STOCHASTIC MODELING OF EVAPOTRANSPIRATION OF POMEGRANATE (*Punica granatum* L.)

DEODAS TARACHAND MESHRAM

THESIS

Doctor of Philosophy

IN

AGRICULTURAL ENGINEERING

(IRRIGATION WATER MANAGEMENT ENGINEERING)

2010

DEPARTMENT OF SOIL AND WATER ENGINEERING

COLLEGE OF TECHNOLOGY AND ENGINEERING
MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
UDAIPUR-313 001 (RAJASTHAN)

COLLEGE OF TECHNOLOGY AND ENGINEERING,

UDAIPUR-313 001

MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY

CERTIFICATE-I

Date: 2/3/2010

This is to certify that **Mr. Deodas Tarachand Meshram** had successfully completed the preliminary examination held on 20th **October, 2008** as required under the regulation for **Doctor of Philosophy** in **Agricultural Engineering** (Irrigation Water Management Engineering).

(**Dr. R. C. Purohit**)
Head
Department of Soil and Water Engineering
C.T.A.E., Udaipur

COLLEGE OF TECHNOLOGY AND ENGINEERING, UDAIPUR – 313 001

MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY

CERTIFICATE-II

Date: 2/3/2010

This is to certify that this thesis entitled **"Stochastic Modeling of Evapotranspiration of Pomegranate (*Punica granatum* L.)"** submitted for the degree of **Doctor of Philosophy** in the subject of **Irrigation Water Management Engineering** (**Agricultural Engineering**), embodies bonafied research work carried out by **Mr. Deodas Tarachand Meshram** under our guidance and supervision and no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged. The draft of the thesis was also approved by the advisory committee on **18th January, 2010.**

(Dr. H. K. Mittal)
Major Advisor

(Dr. S. D. Gorantiwar)
Co-Major Advisor

(Dr. R. C. Purohit)
Head
Department of Soil and Water
Engineering, C.T.A.E., Udaipur

(Dr. R. C. Purohit)
Dean
College of Technology and
Engineering, Udaipur

COLLEGE OF TECHNOLOGY AND ENGINEERING,
UDAIPUR-313 001
MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
CERTIFICATE-III

Date: 14/06/2010

This is to certify that this thesis entitled **"Stochastic Modeling of Evapotranspiration of Pomegranate (*Punica granatum L.*)** submitted by **Mr. Deodas Tarachand Meshram** to the **Maharana Pratap University of Agriculture and Technology, Udaipur** in partial fulfillment of requirements for the degree of **Doctor of Philosophy (Ph.D.)** in **Agricultural Engineering** in the subject of **Irrigation Water Management Engineering** after recommendation by the external examination and defended by the candidate before the following members of the examination committee. The performance of the candidate in the **oral examination** on this thesis has been found satisfactory; we therefore, recommend that thesis be approved on **14 June, 2010**.

(Dr. H. K. Mittal)
Major Advisor

(Dr. S. D. Gorantiwar)
Co-Major Advisor

(Dr. R. S. Kurote)
External Examiner

(Dr. R. C. Purohit)
Advisor

(Dr. H. K. Jain)
Advisor

(Dr. S. R. Bhakar)
Advisor

(Dr. R. C. Purohit)
Head
Department of Soil and Water
Engineering, C.T.A.E., Udaipur

(Dr. R. C. Purohit)
Dean
C.T.A.E., Udaipur

DIRECTOR RESIDENT INSTRUCTIONS
MPUAT, Udaipur

COLLEGE OF TECHNOLOGY AND ENGINEERING,

UDAIPUR-313 001

MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY

CERTIFICATE-IV

Date: 16/06/2010

This is to certify that **Mr. Deodas Tarachand Meshram,** student of **Doctor of Philosophy** in the subject of **Irrigation Water Management Engineering**, **Department of Soil and Water Engineering, College of Technology and Engineering, Udaipur** has made all corrections / modifications in the thesis entitled **"Stochastic Modeling of Evapotranspiration of Pomegranate (*Punica granatum* L.)"** which where suggested by the external examiner and the advisory committee in the **oral examination** held on 14/06/2010. The final copies of the thesis duly bound and corrected were submitted on 16/06/2010.

(Dr. H. K. Mittal)
Major Advisor

(Dr. S. D. Gorantiwar)
Co-Major Advisor

(Dr. R. C. Purohit)
Head
Department of Soil and Water
C.T.A.E., Udaipur

(Dr. R. C. Purohit)
Dean
College of Technology and Engineering,
Engineering, Udaipur

Abstract

The knowledge of water requirement is necessary to match spatial and temporal distribution of water demand with water supply for efficient utilization of water resources. Evapotranspiration is a major parameter for estimating water requirement. Evapotranspiration (ET_c) varies according to crops, their growth stages, crop condition, soil parameters and climate. It is estimated as the product of reference crop evapotranspiration (ET_r) and crop coefficient (k_c). ET_r takes care of variation in climate and k_c is dependent on crop and its growth stages. Hence, the knowledge of appropriate method for estimation of ET_r and k_c values is necessary to know the water requirement of crop. In addition to this, it is important for the decision makers and planners if the values of ET_c at certain probability levels and their forecast few time periods ahead are known. For the purpose the stochastic modeling of ET_r was performed to investigate the suitable model.

Commercial Pomegranate orchards of different ages (i.e. 1st to 5th years) were selected to develop k_c values by using the shaded area approach. The k_c values were computed by using the equation $k_c = 0.014x + 0.08$, where k_c is crop coefficient and x is shaded area in fraction. The k_c values of 1st year pomegranate tree increased from 0.17 to 0.30. However the k_c values of 2nd, 3rd, 4th and 5th year's tree showed the four distinct phases of k_c. Initially the k_c increases from 0.22, 0.13, 0.14, 0.15 in 31st week to 0.50, 1.01, 1.08, 1.11 in 44th week for 2nd, 3rd, 4th and 5th year's tree, respectively. The k_c values are then almost constant from 45th to 52nd weeks (0.50, 1.08, 1.15, 1.18). Then k_c values then reduce from 0.50, 1.08, 1.15, 1.18 in 52nd week to 0.28, 0.65, 0.74, 0.83 in 15th week for 2nd, 3rd, 4th and 5th year's tree. The k_c values again increased from 16th to 30th week (0.29 to 0.35) for 2nd, (0.66 to 0.72) for 3rd, (0.74 to 0.80) for 4th and (0.83 to 0.92) for 5th year's tree, respectively.

The k_c values and LAI are dependent on each other. Therefore LAI values were correlated with k_c values. The leaf area indices were estimated as the ratio of total leaf area to shaded area (LAI_{SN}) and total leaf area to total area occupied by a tree (LAI_{APP}). LAI_{APP} and LAI_{SN} were observed to be 3.51 to 6.84 and 0.20 to 0.70 for 1st year tree; 4.85 to 9.22 and 0.49 to 1.36 for 2nd year tree; 3.98 to 5.62 and 0.13 to 2.50 for 3rd year tree; 3.96 to 4.56 and 0.17 to 2.34 for 4th year tree; 4.93 to 5.73 and 0.23 to 3.33 for fifth year tree. The variation in LAI values was due to increases or decreases in foliage, number of leaves and its area for 1st to 5th year's pomegranate trees. The variation of k_c with LAI for the pomegranate tree of different ages shows that the k_c linearly increases with LAI. The relationship between k_c and LAI for the pomegranate tree for all

the ages together was obtained as: k_c = 0.261 LAI + 0.189. These relationships are useful for estimating the values of k_c from the values of LAI for different ages of pomegranate orchard.

The reference crop evapotranspiration values were estimated by Penman- Monteith, Modified Penman, Hargreaves-Samani, FAO Pan Evaporation, Blanney-Criddle, and FAO Radiation daily records of meteorological parameters viz. maximum and minimum temperature (^{0}C), maximum and minimum relative humidity (%), pan evaporation (mm), wind speed (km/hr) and actual sunshine hours (hours) for Solapur (1983-2007), Ahmednagar (1975-2007), Pune (1987-2006) and Nasik (1985-2007) districts. The results showed that the trend of variation of ET_r values over the year for all the methods is same. However none of the methods shows the same results. The difference in values of ET_r is due to different climatological variables used in each method.

