.45	1.58	84.53	15.47
41	3.47	32.40	4.80	27.60	0.54	84.83	15.17
42	2.71	31.80	5.51	26.28	0.00	81.42	18.59
43	7.63	30.36	2.53	27.82	5.93	90.71	9.30
44	5.17	31.43	2.90	28.53	1.00	90.05	9.95
45	0.13	30.31	2.42	27.89	0.00	91.73	8.28
46	2.03	27.66	3.04	24.62	0.00	89.46	10.54
47	0.00	26.80	1.31	25.49	0.00	94.94	5.06
48	0.00	26.55	0.98	25.57	0.00	96.08	3.93
49	0.00	25.58	0.76	24.81	0.00	96.95	3.06
50	0.00	24.64	0.59	24.05	0.00	97.61	2.39
51	0.00	25.04	0.44	24.59	0.00	98.13	1.88
52	0.07	23.68	0.42	23.26	0.00	98.19	1.81
Annual	372.56	1847.11	229.20	1617.90	143.35	4463.25	736.94
Seasonal	337.68	631.46	193.97	437.48	132.63	1180.71	619.31

Appendix C 2: Normal weekly water balance at Radhanpur (1982-03)

(AWC = 100 mm)

Week	Rainfall, mm	ET ₀ , mm	AET, mm	Deficit, mm	Surplus, mm	I _a , %	I _{ma} , %
1	0.00	24.18	0.43	23.75	0.00	98.14	1.87
2	0.00	24.66	0.35	24.31	0.00	98.52	1.48
3	0.18	25.17	0.47	24.70	0.00	98.18	1.82
4	0.00	27.33	0.24	27.09	0.00	99.10	0.90
5	0.02	28.25	0.22	28.04	0.00	99.23	0.78
6	0.00	30.34	0.15	30.19	0.00	99.50	0.52
7	0.00	31.76	0.12	31.64	0.00	99.63	0.38
8	0.00	34.13	0.10	34.04	0.00	99.73	0.28
9	0.59	35.48	0.66	34.83	0.00	97.77	2.24
10	0.00	38.86	0.05	38.81	0.00	99.86	0.14
11	0.00	41.67	0.04	41.63	0.00	99.92	0.09
12	0.00	44.58	0.03	44.55	0.00	99.95	0.07
13	0.00	47.10	0.02	47.08	0.00	99.97	0.04
14	0.00	49.10	0.01	49.09	0.00	99.99	0.02
15	0.57	51.83	0.58	51.25	0.00	98.86	1.14
16	0.11	53.18	0.12	53.06	0.00	99.79	0.22
17	0.00	56.73	0.00	56.73	0.00	100.00	0.00
18	0.00	58.42	0.00	58.42	0.00	100.00	0.00
19	5.29	59.81	3.03	56.78	0.00	94.09	5.91
20	0.00	61.58	0.94	60.63	0.00	98.25	1.75
21	0.00	61.39	0.56	60.84	0.00	98.98	1.02
22	2.20	59.68	2.53	57.15	0.00	95.23	4.77
23	1.87	58.29	2.06	56.23	0.00	95.71	4.29
24	11.17	52.41	9.45	42.96	0.00	81.16	18.84
25	21.96	50.13	8.94	41.19	5.06	78.10	21.90
26	10.73	47.00	9.55	37.45	0.35	77.13	22.87
27	17.10	40.64	14.34	26.30	0.00	59.43	40.57
28	38.77	38.88	16.21	22.67	13.19	54.86	45.13
29	50.94	33.74	20.10	13.64	15.43	36.40	63.60
30	38.23	32.85	17.67	15.18	11.02	39.13	60.87
31	25.98	32.36	20.28	12.08	4.68	31.26	68.74
32	21.24	32.28	19.54	12.74	2.82	36.27	63.73
33	12.91	31.00	16.81	14.20	0.14	41.87	58.13
34	39.81	31.85	17.54	14.31	19.51	40.17	59.83
35	18.25	33.41	15.17	18.24	10.35	50.90	49.10
36	7.20	34.67	14.01	20.66	0.84	56.59	43.42
37	18.50	35.51	11.15	24.35	9.59	64.74	35.26
38	7.20	36.04	11.10	24.94	0.00	65.73	34.28
39	3.99	36.22	10.40	25.81	0.00	69.09	30.91
40	1.92	36.61	7.05	29.57	0.00	79.42	20.58
41	2.49	35.02	5.44	29.59	0.00	83.40	16.60
42	9.82	32.65	4.09	28.57	5.15	85.86	14.15
43	0.06	31.07	2.94	28.13	0.00	89.86	10.14
44	0.00	30.78	2.09	28.69	0.00	92.50	7.51
45	4.85	29.29	2.98	26.31	0.00	89.77	10.23
46	0.18	27.37	2.00	25.37	0.00	91.90	8.10
47	0.00	26.55	1.47	25.09	0.00	94.21	5.80
48	0.00	25.46	1.11	24.35	0.00	95.49	4.52
49	0.00	24.87	0.84	24.03	0.00	96.45	3.55
50	0.38	24.16	1.04	23.11	0.00	95.60	4.41
51	0.00	24.10	0.54	23.56	0.00	97.80	2.21
52	0.00	22.59	0.38	22.21	0.00	98.25	1.75
Annual	374.53	1973.04	276.92	1696.12	98.13	4343.75	856.48
Seasonal	347.77	693.89	241.37	452.52	92.98	1057.96	742.06

Appendix C 3: Normal weekly water balance at Rajkot (1978-03)

(AWC = 150 mm)

Week	Rainfall, mm	ET ₀ , mm	AET, mm	Deficit, mm	Surplus, mm	I _a , %	I _{ma} , %
1	0.35	25.16	1.59	23.57	0.00	92.98	7.02
2	0.21	26.19	1.38	24.80	0.00	94.37	5.63
3	0.00	27.50	1.04	26.45	0.00	95.92	4.09
4	0.00	28.64	0.92	27.71	0.00	96.57	3.43
5	0.16	31.31	0.99	30.33	0.00	96.60	3.41
6	0.00	33.00	0.72	32.27	0.00	97.67	2.34
7	0.30	33.97	0.91	33.06	0.00	97.25	2.76
8	0.05	36.13	0.57	35.56	0.00	98.33	1.68
9	0.00	39.50	0.44	39.05	0.00	98.80	1.20
10	0.08	41.56	0.44	41.12	0.00	98.89	1.11
11	0.00	44.10	0.31	43.80	0.00	99.30	0.71
12	0.00	46.47	0.23	46.23	0.00	99.48	0.53
13	0.00	48.24	0.18	48.06	0.00	99.61	0.40
14	0.07	51.19	0.21	50.97	0.00	99.59	0.42
15	0.34	54.40	0.45	53.95	0.00	99.20	0.81
16	0.00	56.96	0.08	56.89	0.00	99.85	0.15
17	0.00	61.05	0.06	60.99	0.00	99.91	0.10
18	0.07	62.60	0.11	62.49	0.00	99.85	0.17
19	1.43	65.21	1.45	63.76	0.00	97.32	2.69
20	0.00	66.20	0.02	66.18	0.00	99.98	0.03
21	0.97	65.16	0.98	64.18	0.00	98.37	1.63
22	7.04	65.37	4.88	60.49	0.00	90.93	9.08
23	3.90	62.08	4.38	57.70	0.00	91.60	8.40
24	17.60	52.17	15.93	36.23	0.00	66.14	33.85
25	41.28	48.05	15.44	32.61	3.47	58.53	41.48
26	43.46	42.84	17.71	25.13	6.66	48.73	51.27
27	33.51	39.45	24.62	14.83	2.77	29.79	70.22
28	49.48	35.06	22.54	12.52	13.42	30.60	69.40
29	61.64	30.79	24.99	5.80	16.62	16.12	83.88
30	43.31	30.50	20.35	10.15	16.59	26.45	73.56
31	34.54	29.89	20.26	9.63	10.09	25.96	74.05
32	60.09	27.96	20.42	7.54	40.72	22.03	77.96
33	21.79	28.06	20.14	7.92	3.90	24.40	75.61
34	22.88	28.93	20.26	8.68	4.76	24.96	75.04
35	20.04	30.48	19.41	11.06	5.35	31.55	68.44
36	9.91	33.51	18.07	15.45	3.41	41.32	58.68
37	24.70	33.22	20.06	13.15	6.96	36.03	63.97
38	16.33	34.87	18.86	16.02	0.67	41.00	59.00
39	17.35	32.88	18.04	14.83	0.00	40.30	59.69
40	8.72	34.85	15.68	19.17	0.91	51.19	48.81
41	4.12	34.57	13.53	21.05	0.00	56.91	43.10
42	6.15	34.10	10.33	23.77	3.23	66.99	33.01
43	1.42	33.06	9.13	23.94	0.00	70.65	29.35
44	2.40	32.02	7.17	24.85	0.00	75.74	24.25
45	4.56	32.20	6.93	25.27	0.00	78.25	21.75
46	1.17	30.07	5.56	24.51	0.00	79.77	20.23
47	3.59	28.08	5.00	23.08	0.00	80.88	19.12
48	0.13	27.85	3.64	24.21	0.00	86.33	13.69
49	0.10	27.84	3.00	24.84	0.00	88.50	11.50
50	0.18	26.95	2.70	24.25	0.00	89.87	10.13
51	0.14	27.75	2.18	25.56	0.00	91.54	8.47
52	0.00	26.56	1.67	24.90	0.00	93.35	6.65
Annual	565.56	2026.55	425.97	1600.57	139.51	3816.29	1383.91
Seasonal	530.53	655.59	337.16	318.42	136.28	706.71	1093.30