For Solapur district, the estimates of ET_r by FAO radiation method are higher, followed by modified penman method, Blanney-Criddle, pan evaporation, Hargraeves-Samani and Penman-Monteith methods. For Ahmadnagar district, FAO radiation method are higher, followed by modified penman method, Blanney-Criddle, Hargraeves-Samani, pan evaporation, and Penman-Monteith methods. For Pune district, FAO radiation method are higher, followed by Blanney-Criddle, modified penman method, Hargraeves-Samani, Penman-Monteith, and pan evaporation methods. For Nasik district, FAO radiation method are higher, followed by Modified penman method, Blanney-Criddle, Hargraeves-Samani, Penman-Monteith, and pan evaporation methods. Based on the regression analysis Modified Penman method is highly correlated with Penman-Monteith method for all districts. This is evident due to the fact that both the methods use the same set of data and is based on similar principle. On the basis of regression analysis all the different methods (modified Penman, Hargreaves-Samani and FAO Radiation for Solapur, Ahmednagar and Nasik districts; and modified Penman, FAO radiation and FAO pan evaporation for Pune district) can be used in lieu of Penman-Monteith method. However user needs to decide to select the appropriate method out of these three on the basis of data availability. However based on least root mean square error values, Hargraves-Samani is the best for Solapur and Nasik districts and Modified Penman method for Ahmadnagar and Pune districts. Thus in general in case of availability of data on large number of parameters modified Penman method is recommended and in case of availability of only temperature data, Hargreaves-Samani method is recommended.

The probability distribution functions that were selected are Normal, Log Normal, Gamma, Gumbel and Weibull's. Results of probability distribution analysis indicated that, the probability distribution analysis of ET_r indicate that more than one probability distribution was found suitable for the ET_r values for many weeks. However, it was also observed that there are instances where none of the probability distributions under consideration are found suitable. The ET_r values at different probability levels for the pomegranate under consideration were obtained from the probability distribution functions that give best fit. Normal distribution was the best fit for maximum weeks (25), followed by Log Normal (11), Gumbel (9), Gamma (4) and Weibull's (2) for Solapur district. For Ahmednagar district, Log normal distribution is the best fit for maximum weeks (11), followed by Normal (9), Gumbel (9), Weibull's (8) and Gamma (6). Normal distribution is the best fit for maximum weeks (25), followed by Log Normal (10), Gumbel (8), Weibull's (5) and Gamma (4) for Pune district and for Nasik district, Normal distribution is the best fit for maximum weeks (20) followed by Gamma (11), Log Normal (10), Gumbel (9) and Weibull's (2). The values of ET_r at different probability levels when multiplied by corresponding k_c factors are useful for appropriate irrigation planning for pomegranate.

Stochastic modeling of weekly ET_r estimated by Penman-Monteith method was performed for the generation and forecasting of weekly ET_r. Stochastic models of Autoregressive Integrated Moving Average (ARIMA) class were developed for generation and forecasting of ET_r values. The steps viz. standardization and normalization of time series variables, identification of the models, determination of the parameters of selected models, diagnostic checking and selection of the model were performed for fitting the models.

The $ARIMA(1,1,0)(1,0,1)_{52}$, $ARIMA(1,1,1)(0,1,1)_{52}$, $ARIMA(1,1,1)(0,1,1)_{52}$ and $ARIMA(0,1,1)(0,1,1)_{52}$ models were selected for forecasting and generation of weekly ET_r values for Solapur, Ahmednagar, Pune and Nasik districts, respectively. The values of the parameters of the ARIMA models which are finalized for forecasting and generation of weekly ET_r values for Solapur, Ahmednagar, Pune and Nasik districts are:

Solapur: $\emptyset_1 = -0.3054$, $\Phi_1 = 0.9895$, $\Theta_1 = 0.9336$, C = - 0.001, Ahmadnagar: $\emptyset_1 = 0.3958$, $\theta_1 = 0.96836$, $\Theta_1 = 0.9467$, C = 0.000176, Pune: $\emptyset_1 = 0.4091$, $\theta_1 = 0.9727$, $\Theta_1 = 0.9895$, C = 0.00025, and Nasik: $\theta_1 = 0.559$, $\Theta_1 = 0.9475$, C = 31.24.

Keywords: Pomegranate(***Punica granatum*** L.), Crop coefficient (k_c), Reference crop evapotranspiration (ET_r), Pomegranate evapotranspiration (ET_c), ET_r methods, Probability distribution functions, Stochastic model and Seasonal ARIMA model.

CHAPTER-I
INTRODUCTION

1.1 IMPORTANCE OF EVAPOTRANSPIRTAION IN IRRIGATION WATER MANAGEMENT

Water is prime natural resource and there are many competing sectors of water such as domestic, agricultural (irrigation), industries, power generation and recreation. Currently the share of water for agriculture in India is 82 %; however, as the domestic and industrial sectors are getting priority in National and State Water Policies, the agricultural sector will get a reduced share of water. On the other hand, though the food grain production in India increased to a level of 211.32 Mt in 2001-2002 from 89.36 Mt in 1964-65, this is not sufficient to meet the demands of constantly increasing population (1.5 % per annum) (Anonymous, 2004a).

Irrigation has played a key role in raising food production and achieving self sufficiency in India. The total ultimate irrigation potential of the country is 139.89 Mha, out of which 75.84 Mha is surface water potential and 64.05 Mha is groundwater potential. Against the 93.98 Mha of total irrigation potential created, only 80.80 Mha was utilized till the end of IX five-year plan, thus with a gap in irrigation of about 13.18 Mha . Similar situation exists in Maharashtra state, the 3rd largest state in terms of area. Its economy is dependent upon agricultural production. The state has created approximately 3.7 Mha irrigation potential by 2000-2001. However, only 1.3 Mha area is currently irrigated (Anonymous, 2004b)

As the productivity of irrigated agricultural is 2 to 3 times more than the productivity of rainfed agriculture, it is necessary to increase the area under irrigation to satisfy the food requirement of continuously growing population. The area under irrigation can be increased by creating more water resources through the construction of irrigation projects. However, historically as we have harnessed easily and cheaply available water resources, the cost of creating new water resources is high and often not technically feasible. The environmental and social reasons also limit creating additional water resources. Therefore, the feasible option is to use the available water efficiently. There are several ways of efficiently using water. Theses includes: appropriate irrigation scheduling, adoption of water saving irrigation methods such as sprinkler and drip, optimum allocation of land water resources, canal lining, reservoir desiltation and afforestation of the catchment area.

These options are not alternatives to each other but complimentary to each other. Most of these options call for the exact estimation of water requirement that varies with crops, their growth stages, climate etc. The knowledge of water requirement is further necessary to match spatial and temporal distribution of water demand with water supply so that water resources are used efficiently. The evapotranspiration is the important component of crop water requirement. Evapotranspiration is required for proper water management in the problems involving the estimation of water availability, water supply and water demand/requirement. Evapotranspiration is the main component of irrigation requirement of any crop. Reservoir storage capacity can be adequately designed with accurate estimates of monthly or seasonal net irrigation requirements. Similarly, the information of net irrigation requirement during fortnight or month or a season is useful for deciding the amount of water to be delivered through canal network. The net irrigation requirement requires estimates of evapotranspiration and effective precipitation. Evapotranspiration data are essential for estimating water yields from watersheds, safe yields of ground basins, low depletions in river basins. Evapotranspiration is essential in negotiating water treaties and in irrigation and adjudication of water rights in major river systems in which the welfare of people in villages, cities, valleys, states and even nations are involved. As explained above evapotranspiration is important component in irrigation planning and therefore it is important to know its accurate estimate for different crops and their growth stages. As evapotranspiration is dependent on the climate, it is also essential to know its variation over different climatic conditions. Under water scarcity situations, the estimates of evapotranspiration are required at certain probability levels. In addition to this short term future estimates of evapotranspiration are helpful for proper irrigation planning. Pomegranate being the important fruit crop of the Western part of Maharashtra state, this study which is aimed at stochastic modeling of evapotranspiration of pomegranate (*Punica granatum* L.) was undertaken.

1.2 POMEGRANATE (*Punica granatum* L.) FRUIT CROP

Pomegranate, also called as *Anaar*, is one of favorite fruits of tropical and subtropical regions. Pomegranate is a high value crop and its entire tree is of great economic importance. All parts of the Pomegranate tree have great therapeutic value and are used in leather and dyeing industries. Pomegranate was originated in Iran and widely cultivated in Mediterranean countries like Spain, Morocco, Egypt, Afghanistan and Pakistan. This fruit crop is also grown in Burma, China, Japan and USA. In India Pomegranate is commercially cultivated in Maharashtra followed by Andhra Pradesh, Uttar Pradesh, Tamil Nadu, Karnataka, Gujarat, Rajasthan, Punjab and Haryana. India is the second largest producer of fruits in the world and first in the Pomegranate production. The total pomegranate production in the world is 1.15 MT out of which India produce 0.5 MT, but export only 0.005MT.