Appendix C 4: Normal weekly water balance at Amreli (1974-03)

(AWC = 100 mm)

Week	Rainfall, mm	ET ₀ , mm	AET, mm	Deficit, mm	Surplus, mm	I _a , %	I _{ma} , %
1	0.15	25.37	1.05	24.32	0.00	95.61	4.39
2	0.31	26.11	1.04	25.07	0.00	95.67	4.33
3	0.29	27.63	0.88	26.76	0.00	96.33	3.67
4	0.00	28.70	0.50	28.20	0.00	98.09	1.91
5	0.00	31.25	0.39	30.86	0.00	98.53	1.47
6	0.00	31.40	0.32	31.09	0.00	98.88	1.12
7	0.00	33.56	0.25	33.31	0.00	99.16	0.84
8	0.00	35.15	0.20	34.95	0.00	99.39	0.61
9	0.00	38.51	0.15	38.36	0.00	99.56	0.44
10	0.00	40.71	0.11	40.60	0.00	99.69	0.31
11	0.00	42.59	0.08	42.51	0.00	99.79	0.21
12	0.00	46.05	0.06	45.99	0.00	99.86	0.14
13	0.00	48.45	0.04	48.41	0.00	99.91	0.09
14	0.30	49.38	0.33	49.05	0.00	99.35	0.65
15	0.07	53.30	0.09	53.22	0.00	99.85	0.15
16	0.70	54.09	0.71	53.37	0.00	98.63	1.37
17	0.05	56.78	0.06	56.72	0.00	99.88	0.13
18	0.80	58.30	0.80	57.50	0.00	98.37	1.63
19	0.30	58.28	0.30	57.98	0.00	99.22	0.79
20	1.23	59.69	1.23	58.46	0.00	97.03	2.97
21	1.07	59.40	1.07	58.32	0.00	97.83	2.17
22	5.73	54.88	4.81	50.07	0.00	90.22	9.78
23	13.30	50.67	6.85	43.83	0.38	82.43	17.57
24	24.47	42.26	13.25	29.01	1.81	63.71	36.29
25	45.85	39.65	17.14	22.51	15.48	50.42	49.58
26	39.15	37.57	19.19	18.38	14.59	42.38	57.62
27	32.84	34.36	20.87	13.49	8.90	34.02	65.98
28	46.91	31.66	21.96	9.70	16.06	25.86	74.14
29	40.64	28.75	19.57	9.18	11.55	28.31	71.69
30	41.17	29.32	18.75	10.57	20.30	31.23	68.77
31	27.60	28.84	19.75	9.09	6.96	28.19	71.81
32	29.20	27.81	18.97	8.84	11.89	27.27	72.73
33	25.96	28.31	21.47	6.84	5.57	23.15	76.85
34	23.46	28.60	20.26	8.33	4.86	26.42	73.58
35	38.82	28.88	20.04	8.84	11.99	26.15	73.85
36	16.69	31.04	17.49	13.55	9.60	39.41	60.59
37	22.54	31.48	21.06	10.41	3.53	31.10	68.90
38	20.65	33.79	19.79	14.00	3.98	38.52	61.48
39	29.38	32.59	19.72	12.87	9.25	35.74	64.26
40	12.60	32.93	16.92	16.01	1.05	44.55	55.45
41	4.77	33.86	13.57	20.29	0.00	56.62	43.38
42	2.83	35.13	10.30	24.84	0.00	66.78	33.22
43	2.68	33.66	8.16	25.50	0.00	73.73	26.27
44	2.42	32.77	5.96	26.81	0.00	80.27	19.73
45	13.41	31.47	5.58	25.88	8.71	80.56	19.44
46	4.81	30.75	6.38	24.37	0.00	78.26	21.74
47	2.16	27.84	3.90	23.94	0.00	83.71	16.29
48	3.00	28.08	3.66	24.43	0.00	85.01	14.99
49	0.00	26.19	2.33	23.86	0.00	90.00	10.00
50	0.08	25.29	1.88	23.41	0.00	91.74	8.26
51	0.03	26.29	1.51	24.78	0.00	93.54	6.46
52	0.00	24.83	1.16	23.70	0.00	94.98	5.02
Annual	578.42	1914.25	411.92	1502.35	166.45	3814.89	1385.11
Seasonal	531.23	598.51	333.10	265.44	157.74	678.86	1121.14

Appendix C 5: Normal weekly water balance at S.K. Nagar (1974-03)

(AWC = 100 mm)

Week	Rainfall, mm	ET ₀ , mm	AET, mm	Deficit, mm	Surplus, mm	I _a , %	I _{ma} , %
1	0.00	19.62	0.92	18.70	0.00	95.20	4.80
2	0.38	20.41	1.18	19.23	0.00	94.14	5.87
3	3.23	19.92	1.67	18.26	0.00	91.70	8.30
4	0.00	21.48	1.24	20.23	0.00	95.55	4.46
5	0.74	22.00	1.52	20.48	0.00	92.86	7.14
6	0.00	23.46	0.68	22.78	0.00	97.27	2.73
7	0.79	25.73	1.31	24.42	0.00	94.86	5.15
8	0.00	28.03	0.47	27.56	0.00	98.37	1.64
9	0.45	29.21	0.80	28.41	0.00	96.84	3.16
10	0.00	31.81	0.29	31.52	0.00	99.10	0.91
11	1.75	35.58	1.22	34.36	0.00	96.25	3.75
12	0.01	37.55	0.37	37.17	0.00	98.85	1.15
13	0.00	39.31	0.31	39.00	0.00	99.23	0.78
14	0.23	43.43	0.43	43.00	0.00	98.82	1.19
15	0.00	44.97	0.14	44.83	0.00	99.66	0.35
16	0.58	47.63	0.68	46.95	0.00	98.69	1.32
17	2.53	50.43	2.60	47.83	0.00	94.75	5.26
18	0.59	51.17	0.64	50.53	0.00	98.58	1.42
19	5.08	51.96	2.69	49.27	0.00	93.18	6.83
20	1.53	53.31	2.49	50.82	0.00	95.20	4.81
21	1.30	54.03	1.84	52.19	0.00	96.43	3.58
22	2.68	54.80	3.10	51.70	0.00	93.85	6.15
23	6.19	55.34	5.30	50.04	0.00	90.08	9.92
24	14.01	54.60	9.95	44.65	0.00	77.90	22.10
25	16.25	49.83	10.55	39.28	0.06	74.75	25.25
26	35.12	46.64	11.89	34.74	14.35	67.80	32.21
27	29.64	41.28	13.46	27.82	12.02	57.57	42.43
28	73.37	38.00	20.31	17.70	39.74	42.62	57.38
29	49.52	33.25	23.26	9.99	11.68	24.83	75.17
30	68.80	30.80	20.89	9.90	39.12	27.07	72.94
31	44.42	29.40	22.17	7.23	21.20	19.75	80.25
32	43.16	27.74	20.58	7.16	18.55	22.24	77.76
33	44.29	28.24	19.97	8.27	25.20	26.24	73.77
34	34.05	28.92	18.49	10.43	21.57	31.82	68.18
35	29.64	29.99	18.92	11.07	12.14	31.62	68.38
36	36.90	32.56	18.18	14.38	26.62	40.76	59.25
37	18.60	33.63	17.48	16.15	6.51	44.48	55.52
38	16.42	34.13	15.83	18.30	5.44	50.77	49.22
39	5.75	32.76	14.04	18.72	0.00	54.74	45.26
40	11.34	31.07	10.98	20.09	4.74	62.81	37.20
41	2.21	30.95	8.32	22.63	0.00	72.74	27.26
42	8.37	29.31	6.82	22.49	3.83	74.83	25.18
43	3.83	25.95	5.72	20.24	0.26	78.14	21.87
44	1.72	24.84	4.34	20.49	0.00	83.11	16.89
45	3.93	22.57	4.55	18.01	0.00	81.10	18.91
46	5.84	21.13	5.11	16.02	0.00	75.35	24.64
47	3.11	20.21	3.44	16.77	0.00	83.22	16.78
48	0.01	19.99	2.40	17.59	0.00	87.73	12.27
49	0.15	18.22	2.01	16.20	0.00	89.16	10.84
50	0.70	18.63	2.31	16.33	0.00	87.87	12.13
51	0.83	17.72	1.93	15.80	0.00	89.73	10.28
52	0.14	18.04	1.26	16.78	0.00	93.34	6.66
Annual	630.19	1731.56	367.05	1364.50	263.03	3963.57	1236.59
Seasonal	577.48	658.17	292.26	365.91	258.94	847.86	952.18

Appendix C 6: Normal weekly water balance at Khedbrahma (1978-03)

(AWC = 125 mm)

Week	Rainfall, mm	ET ₀ , mm	AET, mm	Deficit, mm	Surplus, mm	I _a , %	I _{ma} , %
1	0.31	16.65	1.81	14.84	0.00	88.95	11.05
2	0.05	17.04	1.38	15.66	0.00	91.67	8.33
3	0.05	17.45	1.25	16.19	0.00	92.65	7.36
4	0.10	18.52	1.18	17.34	0.00	93.40	6.60
5	0.08	19.35	1.07	18.28	0.00	94.30	5.70
6	0.00	21.06	0.94	20.12	0.00	95.46	4.55
7	1.08	23.29	1.79	21.49	0.00	91.97	8.03
8	0.32	25.30	1.12	24.18	0.00	95.37	4.63
9	0.70	26.71	1.38	25.33	0.00	94.77	5.24
10	0.00	27.75	0.59	27.16	0.00	97.82	2.18
11	0.00	30.12	0.51	29.61	0.00	98.26	1.74
12	0.19	32.55	0.63	31.92	0.00	98.09	1.91
13	0.00	35.08	0.36	34.72	0.00	98.97	1.05
14	0.00	37.05	0.29	36.76	0.00	99.22	0.79
15	0.28	37.64	0.50	37.14	0.00	98.66	1.35
16	1.86	40.20	1.81	38.40	0.00	95.72	4.28
17	0.92	41.58	1.11	40.47	0.00	97.32	2.68
18	1.88	44.15	2.02	42.13	0.00	95.44	4.56
19	1.23	47.61	1.34	46.27	0.00	97.10	2.91
20	0.00	49.60	0.08	49.52	0.00	99.85	0.16
21	0.70	50.75	0.76	50.00	0.00	98.90	1.12
22	3.63	50.22	3.67	46.55	0.00	91.33	8.68
23	4.52	45.35	4.54	40.81	0.00	88.89	11.12
24	19.27	39.86	15.00	24.86	0.00	59.68	40.31
25	22.56	36.88	12.14	24.74	0.00	62.67	37.34
26	48.75	33.10	14.87	18.23	17.18	49.21	50.79
27	55.47	30.01	18.21	11.79	12.72	32.83	67.17
28	59.93	26.25	21.95	4.31	21.82	14.31	85.70
29	58.65	24.56	22.80	1.76	18.72	6.02	93.98
30	66.08	23.72	21.52	2.20	28.47	8.11	91.89
31	89.58	22.51	20.70	1.81	62.98	6.13	93.87
32	42.73	23.51	21.50	2.01	26.67	7.50	92.50
33	46.42	23.08	20.30	2.78	27.65	11.36	88.64
34	42.63	23.05	20.50	2.54	25.35	10.15	89.85
35	38.72	22.96	18.63	4.34	28.17	17.20	82.79
36	31.61	26.04	19.15	6.89	20.78	25.17	74.83
37	17.28	27.37	17.77	9.60	9.39	33.50	66.51
38	12.07	28.31	16.49	11.81	5.59	39.85	60.14
39	21.97	26.90	18.37	8.54	2.72	30.67	69.33
40	6.10	26.83	15.28	11.55	0.00	42.55	57.45
41	2.82	25.40	12.13	13.27	0.00	51.81	48.18
42	0.38	23.96	8.35	15.60	0.00	64.40	35.61
43	3.79	21.73	7.86	13.87	0.00	63.47	36.53
44	0.00	20.91	5.38	15.53	0.00	74.07	25.92
45	2.58	19.45	4.99	14.46	0.00	74.10	25.90
46	2.12	17.94	4.93	13.01	0.00	72.30	27.70
47	1.48	18.28	4.04	14.24	0.00	77.85	22.16
48	0.12	16.20	2.75	13.45	0.00	82.94	17.07
49	0.35	15.44	2.53	12.91	0.00	83.38	16.61
50	1.10	15.17	2.98	12.19	0.00	82.24	17.77
51	0.90	15.26	2.19	13.07	0.00	84.77	15.23
52	0.20	14.68	1.71	12.97	0.00	88.52	11.47
Annual	713.55	1444.35	405.12	1039.22	308.21	3550.88	1649.26
Seasonal	684.35	510.28	319.70	190.58	308.21	545.78	1254.21

Appendix C 7: Normal weekly water balance at Arnej (1982-03)

(AWC = 200 mm)