At present more than 0.13 Mha area is covered in India under pomegranate of which 0.087Mha area is in Maharashtra, producing about 85 % of total Indian production. Thus Maharashtra state leads in pomegranate production in the country. There has been steady increase in area and production of pomegranate in the country. It is estimated that by the year 2025, the area under pomegranate is projected to increase to 0.75 Mha, from 0.13 Mha at present. Consequently production is expected to increase by 10 folds and exports by nearly seven folds by the year 2025. The productivity level is still low (<11.2 t/ha) in India as compared to the major pomegranate producing countries like Israel, Iran, Morocco, Egypt, Afghanistan, Spain, Turkey, China, Greece, Japan France, Italy (>40 t/ha) etc. In Maharashtra pomegranate is commercially cultivated in the districts of Solapur, Nasik, Ahmednagar, Pune, Sangli, Satara, Dhule, Aurangabad, Latur and Osmanabad. In the pomegranate growing area of Maharashtra, water is scarce commodity and hence, there is a need to apply water according to water requirement of the crop. As evapotranspiration is the important component of the water requirement and varies with the climate, there is a need to estimate evapotranspiration for different regions/districts. To consider the variation of water requirement with respect to different stages/ages of pomegranate plantation, it is also necessary to know crop coefficients for pomegranate accordingly to its growth stages/ages. Therefore, there is a need to develop crop coefficient and determine water requirement of pomegranate for different regions. Probability analysis and stochastic modeling of evapotranspiration of pomegranate are required for appropriate irrigation planning and management.

1.3 STOCHASTIC MODELING OF EVAPOTRANSPIRATION OF POMEGRANATE

Optimum utilization of scarce water resources in Pomegranate growing region needs the knowledge on all dimensions of water requirement of pomegranate. Evapotranspiration is the major component of water requirement. Therefore, it is necessary to know the appropriate method for estimation of evapotranspiration and its estimate for different climatic regions. As the water requirement of pomegranate varies with its growth stages and age, it is also important to know the crop coefficient values of Pomegranate. In addition to this, often the available water resources need to be planned at desired probability levels and it becomes necessary to know the short term forecast of evapotranspiration values. Therefore, considering the importance of water requirement for pomegranate, the study was undertaken on estimation of evapotranspiration, determination of crop coefficient, and probability and stochastic modeling of evapotranspiration of pomegranate.

1.3.1 Reference Crop Evapotranspiration

Reference crop evapotranspiration is the major component of crop water requirement. It is defined as the quantity of water transpired by plants during their growth or retained in the plant tissue and the moisture evaporated from the surface of soil and vegetation and not short of water. It is used to describe the atmospheric "demand" for water. Evapotranspiration from vegetated surface is the result of several processes like radiation exchanges, vapour transport and biological growth operating within a system involving the atmosphere, plants and soil. Evapotranspiration which thus includes evaporation of water from land and water surface and transpiration by vegetation continues to be foremost important parameter in water resource planning and management.

Because of ambiguities involved in the interpretation of potential evapotranspiration, the term reference crop evapotranspiration is frequently being used. Doorenbos and Pruitt (1977) defined reference crop evapotranspiration as the rate of evapotranspiration from an extensive surface of 8 to 15 cm, green grass cover of uniform height, actively growing, completely shading the ground and not short of water. Further this definition was reported by Food and Agricultural Organization, (FAO) as the evapotranspiration rate from a reference surface, not short of water (Allen *et al*., 1998) and is denoted as ET_r. The reference surface is a hypothetical grass reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s/m and an albedo of 0.23. Thus, the concept of the reference evapotranspiration or reference crop evapotranspiration was introduced to study the evaporative demand of the atmosphere independent of crop type, crop development and management practices.

Reference crop evapotranspiration are affected by many management and natural factors. Management factor includes soil salinity, water supply, water quality, crop variety, poor land fertility, presence of hard or impermeable soil horizons, planting date, plant spacing, development stages, irrigation scheduling, cultivation and chemical spraying. The natural factors are climate, soils and topography. Climatic factors include air temperature and humidity, precipitation, solar radiation, wind movement and length of growing season.

The major factors affecting reference crop evapotranspiration are climatic parameters. Consequently, reference crop evapotranspiration is a climatic parameter and can be computed from weather data. Reference crop evapotranspiration expresses the evaporative power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors. The Penman-Monteith method is recommended as the sole method for determining ET_r. This method has been recommended because it closely approximates grass ET_r at the location evaluated, is physically based and explicitly incorporates both physical and aerodynamics parameters. Moreover, procedures have been developed for estimating missing climatic parameters.

The various methods for estimating the reference evapotranspiration are: Thornathwaite (Thornathwaite, 1948); Penman (Penman, 1948); Makkink (Makkink, 1957); Hamon (Hamon,1961); Blaney-Criddle (Blaney-Criddle, 1962); Jensen-Haise (Jensen-Haise, 1963); Christiansen (Christiansen, 1968); Priestly-Taylor (Priestly-Taylor, 1972); Hargreaves (Hargreaves, 1975); Modified Penman (Doorenbos and Pruitt, 1977); FAO-24 Pan Evaporation (Doorenbos and Pruitt, 1977); FAO Radiation (Doorenbos and Pruitt, 1977); Kimberly Penman or Penman Wright (Wright, 1982); Hargreaves-Samani (Hargreaves-Samani,1985); Solar radiation (Irmak *et al.,* 2003); Net radiation (Irmak *et al.,* 2003) and Penman-Monteith methods (Allen *et al.,* 1998).

A large number of more or less empirical methods for calculating ET_r over the last 50 years worldwide based on different meteorological and climatic variables have been suggested (Jensen *et al.,* 1990; and Allen, 2000). Many of these models are based on empirical relations with local calibrations of model coefficients and suffer from a limited spatial and temporal validity. Various investigator tested models using the same meteorological data sets and found varying results (Pramele and McGuinness, 1974; Maity *et al.,* 1979; Sharda and Bhushan, 1984; Kuruvilla *et al.,*1989; Jensen *et al.,* 1990; Michalopoulou and Papaioannou, 1991; Ismail, 1993; Steele, 1996; Hatfield and Allen, 1997; Kashyap and Panda, 2001; Gouranga and Chakravarthy, 2002; Hargreaves and Allen, 2003; Magali *et al.,* 2004; Bhakar and Singh, 2005; Lopez-Urrea *et al.,* 2006 and Villa Nova *et al*., 2007). As stated above, there are different methods for estimating ET_r; some requiring huge data but considered as accurate and other requiring less data but considered as approximate. The analysis of the performance of the various methods revealed the need for formulating a standard method for the computation of ET_r. For this reason, the FAO Penman-Monteith method (Allen *et al.,* 1998) has been recommended as a standard. Therefore, in this study it was planned to estimate ET_c of pomegranate by different methods and compare those with ET_c values estimated by Penman-Monteith method recommended by FAO as the most accurate one but needs data on many climatological parameters.

The main purpose of estimating reference evapotranspiration by which a crop coefficient is multiplied is to obtain an estimation of specific crop evapotranspiration (pomegranate). Further, for irrigation planning, it is essential that the ET_c values of pomegranate be determined for different districts of Maharashtra where pomegranate is predominately grown.

1.3.2 Crop Coefficient

As stated earlier the estimation of evapotranspiration of pomegranate fruit crop is necessary for appropriate irrigation water management. The crop evapotranspiration is related to reference crop evapotranspiration (ET_r) through a factor called crop coefficient. The crop evapotranspiration (ET_c) calculations are dependent on the correct estimation of crop factors alternatively referred to as crop coefficient (k_c). Crop coefficient is function of crop developmental stages, crop condition, soil parameters, agro climatic condition prevailing in the area and water availability to the particular crop at particular time. The crop coefficient values are influenced by local climatic condition and need to be measured locally. The information on deciduous fruit crop coefficient (k_c) values is often contradictory and confusing. The crop coefficient values are measured accurately from the lysimetric experiments. However, planning and conduct of lysimetric experiments are expensive and time consuming. Hence the crop coefficient values for deciduous fruit crops that were determined by Food and Agriculture Organization (Doorenbos and Pruitt, 1977) based on the average crop coefficient values all over the world are used by the researchers, planners and managers of water resources system across the world. However, FAO values are average over different agro-climatic regions and provide only guidelines. Therefore, for proper estimation of ET_c, it is necessary to develop k_c values locally. Crop coefficient is linear functions of the amount of shade measured beneath the crops at solar noon hour. Therefore, in this study, the crop coefficient values of the pomegranate crop under consideration have been estimated from the measurements of shaded area of pomegranate orchards at solar noon hour.

1.3.3 Probability Distribution Function for Reference Crop Evapotranspiration (ET_r)

The present practice to estimate water requirement is to take the average estimates of ET_r over some years. However, simply taking the average does not result in proper estimate as the variable evapotranspiration may take on any of the values of a specified set with a certain probability. Therefore, the irrigation planning should be based on the probabilistic approach and for this purpose it is necessary to know the ET_c values at the different probability levels. Therefore, it is essential to know the probability distribution of ET_c. The probability distribution function of ET_c is also required for stochastic modeling. In addition to this, probability analysis can be used for prediction of occurrence of future events from available records. Therefore, in this study it is planned to fit the several probability distribution functions to ET_r data and investigate the probability distribution functions that fit the ET data most suitably.