Week	Rainfall, mm	ET ₀ , mm	AET, mm	Deficit, mm	Surplus, mm	I _a , %	I _{ma} , %
1	0.00	22.74	2.66	20.08	0.00	88.16	11.85
2	1.23	24.31	3.70	20.61	0.00	84.25	15.75
3	0.00	24.66	2.28	22.37	0.00	90.63	9.38
4	0.00	26.51	2.13	24.39	0.00	91.72	8.28
5	0.00	28.01	1.94	26.07	0.00	92.74	7.26
6	0.00	28.65	1.77	26.88	0.00	93.66	6.34
7	0.00	32.29	1.71	30.58	0.00	94.55	5.47
8	0.00	33.26	1.50	31.75	0.00	95.35	4.66
9	0.00	36.50	1.41	35.10	0.00	96.06	3.94
10	0.00	38.78	1.25	37.53	0.00	96.73	3.27
11	0.00	40.76	1.09	39.67	0.00	97.30	2.69
12	0.50	44.51	1.44	43.08	0.00	96.38	3.63
13	0.03	45.51	0.82	44.69	0.00	98.18	1.81
14	1.48	49.63	2.12	47.50	0.00	95.38	4.62
15	0.32	51.12	0.86	50.26	0.00	98.27	1.74
16	0.70	54.28	1.14	53.14	0.00	97.96	2.04
17	0.85	58.77	1.22	57.56	0.00	97.77	2.23
18	2.29	58.15	2.54	55.61	0.00	94.89	5.13
19	0.75	59.30	0.96	58.35	0.00	98.18	1.83
20	0.80	61.82	0.97	60.85	0.00	98.24	1.76
21	5.90	62.73	4.19	58.54	0.00	92.52	7.49
22	5.17	59.98	4.09	55.89	0.00	91.88	8.12
23	7.18	56.83	7.25	49.59	0.00	85.44	14.56
24	17.25	50.33	13.14	37.19	0.00	71.01	28.99
25	65.37	44.71	20.95	23.76	1.36	46.95	53.05
26	31.55	42.31	23.17	19.14	5.45	42.76	57.26
27	39.05	37.99	21.13	16.86	4.82	35.85	64.15
28	47.79	34.67	23.12	11.55	3.29	28.64	71.37
29	56.62	30.54	22.74	7.79	20.02	22.41	77.60
30	40.81	30.38	21.64	8.73	8.78	24.95	75.04
31	58.52	30.18	24.29	5.89	9.92	17.59	82.41
32	35.36	29.05	24.80	4.24	7.77	14.37	85.62
33	29.68	30.49	25.09	5.41	8.37	17.56	82.44
34	40.67	30.88	24.92	5.97	15.88	17.99	82.01
35	26.45	29.53	23.28	6.25	6.86	20.22	79.78
36	36.81	32.77	23.50	9.27	16.00	26.91	73.09
37	17.20	32.73	22.74	9.99	1.87	28.45	71.55
38	12.26	32.95	21.04	11.91	0.73	34.66	65.33
39	13.11	31.92	21.14	10.78	0.00	33.17	66.83
40	9.26	33.39	17.98	15.41	1.08	44.86	55.13
41	11.50	32.08	15.63	16.46	3.96	49.60	50.40
42	3.33	30.45	12.98	17.47	0.00	56.04	43.96
43	2.45	29.15	11.35	17.79	0.00	59.20	40.79
44	0.00	28.43	8.85	19.59	0.00	68.50	31.50
45	4.73	26.55	8.15	18.40	0.00	68.38	31.62
46	0.00	26.75	6.72	20.03	0.00	74.09	25.91
47	0.12	23.59	5.34	18.25	0.00	76.81	23.20
48	0.38	24.11	5.23	18.88	0.00	78.35	21.66
49	0.35	23.54	4.39	19.15	0.00	80.75	19.25
50	0.00	22.08	3.54	18.55	0.00	83.68	16.32
51	0.00	22.21	3.18	19.03	0.00	85.37	14.64
52	0.00	22.41	2.89	19.52	0.00	86.88	13.12
Annual	627.83	1895.26	511.91	1383.35	116.14	3562.23	1637.87
Seasonal	584.94	641.65	381.90	259.74	112.18	613.80	1186.21

Appendix C 8: Normal weekly water balance at Dhandhuka (1982-03)

(AWC = 200 mm)

Week	Rainfall, mm	ET ₀ , mm	AET, mm	Deficit, mm	Surplus, mm	I _a , %	I _{ma} , %
1	0.00	22.94	2.82	20.13	0.00	87.38	12.62
2	0.80	23.60	3.35	20.24	0.00	85.18	14.83
3	0.00	24.41	2.43	21.98	0.00	89.97	10.03
4	0.00	25.89	2.25	23.65	0.00	91.14	8.87
5	0.00	28.23	2.11	26.13	0.00	92.23	7.78
6	0.00	27.98	1.85	26.13	0.00	93.21	6.79
7	0.11	31.57	1.91	29.67	0.00	93.78	6.23
8	0.00	33.44	1.64	31.80	0.00	94.99	5.02
9	0.27	36.77	1.80	34.97	0.00	95.04	4.97
10	0.00	37.90	1.33	36.57	0.00	96.49	3.52
11	0.00	40.48	1.18	39.31	0.00	97.11	2.89
12	0.00	43.99	1.02	42.97	0.00	97.65	2.34
13	0.32	45.33	1.16	44.17	0.00	97.21	2.79
14	0.45	48.63	1.15	47.48	0.00	97.45	2.56
15	1.18	50.41	1.74	48.67	0.00	96.17	3.85
16	0.69	54.73	1.17	53.56	0.00	97.85	2.15
17	2.19	55.32	2.57	52.75	0.00	95.10	4.90
18	1.50	56.70	1.79	54.91	0.00	96.09	3.93
19	5.66	57.66	3.35	54.30	0.00	93.50	6.51
20	0.00	59.88	0.77	59.11	0.00	98.57	1.43
21	2.64	61.70	3.04	58.66	0.00	95.01	4.99
22	11.38	57.43	6.56	50.87	0.00	87.84	12.16
23	16.24	54.55	13.73	40.81	0.00	72.56	27.44
24	14.67	47.25	11.87	35.38	0.00	71.84	28.18
25	44.54	44.66	18.88	25.79	3.00	51.51	48.49
26	50.07	40.61	23.84	16.76	6.88	37.99	62.02
27	35.55	36.49	22.36	14.13	0.62	32.89	67.11
28	37.03	34.44	21.65	12.79	0.00	33.02	66.99
29	26.78	31.18	21.11	10.07	0.00	28.87	71.14
30	39.59	30.80	20.96	9.84	0.27	28.64	71.37
31	36.01	29.33	22.52	6.81	7.28	20.52	79.49
32	34.40	29.01	23.73	5.28	2.58	17.02	82.98
33	25.61	30.37	23.39	6.98	7.88	22.72	77.29
34	38.31	29.92	23.09	6.83	3.30	20.80	79.20
35	23.25	29.34	21.54	7.80	2.32	24.22	75.77
36	27.40	32.98	22.34	10.64	8.18	30.10	69.90
37	17.27	33.00	24.37	8.64	1.36	24.60	75.40
38	25.74	33.37	20.84	12.53	10.92	35.50	64.50
39	14.05	33.10	19.81	13.28	2.92	37.36	62.64
40	22.03	33.78	18.30	15.48	8.25	43.98	56.01
41	19.12	32.37	15.78	16.59	11.55	49.14	50.86
42	4.58	30.69	13.64	17.05	0.34	53.36	46.64
43	2.05	30.71	11.88	18.83	0.00	60.18	39.83
44	0.00	28.37	8.80	19.57	0.00	68.32	31.69
45	7.27	26.95	8.36	18.59	0.00	67.89	32.11
46	0.00	27.65	7.04	20.61	0.00	72.80	27.21
47	0.00	24.56	5.73	18.83	0.00	75.99	24.02
48	1.41	23.31	5.91	17.40	0.00	74.95	25.06
49	0.00	23.25	4.38	18.88	0.00	80.75	19.26
50	0.00	22.05	3.75	18.30	0.00	82.78	17.23
51	0.00	22.73	3.47	19.26	0.00	84.58	15.43
52	0.00	22.42	3.12	19.30	0.00	86.21	13.78
Annual	590.16	1874.20	513.14	1361.06	77.66	3560.05	1640.20
Seasonal	528.52	634.17	374.33	259.85	65.77	634.14	1165.92

Appendix C 9: Normal weekly water balance at Junagadh (1974-03)

(AWC = 150 mm)