Based on the theoretical probability distributions of evapotranspiration data, it would be then possible to generate/forecast crop evapotranspiration with desired level of probability. Theoretical probability distributions generally used for hydrological series includes Normal, Log normal, Log Pearson –III, Gumbel, Gamma, Weibull's and Exponential distributions. The probability distributions that are used for evapotranspiration data are: i) Normal distribution (Ingle, 1993; and Devendrakumar *et al.,* 1998); ii) Log normal distribution (Dalvi and Thakur, 1990) and Gamma distribution (Raj kumar and Kumar, 2007; and Kulshrestha *et al.,* 2007). They used Chi-square test (Dalvi and Thakur, 1990; and Suresh, 2003) and Kolmogorov–Smirnov test (Kulshrestha *et al.,* 2007) to test the goodness of fit of parametric probabilistic distribution to the given set of data. In this study, therefore, normal, log normal, gamma, Gumbel and Weibull's probability distribution functions were proposed to fit to reference crop evapotranspiration.

1.3.4 Stochastic Modeling of Evapotranspiration

A mathematical model representing a stochastic process is called "**stochastic model**". A stochastic model is the mathematical abstraction of an empirical process and is governed by time depended probabilities laws. The word stochastic (which was apparently suggested 300 years ago by Jacob Bernoulli of Switzerland) means, according to its Greek origin, to contemplate or to conjecture. Roughly speaking it can be regarded as synonymous with chance, random or probabilistic but more precisely the interdependence of random variables is accounted for. It has a certain mathematical form or structure and a set of parameters.

The process of evapotranspiration is stochastic in nature. Usually, the deterministic models do not consider the random effects and may not represent the evapotranspiration quite accurately. On the other hand, the stochastic models are based on the time dependent variations and consider random effects involved in the process. Stochastic models explain the extent of dependence of the present observation on the past observations and therefore stochastic modeling of ET_r may provide good insight into and understanding the processes of ET_r that is useful for applications in water resources development and management. Stochastic linear model are fitted to hydrological data or time series such as evapotranspiration series mainly for two main reasons: to enable forecasts of the data one or more time periods ahead and to enable the generation of sequences of synthetic data. The stochastic models are able to generate the data having the statistical properties resembling with the statistical properties of the historical data. Often the historical series is short and inadequate for irrigation planning. Hence, stochastic models are useful for generation of long term ET_r data that are useful for irrigation planning. Stochastic models also have the ability to forecast the data for short term. Forecasting of ET of pomegranate will be useful for pomegranate growers for managing their water resources more efficiently. The synthetic and forecast data are of considerable importance for design and operation of water resources systems.

Several stochastic models have been developed in the past for modeling of hydrological time series, such as autoregressive (AR), moving average (MA), autoregressive moving average (ARMA) and autoregressive integrated moving average (ARIMA) to generate and forecast annual rainfall and runoff values. The multiplicative seasonal autoregressive integrated moving average (ARIMA) that have been described by Box and Jenkins (1976) have been used for generation and forecast of weekly, fortnightly and monthly values. The ARIMA process is a powerful time series modeling and forecasting technique which processes flexibility for the inclusion of many time series characteristics. In past ARIMA models have been used successfully to model hydrological time series (Gorantiwar, 1984). Therefore, in this study, it is proposed to investigate the suitability of ARIMA class of models to ET of pomegranate.

As stated before, Pomegranate is an important fruit crop of this region. The systematic studies on determination of ET_r, development of crop coefficient, probability analysis and stochastic modeling of pomegranate evapotranspiration were not conducted under different climatic conditions of Maharashtra. Present study was therefore, proposed with the following objectives that aims at bridging the gap between existing knowledge and requirement of planners and pomegranate growers. The output of this study obtained will be useful for planning the water resources and the supplemental or life saving irrigation for pomegranate.

1.4 OBJECTIVES

This study entitled **"Stochastic Modeling of Evapotranspiration of Pomegranate (*Punica granatum* L.)"** is therefore undertaken to develop crop coefficient of pomegranate, estimate pomegranate evapotranspiration by suitable methods, develop probability distribution functions and stochastic models for ET_r. The specific objectives of the study were as stated below.

1. To develop crop coefficient curves for pomegranate.
2. To determine and compare the evapotranspiration of pomegranate for major pomegranate growing districts of Maharashtra.

3. To develop the probability distribution functions for evapotranspiration of pomegranate.
4. To develop and validate stochastic model for generating and forecasting evapotranspiration of pomegranate.

CHAPTER-II

REVIEW OF LITERATURE

This section briefly deals with the review of the research work carried out in India and abroad in relation to the objectives of the proposed study. An extensive review of research literature has been made on the lines of objectives contemplated to facilitate devising an appropriate methodology towards accomplishing the entire research topic. The proposed study consists of the development of the methodology for determination of crop coefficient for pomegranate. The crop coefficient values are essential for the estimation of water requirement of pomegranate. Further it is necessary to know the values of water requirement at certain desired probability level and their short term forecast for the appropriate irrigation planning. The scientific studies on these aspects have been underway for many years. The literature on crop coefficient and leaf area index of deciduous fruit crop, reference crop evapotranspiration, actual crop evapotranspiration, probability distribution function of ET_r and stochastic modeling of ET_r time series are extensive and some excellent reviews and books are available on these topics. Brief reference reviews on the topics related to the present study have been presented in this section.

2.1 CROP COEFFICIENT VALUES/CURVES FOR DECIDUOUS FRUIT CROPS

The crop coefficient values for different crops including plantations were determined in the past. However, very few studies have been reported for deciduous fruit crops and none for pomegranate. In this section therefore, a brief review of development of k_c values for deciduous fruit crop is presented.

Pruitt (1992) conducted the lysimeter based crop coefficient studies and developed the season's curves for both the crop coefficient (k_c) and basal coefficient (k_{cb}). He presented smooth curves for k_c for most of the crops studied. The k_c values for early or initial crops period were developed by using FAO-24 methodology. A graph is provided showing the expected length of initial periods of several crops as a function of planting date.

Sepaskhah and Kashefipour (1995) conducted an experiment to determine crop evapotranspiration and coefficients of sweet lime and to establish the relationship between (ET) canopies to air temperature differential (T_c-T_a ^{0}C) under drip irrigation treatments with different amount of water. The maximum value of k_c for sweet lime under drip irrigation (1.17) was greater than that for other citrus trees under irrigation system (0.75). The equation for estimation of average 24 h ET (mm/hr) by monitoring (T_c-T_a, ^{0}C) is ET = 3.02-0.94 (T_c-T_a). Furthermore, the equation for estimation of average 24 hr ET, (mm/day) by monitoring (T_c-T_a) is (ET-ET_p) = -0.43(T_c-T_a), in which T_c is the canopy temperature of well watered trees (^{0}C).

Haman *et al.* (1997) conducted three year studies of water use by two species of cultivated blueberries in Florida, USA. Water was applied to the plants using a micro-irrigation at three soil water tension levels: 10 KPa, 15 KPa and 20 KPa. Water uses for both the species were monitored using drainage type lysimeters and water budget method. The crop coefficients for micro-irrigated blueberries were below 0.2 during the first two years of plant establishment and increased to 0.35 in the third year as the plants rapidly increased in size.

Grismer *et al.* (2000) developed coastal area crop coefficients for Citrus and Avocado fruit crops in two commercial orchards located near Ventura, Southern California, USA. The developed crop coefficient values were 0.46 for young citrus, 0.52 for mature citrus and 0.64 for mature Avocado orchards.

Mishra *et al.* (2000) estimated crop coefficient using computerized irrigation scheduling and water management models in Assam. The continuous functions in the discrete values of k_c and predicting the daily k_c to be used for computation of actual crop evapotranspiration (ET_c) for daily crop root zone water balance and daily water use for wheat, rice, mustard, potato, jute and tea for lower Assam. The computed ET_c values were obtained from using standard discrete values of k_c using long time climatic data. The fitted as well as the predicted ET_c are in good agreement. Therefore, recommended that by using the continuous functions for k_c, the ET_c could be easily computed with the use of model WATERMAN.

Naor *et al.* (2000) investigated interaction between irrigation and crop load in their effect on fruit size distribution for Pear orchard at semi-arid zone of Israel. Five crop coefficient treatments were applied during the main fruit expansion phase: 0.25 k_c, 0.40 k_c, 0.60 k_c, 0.80 k_c and 1.00 k_c where the crop coefficient is the applied irrigation level (mm) divided by the USDA class A Pan evaporation rate (mm). Cumulative irrigation level from the beginning of the season until harvest was 271, 351, 465, 572, 502 and 688 mm, in the 0.25 k_c, 0.40 k_c, 0.60 k_c, 0.80 k_c and 1.00 k_c treatments, respectively. The relative yields of fruits exceeded by 55, 60 and 65 mm with increasing crop coefficient up to 0.80 k_c, whereas the relative yields of fruits larger than 55, 60 and 65 mm increased with increasing crop coefficient up to 0.60, 0.80 and 1.0, respectively. The fruit weight was highly correlated with the midday stem water potential.