Week	Rainfall, mm	ET ₀ , mm	AET, mm	Deficit, mm	Surplus, mm	I _a , %	I _{ma} , %
1	0.00	24.84	1.90	22.94	0.00	92.25	7.74
2	0.31	25.61	1.94	23.67	0.00	92.34	7.67
3	0.47	25.62	1.86	23.75	0.00	92.64	7.36
4	0.00	28.65	1.31	27.34	0.00	95.34	4.65
5	0.06	29.35	1.16	28.19	0.00	95.88	4.13
6	0.01	31.77	0.99	30.78	0.00	96.83	3.17
7	1.25	31.55	1.85	29.70	0.00	94.14	5.87
8	0.18	34.16	0.91	33.25	0.00	97.36	2.65
9	0.00	37.20	0.65	36.55	0.00	98.28	1.72
10	0.00	40.01	0.52	39.49	0.00	98.66	1.34
11	0.20	41.20	0.63	40.58	0.00	98.48	1.52
12	0.00	45.20	0.34	44.86	0.00	99.25	0.77
13	0.00	47.24	0.27	46.97	0.00	99.43	0.57
14	0.03	48.12	0.23	47.89	0.00	99.52	0.49
15	0.61	49.72	0.75	48.97	0.00	98.47	1.53
16	0.00	50.73	0.11	50.62	0.00	99.79	0.22
17	0.22	51.16	0.30	50.86	0.00	99.34	0.66
18	0.00	51.87	0.06	51.81	0.00	99.89	0.11
19	0.00	52.00	0.04	51.96	0.00	99.93	0.08
20	1.18	51.50	1.21	50.29	0.00	97.06	2.96
21	0.47	49.65	0.49	49.16	0.00	98.97	1.04
22	3.38	49.14	3.39	45.74	0.00	92.53	7.48
23	12.89	48.07	8.58	39.49	0.00	78.21	21.80
24	47.32	38.49	14.41	24.08	7.58	57.88	42.12
25	57.93	33.86	19.40	14.46	12.24	37.01	62.99
26	64.42	32.68	19.83	12.85	30.48	34.23	65.77
27	63.02	29.15	19.82	9.33	34.74	28.46	71.54
28	82.82	24.97	21.80	3.17	35.96	10.51	89.49
29	98.75	22.37	19.75	2.62	65.50	8.39	91.62
30	57.96	22.26	19.00	3.26	39.22	12.11	87.88
31	52.17	21.78	18.76	3.02	32.18	9.76	90.24
32	60.34	21.74	19.53	2.21	40.59	9.04	90.96
33	47.18	21.98	19.82	2.16	23.74	8.37	91.63
34	20.29	23.34	20.46	2.89	2.44	10.53	89.47
35	28.71	24.32	20.47	3.85	12.23	13.40	86.60
36	26.00	26.74	20.73	6.01	11.92	18.80	81.20
37	24.59	29.07	21.60	7.47	11.59	22.65	77.35
38	25.33	31.07	24.17	6.90	5.35	19.58	80.42
39	19.69	30.40	23.70	6.70	1.23	20.61	79.38
40	16.70	31.79	21.20	10.59	5.11	30.39	69.61
41	7.15	31.91	17.85	14.06	1.87	41.40	58.60
42	6.08	33.34	15.97	17.37	0.00	48.97	51.04
43	6.34	34.22	14.47	19.76	0.00	56.33	43.67
44	2.76	34.44	11.71	22.73	0.00	64.77	35.25
45	4.22	30.98	9.78	21.20	0.00	67.29	32.72
46	1.17	29.80	7.77	22.03	0.00	72.62	27.39
47	3.46	27.33	6.46	20.87	0.00	73.77	26.23
48	0.00	28.88	5.19	23.69	0.00	81.45	18.55
49	0.00	27.76	4.12	23.64	0.00	84.55	15.46
50	0.01	25.91	3.31	22.60	0.00	86.97	13.03
51	0.14	25.97	2.85	23.12	0.00	88.42	11.58
52	0.38	24.56	2.59	21.97	0.00	89.09	10.92
Annual	846.16	1765.48	476.00	1289.48	373.98	3421.94	1778.27
Seasonal	806.10	514.08	353.04	161.05	372.11	429.93	1370.09

Appendix C 10: Normal weekly water balance at Mahuva (1982-03)

(AWC = 150mm)

Week	Rainfall, mm	ET ₀ , mm	AET, mm	Deficit, mm	Surplus, mm	I _a , %	I _{ma} , %
1	0.00	25.76	2.08	23.67	0.00	91.57	8.43
2	0.43	26.11	2.27	23.84	0.00	91.40	8.60
3	0.47	26.76	2.01	24.75	0.00	92.36	7.66
4	0.00	29.91	1.51	28.39	0.00	95.03	4.98
5	0.00	28.30	1.13	27.17	0.00	95.90	4.10
6	0.00	30.05	0.99	29.06	0.00	96.60	3.40
7	0.00	30.79	0.81	29.98	0.00	97.21	2.80
8	0.00	33.40	0.70	32.69	0.00	97.71	2.29
9	0.06	35.13	0.69	34.45	0.00	97.90	2.11
10	0.00	35.80	0.52	35.28	0.00	98.55	1.47
11	0.00	38.69	0.45	38.24	0.00	98.85	1.15
12	0.00	40.19	0.34	39.85	0.00	99.12	0.89
13	0.00	40.82	0.28	40.55	0.00	99.33	0.68
14	0.00	41.66	0.22	41.45	0.00	99.50	0.52
15	0.00	42.81	0.17	42.65	0.00	99.61	0.39
16	0.00	45.35	0.13	45.22	0.00	99.72	0.29
17	0.00	44.46	0.09	44.36	0.00	99.80	0.22
18	0.05	46.24	0.13	46.11	0.00	99.73	0.28
19	0.60	46.02	0.65	45.37	0.00	98.20	1.81
20	0.68	44.18	0.72	43.46	0.00	97.72	2.29
21	0.00	44.10	0.03	44.07	0.00	99.94	0.07
22	7.33	43.54	3.53	40.01	0.00	92.47	7.53
23	5.22	42.79	5.80	36.99	0.00	85.03	14.99
24	28.21	37.86	14.39	23.46	0.43	60.72	39.28
25	35.90	36.66	15.77	20.89	3.13	53.56	46.45
26	19.72	34.57	14.40	20.17	0.00	55.33	44.67
27	26.54	33.29	17.87	15.42	1.22	43.32	56.69
28	41.13	31.15	18.13	13.01	12.27	39.03	60.98
29	42.29	28.27	21.19	7.08	13.44	22.91	77.08
30	40.15	28.41	18.93	9.47	11.48	31.14	68.87
31	49.25	27.66	22.92	4.74	10.62	15.66	84.34
32	24.76	28.19	21.40	6.79	6.05	22.66	77.33
33	19.80	27.89	20.91	6.98	1.56	23.14	76.86
34	32.20	27.13	19.84	7.29	6.76	24.60	75.40
35	27.32	27.34	19.91	7.42	6.21	25.54	74.47
36	35.35	28.12	20.68	7.43	5.48	24.85	75.15
37	14.16	29.12	19.72	9.40	4.73	30.81	69.19
38	22.80	30.04	18.70	11.34	9.73	35.80	64.20
39	32.94	29.32	18.71	10.61	13.70	34.39	65.61
40	5.38	30.19	17.82	12.38	0.00	40.29	59.71
41	5.10	30.20	14.67	15.53	0.00	50.36	49.64
42	6.11	31.18	13.22	17.95	0.00	55.57	44.43
43	7.45	31.39	12.34	19.05	0.02	59.31	40.68
44	8.58	32.24	10.83	21.40	2.34	65.81	34.19
45	3.51	31.98	9.44	22.54	0.13	68.68	31.33
46	0.12	30.47	7.29	23.18	0.00	75.18	24.82
47	1.52	28.62	6.10	22.52	0.00	77.91	22.08
48	0.00	29.09	4.85	24.25	0.00	82.30	17.71
49	0.00	27.98	4.10	23.88	0.00	85.27	14.73
50	0.00	26.29	3.16	23.13	0.00	87.67	12.33
51	0.00	26.32	2.62	23.70	0.00	89.59	10.41
52	0.00	25.40	2.16	23.25	0.00	91.18	8.82
Annual	545.14	1729.17	437.33	1291.84	109.32	3695.82	1504.39
Seasonal	503.13	557.97	327.10	230.87	106.83	668.78	1131.25

Appendix C 11: Normal weekly water balance at Anand (1974-03)

(AWC = 200 mm)

Week	Rainfall, mm	ET ₀ , mm	AET, mm	Deficit, mm	Surplus, mm	I _a , %	I _{ma} , %
1	0.03	19.51	3.64	15.87	0.00	81.67	18.34
2	1.09	19.69	4.07	15.62	0.00	79.09	20.91
3	0.38	20.30	3.40	16.90	0.00	83.16	16.84
4	0.00	21.59	2.93	18.65	0.00	86.36	13.64
5	0.00	22.89	2.77	20.12	0.00	87.80	12.22
6	0.21	24.32	2.85	21.47	0.00	88.43	11.57
7	0.19	25.72	2.66	23.06	0.00	89.66	10.35
8	0.90	27.90	3.17	24.73	0.00	88.44	11.55
9	0.04	30.48	2.25	28.23	0.00	92.58	7.42
10	0.09	31.75	2.07	29.68	0.00	93.52	6.49
11	0.04	33.96	1.85	32.11	0.00	94.60	5.40
12	0.31	35.71	1.88	33.83	0.00	94.58	5.41
13	0.00	37.70	1.38	36.32	0.00	96.28	3.71
14	0.36	39.04	1.53	37.51	0.00	95.88	4.12
15	0.27	41.59	1.30	40.28	0.00	96.76	3.24
16	0.53	42.58	1.38	41.20	0.00	96.74	3.27
17	0.37	44.42	1.09	43.32	0.00	97.48	2.53
18	0.23	45.88	0.83	45.06	0.00	98.10	1.91
19	1.78	46.85	1.81	45.04	0.00	95.48	4.53
20	2.19	49.15	1.93	47.21	0.00	95.65	4.37
21	1.80	49.72	2.35	47.37	0.00	94.91	5.10
22	6.15	49.17	3.89	45.28	0.00	90.88	9.13
23	19.04	47.93	7.06	40.86	5.25	82.00	18.00
24	15.65	42.31	13.29	29.02	0.00	64.59	35.41
25	38.24	39.38	15.25	24.13	0.00	52.70	47.31
26	59.73	35.79	22.34	13.45	14.84	32.32	67.69
27	40.93	33.04	19.52	13.51	5.74	33.92	66.08
28	68.10	29.77	22.95	6.81	12.26	19.22	80.79
29	64.23	26.37	21.28	5.08	23.80	16.58	83.42
30	72.80	26.65	22.68	3.96	34.57	11.93	88.07
31	64.97	25.50	21.77	3.74	32.55	12.01	87.99
32	71.71	23.83	21.89	1.95	35.97	6.68	93.32
33	51.74	25.49	23.45	2.04	25.26	6.96	93.03
34	64.48	26.16	23.72	2.44	40.08	8.34	91.66
35	44.66	26.46	23.12	3.34	24.84	10.29	89.71
36	41.11	29.77	24.13	5.64	26.48	16.99	83.01
37	22.54	30.83	23.50	7.33	11.73	21.46	78.53
38	17.30	31.63	23.29	8.35	4.58	24.54	75.46
39	12.30	31.23	21.11	10.12	2.94	29.70	70.30
40	3.63	31.39	18.91	12.48	0.00	39.21	60.79
41	9.68	29.80	16.87	12.93	1.66	41.88	58.12
42	4.72	28.74	14.55	14.19	0.00	48.74	51.26
43	3.57	26.59	12.43	14.16	0.00	52.56	47.44
44	3.27	25.56	10.25	15.32	0.00	59.57	40.43
45	2.39	24.31	9.06	15.25	0.00	62.35	37.65
46	3.81	23.01	8.41	14.61	0.00	63.30	36.71
47	7.97	21.51	7.29	14.22	0.19	65.52	34.48
48	1.98	20.91	6.88	14.03	0.00	66.83	33.18
49	0.58	19.77	5.83	13.93	0.00	70.86	29.14
50	0.28	18.96	5.03	13.93	0.00	73.87	26.14
51	0.55	18.79	4.76	14.02	0.00	74.83	25.18
52	0.14	18.31	3.90	14.40	0.00	78.68	21.32
Annual	829.09	1599.67	525.55	1074.11	302.75	3266.50	1933.66
Seasonal	773.17	563.52	369.26	194.26	300.89	489.46	1310.55

Appendix C 12: Normal weekly water balance at Nawagam (1978-03)

(AWC = 150 mm)

Week	Rainfall, mm	ET ₀ , mm	AET, mm	Deficit, mm	Surplus, mm	I _a , %	I _{ma} , %
1	0.16	21.92	2.62	19.31	0.00	87.94	12.07
2	0.47	22.28	2.60	19.68	0.00	87.84	12.16
3	0.25	22.69	2.13	20.56	0.00	90.36	9.66
4	0.35	23.53	1.99	21.54	0.00	91.50	8.49
5	0.35	24.48	1.78	22.69	0.00	92.60	7.41
6	0.00	25.22	1.33	23.89	0.00	94.65	5.36
7	0.39	26.39	1.55	24.85	0.00	93.90	6.11
8	0.00	28.00	1.03	26.96	0.00	96.22	3.79
9	0.00	30.47	0.92	29.56	0.00	96.87	3.14
10	0.15	32.96	0.98	31.97	0.00	97.02	2.98
11	0.00	35.46	0.73	34.74	0.00	97.97	2.03
12	0.19	38.11	0.79	37.33	0.00	97.91	2.10
13	1.05	41.09	1.51	39.58	0.00	96.56	3.45
14	0.50	40.75	0.88	39.87	0.00	97.73	2.27
15	0.43	44.51	0.74	43.76	0.00	98.18	1.83
16	0.11	47.57	0.36	47.21	0.00	99.23	0.76
17	1.20	48.28	1.39	46.89	0.00	97.01	3.00
18	0.87	49.43	1.01	48.42	0.00	97.62	2.37
19	0.88	52.84	0.99	51.85	0.00	98.03	1.98
20	1.18	56.19	1.27	54.93	0.00	97.09	2.92
21	0.80	57.46	0.86	56.60	0.00	98.22	1.80
22	5.26	56.42	4.24	52.18	0.00	90.55	9.46
23	7.30	54.62	6.90	47.72	0.00	85.25	14.76
24	20.20	47.51	14.34	33.17	0.00	66.77	33.24
25	39.44	43.10	12.11	30.99	4.07	63.08	36.92
26	44.65	37.63	22.00	15.63	8.75	34.59	65.42
27	48.14	35.46	21.44	14.02	2.93	29.55	70.45
28	74.13	32.39	22.34	10.05	37.62	26.06	73.94
29	75.18	28.11	23.87	4.24	36.63	12.02	87.98
30	69.42	25.74	21.76	3.98	32.73	9.79	90.21
31	83.93	25.56	21.25	4.31	53.13	11.20	88.80
32	43.02	25.18	22.64	2.54	17.57	7.71	92.29
33	57.23	25.32	23.75	1.56	30.02	5.52	94.48
34	58.44	26.47	24.12	2.35	34.88	7.82	92.19
35	42.10	25.87	22.16	3.72	23.64	12.21	87.79
36	46.06	29.25	23.62	5.63	31.48	17.63	82.37
37	21.13	30.36	22.17	8.19	11.24	25.02	74.98
38	13.85	31.26	21.17	10.09	5.13	30.25	69.74
39	14.77	30.59	19.21	11.38	3.00	35.90	64.10
40	7.86	30.09	16.35	13.74	1.06	44.19	55.82
41	4.68	28.25	13.65	14.60	1.39	50.20	49.79
42	4.09	26.91	10.99	15.92	0.07	58.09	41.91
43	1.98	24.30	8.70	15.60	0.00	62.45	37.55
44	3.01	24.60	7.64	16.96	0.00	67.95	32.05
45	4.00	24.12	7.15	16.97	0.00	69.35	30.65
46	7.20	23.07	8.04	15.03	0.00	64.58	35.43
47	1.38	21.90	6.06	15.84	0.00	72.13	27.87
48	1.83	21.56	5.71	15.85	0.00	73.51	26.50
49	0.66	21.41	4.76	16.65	0.00	78.07	21.93
50	0.61	21.37	4.31	17.07	0.00	80.02	19.98
51	0.00	20.71	3.13	17.59	0.00	85.11	14.88
52	0.00	21.60	2.78	18.82	0.00	87.09	12.92
Annual	810.88	1690.34	475.76	1214.58	335.34	3468.12	1732.04
Seasonal	766.85	584.50	361.18	223.31	333.87	524.57	1275.45

Appendix C 13: Normal weekly water balance at Bharuch (1974-03)

(AWC = 200 mm)