Ayars *et al.* (2003) conducted experiment for four years using a large weighing lysimeter to determine the crop coefficient and crop water use of a late-season peach cultivar. Two trees were planted in a 2x4x2 m deep weighing lysimeter that was surface irrigated with 2 l/h in-line drip emitters spaced evenly around the trees. Irrigation was applied in 12 mm applications after a 12 mm water loss threshold was exceeded as measured by the lysimeter. The crop coefficient (k_c) was calculated using the measured water losses and grass reference evapotranspiration calculated using the CIMIS Penman equation. k_c was plotted against day of the year and linear, quadratic, and cubic regressions were fitted to the data. These equations are: $k_c = 7.448 - 0.0221 *DOY$ for DOY 290 -304, $k_c = 0.9758 + 0.2223*D + 0.1646*D^2$ and $k_c = 0.9695 + 0.3691*D + 0.1549 *D^2 - 0.07034 * D^3$, Where DOY – Days of the year, D = (DOY-182)/70.76) A three segment linear and the cubic equation was the best fit to the data. The maximum k_c determined for the linear fit was 1.06. The peach tree crop coefficients as a function of the proportion of available light intercepted by the canopy at mid-day and the equation of the regression line is $k_c = 1.59 *x + 0.082$, $R^2 = 0.86$. Average annual water use of the 4 years of the experiment was 1034 mm. Mid-day light interception was found to be well correlated with the crop coefficient determined by using the lysimeter data.

Garcia *et al.* (2003) estimated irrigation requirements of Quinoa in a representative site of the Bolivian Altiplano, South America. The crop water requirement, crop coefficient, the yield response factor and the relative yield were derived from lysimeter and field data. The Penman-Monteith formulae were calibrated in relation to grass evapotranspiration data used as reference crop from lysimeter. The k_c for Quinoa obtained from lysimeter data varied over the growing season being 0.5 in the initial growth stages, 1.0 in the mid-season stages and 0.7 at the harvest.

Erraki *et al.* (2004) estimated crop coefficients of olive orchards using olives transpiration determined by sap flow method and soil evaporation measured by eddy covariance method in southern Morocco. Crop coefficient values were estimated as a ratio of olive evapotranspiration and the reference crop evapotranspiration computed by using different methods. The reference crop evapotranspiration values were estimated by using various methods (i.e. Penman-Monteith, Penman, Priestly-Taylor, Makkink and Turc’s Radiation). The mean annual values of crop coefficient were 0.67 for Penman-Monteith, 0.65 for Penman, 0.83 for Priestly Taylor, 0.75 for Makkink and 0.7 for Turc’s Radiatiation methods, respectively. Results indicated that the combination methods give the crop coefficient values near to the values recommended by Allen *et al.* (1998).

Johnson *et al.* (2005) installed two large weighing lysimeters, one in a peach and other in grape vineyard orchards in the San Joaquin Valley California, USA. Hourly weight changes in the lysimeters were used to measure the daily and seasonal water use of trees and vines for nearly 20 years. Peaches and grapes exhibited similar crop coefficients patterns that start as low as 0.1 in March, increased linearly until early July and remained constant between 1.1 and 1.2 for the remainder of the season. The linear increase phase was proportional to the increase in canopy light-interception and leaf area. These relationships have facilitated modeling to predict crop evapotranspiration under various conditions.

Kang *et al.* (2005) investigated transpiration ratio, crop coefficient and the ratio of transpiration to evapotranspiration by using three irrigation methods (i.e. conventional flood irrigation(CFI), fixed partial root zone drying with irrigation (FPRD) and alternative partial root zone drying with irrigation(APRD)) in a semi-arid region of Victoria, Australia. The average seasonal ET was 865.3, 795.6 and 804.6 mm, respectively for CFI, FPRD and APRD with ET_r of 817.6 mm for pear fruiting season. The seasonal transpiration accounted for 81.1 %, 84.4 % and 84.1 % of evapotranspiration of CFI, FPRD and APRD, respectively. The seasonal average k_c was 1.05, 0.973 and 0.985 for CFI, FPRD and APRD, respectively. The ratio of transpiration and evapotranspiration varied from 0.736 to 0.909, 0.743 to 0.947 and 0.741 to 0.925 in the pear fruiting season for CFI, FPRD and APRD, respectively. Results indicated that, the APRD and FPRD can improve the ratio of transpiration to evapotranspiration and reduce transpiration coefficient and crop coefficient.

Williams and Johnson (2005) developed relationship between canopy size and sunlight exposure to grapevine water consumption for peaches and grapevine trees in California, USA. They mentioned that, the crop coefficients of deciduous fruit crop are a function of size of canopy and how much of it is exposed to direct sunlight. They also showed that the grapevine and peaches crop coefficient can be readily estimated for a vineyard and peaches by estimating the percentage of shaded area of the vineyard and peaches that is shaded. According to them, the percentage of shaded area must be estimated during the solar noon hour (between 12 to 1.30 PM) by one of the following methods (1) Measured the average width of shaded area beneath the vine row (2) Estimate the canopy of shaded area from board with gridline placed in the shade beneath the vine row (3) Determine the canopy shaded area from pixel analysis of digital photograph.

Consoli *et al.* (2006) evaluated crop evapotranspiration and crop coefficient values of four Orange orchards that were irrigated with micro-sprinklers having different canopy features (i.e. age, height and canopy cover). Crop evapotranspiration were determined by using surface renewal method and reference evapotranspiration were determined by using Penman-Monteith equation. Crop coefficient were determined by calculating the ratio of $k_c = ET_c/ET_r$. The estimated crop coefficient values ranged from 0.45 to 0.93 for canopy covers having between 3.5 to 70 percentage ground shading.

Conceicao *et al.* (2006) developed crop coefficient for a Peach orchards, obtained with a direct measurements of evapotranspiration. Eddy covariance micrometeorological method was used to measure evapotranspiration. The closure error of the surface energy balance equation was around 15 %. The average ET rates were 2 mm/day and mean crop coefficient of peach orchard (mid growing days) was around 0.5.

Miranda *et al.* (2006) determined the crop evapotranspiration and crop coefficients for Tabasco Pepper in the North East region of Brazil. Crop evapotarnspiration was measured daily using a precision weighing lysimeter with a surface area of 2.25 m^2 and reference evapotranspiration was estimated by using Penman-Monteith method. The results indicated that, the total crop evapotranspiration observed throughout the 300 days crop season was 888 mm. The maximum daily values of 5.6 mm/day and maximum values of crop coefficient were observed during the two periods of intense flowering and fruit development preceding fruit harvest. Average crop coefficients observed during the first harvest cycle were 0.3, 1.22 and 0.65 for the initial, mid season and end of the late season stages.

Alves *et al.* (2007) estimated the actual evapotranspiration of young ‘Tahiti’ lime orchards by considering soil evaporation coefficient and crop transpiration coefficient in Sao Paulo, Brazil. The soil evaporation coefficient varied between 0.6 to 1.22 and crop transpiration coefficient varied between 0.4 to 1.0. The results suggested that for young lime trees, the actual evapotranspiration per tree calculated by using both the coefficient is about 80 % higher than the calculated actual evapotranspiration by using only crop coefficient.

De Azevedo *et al.* (2007) determined the water requirements of the Pineapple crop grown in the coastal table lands of Paraiba State, Brazil. Crop evapotranspiration was estimated by the Bowen ratio–energy balance and reference evapotranspiration by the Penman-Monteith method. The results indicated that, the crop evapotranspiration was lower in the beginning of the vegetative growth and fruit harvest and higher in the middle of the productive cycle. Lower values of the crop coefficient were observed during the vegetative growth stage while for the whole crop cycle $k_c = 0.88 \pm 0.06$.

Petillio and Castel (2007) developed average annual crop coefficient values for citrus irrigated trees which was 0.69. Monthly crop coefficient values showed a clear seasonal trend, with minimum values in summer (0.60), intermediate values in autumn and spring (0.70 and 0.80, respectively) and maximum values in winter (0.87). The maximum monthly average water requirement of citrus tree was 3.3 mm/day or 80 litres/day/tree. These values are useful for the design and operation of micro-irrigation system, for mature citrus trees in Uruguay.

Wang *et al.* (2007) derived a regression relationship in the form of ratio of crop coefficient and maximum crop coefficient is equal to the function of effective crop cover for open canopy Pecan orchards. Effective canopy cover was measured for orchards with different canopy covers using image analysis. A regression equation (i.e. $k_c = k_{cmax}$ x 1.33*ECC) for open canopy Pecan orchards was obtained from open pan effective cover, effective canopy cover and remote sensing techniques and was found to be statistically significant ($r^2 = 0.96$). This crop coefficient equation can be help to the Pecan growers and researchers to get more accurate estimates of Pecan irrigation requirements.

Netzer *et al.* (2008) estimated crop water use and seasonal crop coefficient for grapevine by using drainage lysimeter during 2001-2005 in Rehovot, Israel. Water consumption of the lysimeters grown vines was used as the basis for the calculation of irrigation applications in the vineyard. Three irrigation treatments (80%, 60% and 40%) of vine water use of the lysimeter grown vines were applied. ET_r was calculated from regional meteorological data according to the Penman-Monteith method. Seasonal crop coefficient curve were calculated as $k_c=ET_c/ET_r$. Maximum ET_c values in different seasons ranged from 7.26 to 8.59 mm/day and seasonal ET_c ranged from 1,087 to 1,348 mm over the growing season. LAI was measured monthly using the SunScan Canopy Analysis System. Maximum LAI ranged from 4.2 to 6.2 for the year 2001 - 2005. A second order polynomial curve relating k_c to LAI ($R^2 = 0.907$, $P<0.0001$) was proposed as the basis for efficient irrigation management.

Teixeira *et al.* (2008) estimated the values of crop coefficient for commercial mango orchards at Northwest Brazil. They estimated crop evapotranspiration by eddy covariance technique and ET_r by Penman-Monteith method. The mean values of k_c based evapotranspiration and transpiration were 0.91 and 0.73, respectively.

Villalobos *et al.* (2009) studied the contribution of transpiration and soil evaporation in a drip irrigated, clean cultivated mandarin orchard on a sandy soil in Southern Spain. Evapotranspiration was measured using eddy covariance, while the soil evaporation was determined with micro-lysimeter, during August, 2000 and May, 2001. Average evapotranspiration was 2.6 mm/day in August, 2000 and 2.1 mm/day in May. The average crop coefficients were 0.44 and 0.43 in 2000 and 2001, respectively.

Martinez-Cob and Faci (2010) estimated evapotranspiration of Olive orchards by using eddy covariance micro-meteorological method during 2004-2005 under the semi-arid conditions of the middle Ebro River Valley, Spain. An eddy covariance system (krypton hygrometer KH20 and 3D sonic anemometer CSAT3 and Campbell scientific) was used. The highest measured monthly crop evapotranspiration values were about 3.1–3.3 mm/day, while the total seasonal crop evapotranspiration was 585 mm in 2004 and 597 mm in 2005. Monthly k_c values varied from 1.0 for winter, 0.4 for spring and 0.5 for summer.

The studies reported in this section concerns with crop coefficient for deciduous to evergreen fruit crops by using various methods. These methods include lysimeter studies (drainage, large weighing, precision weighing and micro-lysimeter), shaded area, water balance, and leaf area indices. The different deciduous to even green fruit crops included grapevine, peach, sweet lime, orange, citrus, avocado, tea, quinoa, tabasco, pineapple and pecan. It was observed from these studies, the k_c values for initial, mid and late seasons of deciduous to even green fruit crops range from 0.1 to 1.0, 1.0 to 1.22 and 0.45 to 0.93, respectively. There were no studies that reported the crop coefficient values for pomegranate. Therefore, it was decided to develop k_c values for pomegranate from young orchard of 1st year to mature orchard of 5th year. It is difficult to conduct the lysimeter studies for the pomegranate fruit crop that have the spacing of 4.5 m x 3 m and matures after 4-5 years. Therefore, in this study the shaded area approach was used for the determination of k_c.

2.2 MEASUREMENT OF EVAPOTRANSPIRATION FOR DETERMINATION OF CROP COEFFICIENT

For determining crop coefficient, two parameters viz. crop evapotranspiration (ET_c) and reference crop evapotranspiration (ET_r) are needed. The reference crop evapotranspiration (ET_r) is estimated by various method and crop evapotranspiration (ET_c) needs to be measured or determined by appropriate methods. In this section different methods used in past for measurement of evapotranspiration are discussed.

2.2.1 Lysimetric Method

Crop evapotranspiration is very difficult to measure, but several methods have been developed for this purpose. First, a lysimeter can be used to measure crop evapotranspiration. It is a device in which volume of soil, with or without crop is located in container to isolate it hydrologically from the surrounding. For accurate and reliable measurement of evapotranspiration, the lysimeter needs to be constructed, installed and operated properly. According to the system used for estimating the water loss two general types of lysimeters are in use (i) non-weighing type and (ii) weighing type. Non-weighing lysimeters are well suited for measuring the long term evapotranspiration data. Non weighing lysimeters can be classified as (a) constant water table and (b) percolation type. Constant water table non-weighing lysimeters provide reliable data in areas of high water table condition. Percolation type non-weighing lysimeters are often used in areas of high rainfall. Singh and Sukhla (1978) discussed the procedure for measurement of evapotranspiration by different types of non-weighing lysimeters.

Weighing lysimeters furnish evapotranspiration data for short periods but their installation and operation cost is too high. The weighing type is generally more accurate, but more costly to install and operate (Watson and Burnett, 1995). Weighing lysimeters differ not only in the mode of weighing but also in features of construction. Four types of weighing systems have been developed by different investigators. These are:

2.2.1.1 Mechanical weighing lysimeter

The most common types of mechanical weighing lysimeters have mechanical balances to measure the weight loss. Precision mechanical weighing lysimeters were developed and used by Pruitt and Angus (1960), Van Bavel and Myers (1962), Ritchie and Burnett (1968), Mottram and De Jaggar (1973), Bhardwaj and Shastry (1979) and Hutson *et al*., (1980). They also explained the working of these lysimeters for measurement of evapotranspiration. These lysimeters permit large counter weights to offset the container and soil mass to permit precise measurements of the mass change of the water within the lysimeters. Several weighing lysimeters installations have used air conditioning/heating/dehumidification equipment to prevent condensation on mechanical scales.

2.2.1.2 Electronic weighing lysimeter

Load cells are used in electronic weighing lysimeters. Load cell electronic weighing lysimeter usually measure the total lysimeters mass without counter weight so the accuracy is dictated by the load cell accuracy data processing and recording instrumentation. Allen and Fisher (1990) described the working of the load cell lysimeter for measurement of evapotranspiration.

2.2.1.3 Hydraulic load cell weighing lysimeter

Hydraulic load cell type weighing systems are used where economy and simplicity of the system are important. Temperature sensitivity of the liquid on which the soil mass rests limits the convenience and accuracy of such systems. With proper corrections for temperature sensivity, however, these units can be made accurate enough for daily or possible more frequent observations of evapotranspiration. Hydraulic load cell lysimeters have been developed by Hanks and Shawcroft (1965) and Korven and Pelton (1972).

2.2.1.4 Floating weighing lysimeter

King *et al.* (1956) described a floating lysimeters for measuring actual evapotranspiration. The lysimeters floated within water fill tank and the mass change was measured by the depth change of the fluid in stilling well. McMillan and Paul (1962) used a zinc chloride solution (specific gravity of 1.9) instead of water to reduce the buoyancy chambers within the lysimeter. The zinc chloride solutions were found to have large thermal expansion error than water. Aslyng and Kristensen (1961) used floatation to partially offset the dead mass of the lysimeters.

2.2.2 Aerodynamic

An aerodynamic technique assumes similarity in the mechanism of flux of momentum (τ), sensible heat (H) and water vapor (E). The three principle vertical fluxes resulting from turbulent diffusion in the surface boundary are given by the following analogous equations.

$$\tau = \rho_a k_m \frac{\partial u}{\partial z} \qquad (2.1)$$

$$H = \rho_a C_p k_h \frac{\delta \theta}{\delta z} \qquad (2.2)$$

$$E = \frac{\left(\frac{M_w}{M_a}\right)}{\rho_a} e_a k_w \frac{\delta \vartheta}{\delta z} \qquad (2.3)$$

Where, k_m, k_h and k_w are the turbulent exchange coefficients for momentum, sensible heat and water vapor, ρ_a is the air density, Cp is the specific heat at constant pressure, P is the atmospheric pressure $\frac{\delta u}{\delta z}, \frac{\delta \theta}{\delta z}, \mathbf{and}\ \frac{\delta \vartheta}{\delta z}$ are the vertical gradients of wind speed, potential temperature and vapor pressure and M_w and M_a are the molecular weight of water vapor and air.

If it is assumed that $k_m = k_h = k_{w,}$ it can readily be seen that E may be evaluated from the vapour pressure gradient if simultaneous measurements of the gradients of θ or U and of the flux of sensible heat of momentum are made at the same site. However, independent measurements of sensible heat or momentum flux are difficult to achieve and have thus been used only rarely. The assumptions of identity in k_m , k_h , k_w is valid only when the atmosphere is in a condition of near neutral stability.