Week	Rainfall, mm	ET ₀ , mm	AET, mm	Deficit, mm	Surplus, mm	I _a , %	I _{ma} , %
1	0.44	22.63	4.37	18.27	0.00	79.77	20.23
2	1.20	23.34	4.56	18.77	0.00	78.37	21.64
3	0.23	24.54	3.70	20.84	0.00	84.22	15.79
4	0.00	24.30	2.99	21.30	0.00	86.72	13.28
5	0.00	26.83	2.88	23.95	0.00	88.20	11.81
6	0.00	27.93	2.70	25.23	0.00	89.60	10.41
7	0.91	29.37	3.36	26.01	0.00	88.10	11.91
8	0.43	33.38	2.98	30.40	0.00	90.89	9.11
9	0.60	34.52	2.80	31.72	0.00	91.61	8.40
10	0.02	35.33	1.91	33.42	0.00	94.27	5.74
11	0.05	36.92	1.73	35.19	0.00	95.08	4.93
12	0.00	38.83	1.46	37.37	0.00	96.01	4.00
13	0.00	40.95	1.30	39.65	0.00	96.70	3.31
14	0.25	42.46	1.32	41.14	0.00	96.69	3.31
15	0.00	45.87	0.95	44.93	0.00	97.78	2.21
16	0.02	47.25	0.80	46.46	0.00	98.19	1.82
17	0.08	49.89	0.74	49.15	0.00	98.42	1.59
18	1.33	51.68	1.87	49.81	0.00	96.39	3.61
19	1.03	52.32	1.43	50.89	0.00	96.44	3.57
20	1.44	51.91	1.77	50.15	0.00	96.11	3.90
21	0.27	51.10	0.52	50.58	0.00	98.95	1.05
22	8.17	51.10	4.76	46.34	0.00	88.96	11.04
23	29.03	47.76	9.59	38.17	12.23	75.58	24.42
24	30.83	41.80	16.13	25.68	1.99	56.28	43.73
25	44.56	36.25	17.83	18.42	2.71	45.78	54.23
26	89.33	32.28	18.76	13.52	26.82	33.03	66.96
27	45.39	30.43	22.53	7.90	5.69	21.31	78.69
28	68.59	28.05	22.96	5.09	25.89	14.10	85.90
29	90.51	26.61	23.93	2.69	43.91	9.05	90.95
30	53.03	26.87	23.32	3.55	26.43	10.76	89.24
31	51.95	25.47	22.45	3.02	31.97	9.74	90.27
32	63.93	25.53	23.45	2.08	34.41	7.40	92.60
33	45.08	26.49	24.22	2.28	18.21	7.39	92.60
34	51.85	26.92	24.43	2.48	18.89	8.44	91.56
35	41.06	27.23	23.43	3.80	24.19	11.26	88.74
36	46.05	28.34	23.12	5.22	32.54	15.87	84.13
37	36.18	29.44	23.73	5.71	18.77	17.06	82.94
38	30.48	29.52	22.70	6.82	14.05	21.10	78.90
39	39.74	29.20	21.60	7.60	21.51	23.76	76.24
40	11.52	30.52	20.89	9.63	2.76	30.22	69.79
41	5.79	29.74	18.21	11.53	1.28	36.49	63.51
42	1.46	29.93	15.86	14.07	0.00	46.25	53.76
43	1.61	28.48	13.43	15.05	0.00	52.12	47.87
44	6.48	27.57	11.44	16.13	0.80	57.43	42.57
45	0.82	26.03	10.01	16.02	0.00	61.23	38.77
46	8.58	24.40	9.57	14.82	0.00	58.11	41.90
47	4.87	23.19	8.51	14.68	1.51	61.41	38.59
48	0.10	22.75	6.67	16.08	0.00	69.42	30.59
49	1.81	20.77	6.08	14.69	0.00	69.12	30.89
50	0.30	20.96	5.31	15.65	0.00	73.05	26.94
51	0.53	21.29	5.05	16.25	0.00	74.62	25.38
52	0.20	21.59	4.41	17.17	0.00	78.20	21.80
Annual	918.13	1687.85	550.52	1137.33	366.55	3183.04	2017.09
Seasonal	869.11	548.70	385.07	163.64	362.96	418.12	1381.90

Appendix C 14: Normal weekly water balance at Surat (1974-03)

(AWC = 200 mm)

Week	Rainfall, mm	ET ₀ , mm	AET, mm	Deficit, mm	Surplus, mm	I _a , %	I _{ma} , %
1	0.00	23.47	4.03	19.44	0.00	82.42	17.58
2	0.72	23.61	4.27	19.33	0.00	81.15	18.86
3	0.27	25.07	3.68	21.39	0.00	84.94	15.06
4	0.00	24.85	3.00	21.84	0.00	87.66	12.34
5	0.00	26.62	2.85	23.77	0.00	89.13	10.87
6	0.07	27.49	2.63	24.85	0.00	90.22	9.79
7	1.90	28.68	3.28	25.40	0.00	88.29	11.71
8	0.08	31.49	2.40	29.09	0.00	92.13	7.87
9	0.07	33.64	2.21	31.43	0.00	93.33	6.68
10	0.00	35.07	1.85	33.22	0.00	94.50	5.50
11	0.33	35.94	1.92	34.01	0.00	94.39	5.61
12	0.00	36.99	1.41	35.58	0.00	96.11	3.88
13	0.00	39.08	1.24	37.84	0.00	96.78	3.22
14	0.00	40.15	1.04	39.11	0.00	97.36	2.65
15	0.00	42.21	0.89	41.32	0.00	97.83	2.17
16	0.00	43.97	0.75	43.23	0.00	98.24	1.76
17	0.00	44.53	0.62	43.91	0.00	98.58	1.42
18	0.00	46.29	0.51	45.78	0.00	98.86	1.14
19	1.55	45.11	1.94	43.17	0.00	95.17	4.82
20	0.13	45.13	0.45	44.68	0.00	98.91	1.09
21	2.59	45.41	1.70	43.71	0.00	96.08	3.92
22	6.78	45.13	4.00	41.13	0.00	89.61	10.40
23	43.42	42.38	8.64	33.74	25.42	76.01	24.00
24	46.48	38.52	14.49	24.03	7.11	55.64	44.36
25	130.51	33.27	20.48	12.79	53.15	31.56	68.44
26	86.17	30.66	22.10	8.55	32.52	22.40	77.60
27	90.67	29.42	25.64	3.78	43.21	9.64	90.36
28	108.19	27.64	25.88	1.76	61.83	5.02	94.97
29	137.00	26.22	25.22	1.00	101.41	3.04	96.96
30	86.94	26.69	25.28	1.41	57.98	4.65	95.35
31	70.68	25.56	23.88	1.68	50.43	5.38	94.62
32	76.47	24.84	24.04	0.80	48.40	2.98	97.03
33	42.65	26.70	25.52	1.19	19.30	3.86	96.14
34	41.15	27.39	25.26	2.13	21.29	7.11	92.88
35	38.52	27.01	24.19	2.81	17.39	8.88	91.12
36	42.99	28.10	23.88	4.22	31.97	13.70	86.30
37	24.70	28.36	23.60	4.77	11.09	15.75	84.25
38	24.37	28.80	22.82	5.98	6.04	20.02	79.98
39	26.96	28.76	22.05	6.71	12.70	21.99	78.01
40	16.83	30.19	21.88	8.31	4.07	26.05	73.95
41	11.79	29.60	19.28	10.31	3.57	33.59	66.40
42	4.79	29.71	17.08	12.62	0.51	41.53	58.47
43	0.70	28.90	14.40	14.50	0.00	49.54	50.45
44	2.30	28.09	12.40	15.69	0.00	55.09	44.92
45	1.36	27.08	10.64	16.45	0.00	60.07	39.93
46	4.01	25.37	9.35	16.02	0.00	62.20	37.80
47	3.77	23.79	7.85	15.94	0.37	64.43	35.57
48	2.41	23.44	7.84	15.60	0.00	64.66	35.34
49	0.00	21.98	5.86	16.12	0.00	72.65	27.35
50	0.00	21.81	5.24	16.57	0.00	75.42	24.58
51	0.00	22.35	4.77	17.59	0.00	77.92	22.08
52	0.00	22.19	4.27	17.92	0.00	80.18	19.82
Annual	1180.29	1624.72	570.51	1054.20	609.75	3112.69	2087.35
Seasonal	1134.70	530.51	404.86	125.64	605.30	333.70	1466.31

Appendix C 15: Normal weekly water balance at Navsari (1974-03)

(AWC = 150 mm)