The brief reviews on aerodynamic approach that was used in the past are enlisted here under

Thornthwaite and Holzman (1942) were among the first to apply the aerodynamic approach for the determination of evaporation under neutral stability condition of the atmosphere.

Dyer (1974) presented a detailed review of flux profile relationships. With the knowledge of the appropriate gradients in conjunction with the stability corrections, the fluxes of sensible heat and water vapour were estimated.

Rosenberg *et al.* (1983) have discussed the concept of stability of the atmosphere in details. According to them an adiabatic temperature profile corresponds to neutral stability condition of the atmosphere and the lapse and inversion profiles of actual temperature corresponds, to unstable and stable conditions of the atmosphere.

Malek (1993) applied the Bowen ratio-energy balance and corrected aerodynamic methods to estimate turbulent fluxes of sensible and latent heat at an irrigated alfalfa site in Utah, USA. The aerodynamic method under estimated the daytime sensible and latent heat fluxes by 30 per cent relative to the Bowen ratio energy method thereby indicating the need to modify stability functions of the aerodynamic model.

Teixeira *et al.* (2008) estimated crop water parameters (i.e. actual evapotranspiration, transpiration, soil evaporation, crop coefficients, evaporative fractions, aerodynamic resistances, surface resistance and percolation fluxes) in commercial mango orchards at Northwest Brazil. The actual evapotranspiration was obtained by eddy covariance technique, while reference crop evapotranspiration was estimated by Penman-Monteith method. The energy balance closure showed that a gap of 12%. The mean accumulated actual evapotranspiration of two seasons was

1419 mm/year, which corresponds to a daily average rate of 3.7 mm/day. The mean values of crop coefficients based on evapotranspiration and based on transpiration were 0.91 and 0.73, respectively. 20% of evapotranspiration originated from direct soil evaporation. The evaporative function was 0.83 on average. The resulting evapotranspiration deficits were 73-95 mm per season only. The mean aerodynamic resistance was 37 s/m and bulk surface resistance was 135 s/m.

2.2.3 Soil Moisture Depletion Method

Evapotranspiration under field condition can be determined by measuring the change of soil water content over a period of time. The soil water content can be measured by gravimetric sampling or with neutron probe or other indirect techniques. Other methods used for measuring soil water content include tensiometers and gypsum blocks. These techniques require calibration for each type of soil to determine the amount of water that must be applied to refill the profile.

The average rate of evapotranspiration in mm/day between sampling dates, ET_c can be calculated using the following equation (Singh, 2000).

$$ET_c = \sum_{i=1}^{n} \frac{(\theta_1 - \theta_2)\,\Delta S_i\,(R_e - W_d)}{\Delta t} \tag{2.4}$$

Where, n is the number of layers to depth of the effective root zone, ΔS_i is the thickness of each layer in mm, $(\theta_1 - \theta_2)$ are the volumetric content of the first and second date of sampling in m^3/m^3, R_e is effective rainfall in mm, W_d is the drainage or capillary contribution from the root sample in mm.

2.2.4 Surface Renewal Method

Spano *et al.* (1997) estimated sensible heat flux density over different crop canopies by using surface renewal method and compared results with eddy covariance measurements in Sassari, Italy. According to them the use of surface renewal sensible heat flux density values in energy balance determination of λE can give results nearly as accurate as those obtained using sonic anemometer.

Spano *et al.* (2000) estimated sensible heat flux density above and within canopies of grapevine by using surface renewal method in Italy. The results indicated that the surface renewal technique provides good estimates of sensible heat flux density under all stability conditions without the need for calibration when the data are measured at about 90% of the canopy height.

The value is 45 W/m^2 of what was measured with a sonic anemometer. According to authors the surface renewal technique offers an inexpensive alternative for estimating evapotranspiration with good accuracy.

2.2.5 Eddy Covariance Micro-Meteorological Method

Amiro and Wuschke (1987) measured evapotranspiration at two sites in a boreal forest drainage basin located in Southern Manitoba, Canada. An energy balance method was used in which net radiation and ground heat flux was measured directly. Sensible heat flux was measured by the eddy correlation technique, using a propeller anemometer and fine-wire thermocouple. The instruments were mounted at heights of 6 and 12 m above the forest canopy. One set of instruments was located on an upland area characterized by a sparse jack pine canopy and rock outcrops over 75% of its area. A basin-wide ET was calculated by weighting the values for the two sites in proportion to their area. The measured ET agreed well with precipitation minus runoff for the basin.

Echeverria and Farias (2009) evaluated the three sources model (Clumped model) for direct estimation of actual evapotranspiration and latent heat flux over drip irrigated vineyard under semi-arid condition in Talca Valley, Chile. The performance of the Clumped model was evaluated using an eddy covariance system during 2006-2008. Results indicated that the Clumped model was able to predict actual evapotranspiration with root mean square error value, mean bias error and model efficiency of 0.33, - 0.15 mm/day and 74%, respectively. Clumped model also simulated the daytime variation of latent heat with RMSE, MBE and EF was 36, -8 w/m^2 and 83%, respectively.

2.2.6 Bowen Ratio Energy Balance Method

Fritschen (1966) determined biweekly evapotranspiration rates for different crop combinations in the arid region of south-central Arizona, USA. The Bowen ratio method was used as continuous sampling to determine the evapotranspiration rates. Evapotranspiration rates ranged from 1.0 to 1.8 times net radiation indicating that large amounts of energy were extracted from the air mass.

Bidlake and Woodham (1990) estimated evapotranspiration from selected areas of types of native vegetation by using three methods (i.e. Bowen ratio energy balance, Eddy covariance and Penman) in west-central Florida, USA. The vegetation types were dry prairie, marsh, pipe flat wood, and cypress swamp. Evapotranspiration was estimated using the Bowen ratio energy balance and eddy covariance. Potential ET was computed using the Penman method. The Bowen ratio energy balance method was used in both forested and non-forested areas. Analysis of eddy covariance and energy balance data indicated that the sum of sensible and latent heat fluxes accounted for 68 % of available energy at the pinewood site and 45 % at the cypress swamp site. Annual ET was 1010 mm per year for the dry prairie, 990 mm per year for the marsh, 1060 mm per year for the flat wood and 970 mm per year for the cypress swamp.

Collier and Olioso (1993) estimated fluxes of sensible heat and evaporation between plants and the atmosphere in France. A simple system, using a capacitive hygrometer and alternate sampling of air at two levels with pumps to measure humidity gradients was developed. Results indicated that long term measurements, low power consumption, low charge of maintenance and low cost. Testing was done by comparison of hourly sensible and latent heat flux measurements, performed by both eddy correlation and Bowen ratio, over a bare soil field and fully developed canopy of crop. The system gave good flux estimates even with very low humidity gradients.

Malek (1994) calibrated the wind function constants in aerodynamic term of the Penman equation for computation of hourly and 24 hour reference crop evapotranspiration by using Bowen ratio energy balance method at an irrigated semi-arid valley in Utah, USA. Results showed that the hourly and daily constants in the wind function were $a_w = 2.677$, $b_w = 0.127$ and $a_w = 1.00$, $b_w = 0.014$, respectively. The hourly and daily relationships between ET_r estimated by Bowen ratio energy balance (BREB) method and computed by Penman method were $ET_{r(Penman)} = 0.976 * ET_{r(BREB)}$, and $ET_{r(Penman)} = 1.009 * ET_{r(BREB)}$ with the correlation coefficient is 0.974 and 0.988, respectively.

de Silva *et al.* (2007) investigated the energy flux relations and evapotranspiration of Mango orchards during 1998 -1999 in the semi-arid climatic conditions of Northeast Brazil. The Bowen ratio–energy balance method was applied to estimate the energy balance components, while the Penman-Monteith method was used for determining the reference crop evapotranspiration. Results indicated that latent heat flux density could be obtained with reasonable precision, as a function of measured net radiation flux density. The percentage of net radiation flux density was higher for the fruit growth and fruit maturation phenological stages and lower for the flowering and fruit fall stages.

Zhang *et al.* (2008) estimated vineyard evapotraspiration by using Bowen ratio energy balance method in the arid desert region of northwest, China. Results indicated that the Bowen ratio energy balance provide the accurate measurements of vineyard ET from the arid desert region when the Bowen ratio instrument with higher accuracy was correctly installed.

2.2.7 Remote Sensing Technique

A technique was developed for indirectly estimating evaporation on real time basis by the use of remotely sensed canopy temperatures, air temperature and vapour pressure deficit of the air (Jackson *et al.*, 1980). This technique provides an interesting concept for estimating evapotranspiration. However, the results and techniques developed for measuring evapotranspiration are complex and raise questions in terms of the limitations and constraints in the use of various instruments (Singh, 2000).