Week	Rainfall, mm	ET ₀ , mm	AET, mm	Deficit, mm	Surplus, mm	I _a , %	I _{ma} , %
1	0.42	23.17	3.45	19.72	0.00	84.59	15.41
2	1.56	22.91	3.81	19.10	0.00	82.55	17.46
3	2.35	24.54	3.29	21.26	0.00	85.86	14.15
4	0.35	25.45	2.68	22.78	0.00	89.36	10.64
5	0.00	25.87	2.14	23.73	0.00	91.71	8.29
6	0.07	27.91	2.02	25.89	0.00	92.81	7.20
7	0.55	28.43	2.17	26.26	0.00	92.15	7.85
8	0.40	30.96	1.83	29.13	0.00	93.99	6.02
9	0.61	33.15	1.84	31.31	0.00	93.84	6.16
10	0.00	33.73	1.03	32.71	0.00	96.91	3.09
11	0.00	34.19	0.85	33.34	0.00	97.54	2.47
12	0.15	36.52	0.85	35.67	0.00	97.69	2.31
13	0.06	38.58	0.64	37.94	0.00	98.27	1.73
14	0.04	39.71	0.50	39.21	0.00	98.71	1.29
15	0.00	42.12	0.37	41.75	0.00	99.09	0.91
16	0.01	43.17	0.30	42.88	0.00	99.30	0.71
17	0.00	43.43	0.22	43.20	0.00	99.49	0.52
18	0.37	43.71	0.54	43.17	0.00	98.72	1.28
19	0.38	45.94	0.51	45.43	0.00	98.73	1.28
20	0.03	43.40	0.12	43.28	0.00	99.71	0.29
21	0.82	44.52	0.90	43.63	0.00	98.17	1.83
22	9.22	43.04	5.06	37.98	0.00	86.10	13.89
23	17.48	39.49	7.08	32.40	3.00	77.32	22.70
24	71.48	33.46	15.88	17.58	25.48	47.52	52.48
25	121.85	30.09	20.55	9.55	54.76	27.43	72.57
26	94.04	28.77	22.52	6.24	51.20	16.49	83.52
27	121.03	27.49	23.47	4.03	86.36	9.79	90.21
28	110.17	26.45	24.06	2.38	76.61	6.74	93.25
29	150.00	24.41	23.09	1.33	117.28	3.74	96.26
30	128.07	24.52	22.71	1.81	108.02	5.08	94.92
31	94.42	23.05	22.20	0.86	69.37	2.83	97.17
32	100.29	21.93	21.07	0.87	74.06	2.83	97.17
33	61.61	24.41	23.11	1.30	44.84	3.98	96.03
34	49.01	24.73	22.89	1.84	30.23	5.97	94.03
35	64.88	24.30	22.76	1.54	39.30	4.98	95.02
36	80.71	25.92	23.37	2.55	64.13	8.09	91.92
37	39.62	27.34	24.36	2.98	20.01	9.11	90.89
38	33.31	28.29	24.99	3.31	12.54	10.29	89.71
39	38.84	27.29	21.98	5.31	24.91	16.53	83.47
40	21.44	30.42	23.39	7.03	5.04	21.74	78.25
41	18.18	29.25	19.67	9.58	10.93	30.61	69.38
42	7.62	29.32	17.47	11.84	3.01	37.85	62.16
43	5.96	28.93	14.53	14.40	1.39	47.50	52.50
44	6.93	27.83	12.69	15.14	0.07	52.07	47.92
45	2.76	27.21	11.31	15.89	0.00	56.47	43.53
46	3.93	25.68	9.90	15.78	0.00	60.11	39.88
47	3.99	24.89	8.92	15.97	0.00	61.87	38.13
48	0.93	23.37	7.17	16.20	0.00	68.95	31.05
49	1.22	22.27	6.40	15.87	0.00	70.78	29.22
50	0.18	22.06	4.82	17.24	0.00	78.13	21.87
51	0.50	22.02	4.43	17.59	0.00	79.55	20.45
52	0.13	21.63	3.50	18.13	0.00	83.57	16.43
Annual	1467.98	1571.27	545.38	1025.90	922.53	3083.23	2116.88
Seasonal	1398.28	492.36	389.46	102.90	907.14	280.45	1519.57

Appendix C 16: Normal weekly water balance at Gandevi (1982-03)

(AWC = 200 mm)

Week	Rainfall, mm	ET ₀ , mm	AET, mm	Deficit, mm	Surplus, mm	I _a , %	I _{ma} , %
1	0.40	20.55	4.77	15.78	0.00	75.98	24.01
2	0.66	20.32	4.47	15.85	0.00	77.04	22.96
3	0.24	21.84	4.08	17.76	0.00	80.65	19.35
4	0.00	22.52	3.61	18.91	0.00	83.55	16.46
5	0.00	22.61	3.28	19.33	0.00	85.27	14.73
6	0.00	23.77	3.09	20.68	0.00	86.85	13.14
7	0.00	25.62	2.95	22.67	0.00	88.35	11.63
8	0.00	27.45	2.76	24.69	0.00	89.80	10.21
9	0.00	29.32	2.56	26.75	0.00	91.12	8.88
10	0.00	30.18	2.28	27.90	0.00	92.33	7.67
11	0.11	30.52	2.12	28.40	0.00	92.98	7.02
12	0.52	33.65	2.37	31.28	0.00	92.91	7.09
13	0.00	34.77	1.63	33.14	0.00	95.24	4.76
14	0.83	35.81	2.19	33.62	0.00	93.42	6.57
15	0.00	37.65	1.25	36.40	0.00	96.65	3.36
16	0.00	39.78	1.09	38.69	0.00	97.22	2.79
17	0.00	40.66	0.91	39.75	0.00	97.71	2.28
18	0.35	41.42	1.10	40.33	0.00	97.25	2.76
19	0.45	41.74	1.08	40.66	0.00	97.28	2.73
20	2.05	41.39	2.15	39.24	0.00	94.31	5.70
21	0.13	42.02	0.61	41.40	0.00	98.50	1.51
22	5.27	40.76	3.06	37.70	0.00	90.91	9.09
23	8.41	38.66	6.04	32.61	0.00	83.67	16.32
24	76.75	30.75	19.91	10.84	15.67	34.03	65.96
25	127.80	29.02	20.43	8.59	50.35	23.93	76.08
26	98.31	28.33	20.91	7.42	54.36	22.57	77.43
27	123.23	26.31	22.80	3.51	78.00	12.90	87.10
28	143.31	25.70	23.08	2.62	110.64	8.66	91.34
29	197.55	23.09	20.92	2.17	156.55	6.60	93.40
30	127.85	23.57	22.52	1.04	104.81	3.24	96.77
31	107.18	22.32	22.19	0.14	77.04	0.60	99.40
32	96.86	21.31	21.29	0.02	71.33	0.08	99.92
33	100.29	22.28	22.21	0.08	73.12	0.33	99.68
34	59.66	22.93	22.70	0.23	40.47	0.95	99.06
35	65.33	23.01	22.69	0.32	44.22	1.33	98.68
36	49.30	24.85	23.88	0.97	30.52	3.27	96.73
37	55.56	25.14	23.79	1.35	34.30	4.71	95.29
38	42.48	26.28	24.23	2.05	26.81	7.00	93.00
39	51.92	26.78	22.93	3.85	39.87	12.89	87.12
40	9.54	28.63	23.33	5.30	0.02	18.02	81.98
41	18.13	26.89	20.55	6.34	8.81	22.63	77.37
42	1.97	26.93	17.99	8.94	0.00	32.23	67.77
43	2.64	25.39	15.33	10.06	0.00	38.73	61.26
44	0.66	25.38	13.43	11.96	0.00	46.88	53.12
45	2.39	23.65	11.57	12.08	0.00	50.05	49.95
46	0.54	22.55	9.79	12.75	0.00	56.00	44.00
47	1.48	20.47	8.35	12.13	0.00	59.06	40.94
48	0.07	20.01	7.02	13.00	0.00	64.64	35.36
49	0.00	18.25	5.79	12.47	0.00	68.05	31.94
50	0.00	17.99	5.22	12.77	0.00	70.80	29.19
51	0.00	18.14	4.84	13.30	0.00	73.32	26.68
52	0.32	18.34	4.70	13.64	0.00	74.24	25.75
Annual	1580.53	1437.31	563.82	873.48	1016.88	2896.75	2303.26
Seasonal	1541.33	468.97	385.85	83.12	1008.08	244.78	1555.23