2.2.8 Shaded Area for Deciduous Fruit Crops

The crop coefficient is a function of size of crop canopy and how much of it is exposed to the direct sunlight. The driving force of evapotranspiration, net radiation, is the greatest during solar noon. Hence, the crop coefficient can be directly estimated through the percentage of shaded area of the crop at solar noon. In this section, a brief review of estimation of percentage of shaded area for deciduous fruit crop is presented.

Williams (2000) found that the vine water use of grapevines grown in the lysimeters was a linear function of the shaded area measured beneath the vine at solar noon. According to authors, there are several reasons why such relationships would exits that: (1) The driving force of ET, net radiation, is greatest between 11 a.m. to 2 p.m. (2) Approximately 75 % of the water used by vines growing in the lysimeters on a daily basis is between 10 a.m. to 2 p.m. (3) The shade beneath a vine is an indirect measure of how much solar radiation the vine is intercepting. (4) The shade beneath the vines varies only slightly between 9 a.m. to 3 p.m. for east west rows. (5) As the seasons progresses, the vine's canopy gets larger resulting in more light being intercepted (more shaded area on the ground) and greater water use.

Williams (2001) determined irrigation requirements for raisin, table grape and wine grape vineyards in grape growing regions of California, USA. Irrigation requirements were dependent upon evaporative demand (ET_r) at the location of the vineyards, stage of vine developments and percentages of ground cover. ET_r varied seasonally, low at the beginning of the seasons and highest mid-summer. The greatest demand of water use by the grapevine at the full canopy again occurred mid to late summer. The daily water use of vines within the lysimeter averaged 40 to 45 litres at maximum canopy. The percentage ground cover (shaded area) at this time was approximately 50%. The results also demonstrated that the crop coefficient was a linear function of percentage shaded area beneath the vine at solar noon. This relationship currently is being used to develop seasonal crop coefficients for different trellis systems.

William and Ayars (2005) developed relationship among water use and crop coefficient of grapevine with several measures of canopy development with the aid of a weighing lysimeter in San Joaquin Valley, California, USA. They determined the leaf area index and the amount of shaded cast on the ground directly beneath the canopy at solar noon hour. Daily water use ranged from 4 to 60 liters per vine during the year 1998 -1999. Leaf area per vine ranged from 2 to 34 m^2 per vine. The shaded area per vine ranged from 0.82 to 4.76 m^2. The leaf area index per vine ranged from 0.5 to 5.57. The amount of shade cast on the ground was a linear function of total vine leaf area although there were differences between the years. Vine water use and crop coefficient were linearly related to leaf area per vine ($y = 0.366 + 0.209x$, $R^2 = 0.89$), LAI ($y = 0.369 + 1.587x$, $R^2 = 0.89$) and amount of shade cast of the ground ($y = -0.008 + 0.017x$, R^2 0.95). They developed the relationship between calculated crop coefficient and estimated LAI ($y = 0.115 + 0.235x$, $R^2 = 0.87$) and percentage of shaded area ($y = -0.008 + 0.017x$) for grapevine. However, the greatest R^2 value (0.95) of the relationship with the K_c was that of shaded area compared with an R^2 value of 0.87 for leaf area and leaf area index. The results indicated that due to the structures of grapevine canopy, the interception of light, as measured by the amount of the shade cast on the ground is more important to determine water use of grapevine and crop coefficient.

2.2.9 Leaf Area Index for Deciduous Fruit Crops

Leaf is an important plant organ, and is associated with photosynthesis and evapotranspiration. Leaf area index is one of the most powerful diagnostic of plant productivity and biophysical variables for the modeling of evapotranspiration. It is directly related to evapotranspiration, vegetation yield, plant productivity and light interception and its properties of canopies of crop affect the evapotranspiration. Therefore, the estimation of leaf area index is required for physiological and evapotranspiration studies. Leaf area index is the average total area of leaves per unit area of ground surface. In this section, a brief review of estimation of leaf area index for deciduous fruit crop is presented.

Watson (1947) described the leaf area index as dimensionless variable and was the first to define it as the total one sided area of photosynthetic tissue per unit ground surface area.

Grantz and Williams (1993) developed a protocol for using a commercially available instrument to determine leaf area index indirectly in trellised vineyard system at Parliar, USA.

From knowledge of plant spacing, leaf area per vine can be calculated as required. A derived calibration equation resulted in a near 1:1 relationship ($y = 0.00 + 1.00*x$, $r^2 = 0.998$) between actual and indirect determined leaf area indices over a range of leaf area index induced by irrigation treatments.

Sommer and Lang (1994) measured leaf area index of Spur and minimum pruned vines directly by destructive leaf sampling and indirectly from light transmission measurements using the LAI-2000 and DEMON instruments. Both instruments provided good estimates of plant and leaf area index. The LAI-2000 had a tendency to underestimate leaf area index. The DEMON instruments provided the most accurate estimate of plant and leaf area index. It is important to validate indirect measurement by both the instruments with direct estimates of vine leaf area.

Maass *et al.* (1995) assessed monthly LAI by using light canopy transmittance and Beer-Lambert equation of a tropical deciduous forest ecosystem on the west coast of Mexico. The light transmittance coefficient was obtained by analyzing vertical leaf and light distribution in the forest canopy. An independent LAI estimate was obtained using litter fall data. An average maximum LAI obtained with litter fall data was 4.2 ± 0.4 m^2/m^2. There was a significant correlation ($P<0.001$, $R=0.98$) between litter-LAI estimations and those obtained with the Beer-Lambert equation.

Villlalobos *et al.* (1995) estimated leaf area index of canopy of trees from transmittance of radiation at various angles during 1992-1993 in Cordoba, Spain. Plant canopy analyzer LI-COR LAI-2000 was tested for Olive tree during 1992 and 1993. Plant leaf area of single Olive tree was measured destructively and compared with indirect measurements with the plant canopy analyzer. A simulation model was constructed to test sampling strategies to determine plant area index with the plant canopy analyzer in tree orchards. Plant areas and area densities of isolated trees in the field were accurately determined using the plant canopy analyzer. The results of the simulation model indicated that the plant canopy analyzer alone would under predicted plant area index around 30 percent in Olive orchards with similar geometry.

Sampson and Allen (1995) compared direct and indirect estimates of leaf area index for lodge pole and loblolly pine stands. Indirect estimates of leaf area index using radiative methods of the LICOR LAI-2000 plant canopy analyzer did not correlate with allometric estimates for lodge pole pine stands and correlated only with weekly little trap estimates for loblolly pine stands. Results from the physical model suggested that increase foliage overlap decreases the ability of the plant canopy analyzer to accurate estimates leaf area index. The relationship between radiative and allometric measures suggested an upper asymptote in leaf area index estimated by using the plant canopy analyzer.

Oliveira and Santos (1995) measured true leaf area of Vineyard canopy by using leaf area integrating meter and correlated with the calculated area at Utad, Portugal. The interception of radiation by plant canopies was used to calculate total leaf area of vineyard canopy. Both the measurements were highly correlated and their relationship was suitably described by either one of the following regression equations: $Am = -8365.79 + 1.21(Ac)$ and $Am = 0.11147\ (Ac)^{1.2045}$, where, Am is the area measured with leaf area integrating meter and Ac is the calculated area.

Coops *et al.* (2000) compared three different methods for estimating leaf area index (i.e. point-quadrant camera, plant canopy analyzer and digital hemispherical photography methods) for eucalypt forest canopy at Tumbarumba in New South Wales, Australia. The individual leaf area indices were compared and the potential advantages and disadvantages of each method were discussed in relation to use in forest inventory and field data collection programmes for remote sensing calibration and verification. Results indicated that all three methods produced similar estimates with standard error between techniques of less than 0.2 leaf area index units.

Asner *et al.* (2004) presented the first global synthesis of plant canopy leaf area index measurements from more than 1000 published estimates. LAI values ranged from 1.3±0.9 for deserts to 8.7 ± 4.3 for tree plantations, temperate evergreen forests (needle leaf and broad leaf), displaying the highest average leaf area index (5.1 - 6.7) among the natural terrestrial vegetation classes.

Johnson and Pierce (2004) used indirect and direct measurement methods for the evaluation of leaf area index of grape vineyards by using LAI-2000 plant canopy analyzer and electronic meter (Model LI-3000, LICOR) at north coast region of California, USA. Indirect leaf area index derived by a standard two-azimuth, diagonal transect measurement protocol was significantly related to direct leaf area index ($r^2 = 0.78$, $p \leq 0.001$). The mean leaf area index ranged from 0.5 to 2.25 m^2 leaf area per m^2 ground area by direct measurement and indirect measurement of leaf area index ranged from 0.26 to 1.24.

Cittadini and Peri (2006) developed a simple, accurate, non-destructive and time saving predictive model for leaf area estimation in sweet cherry trees at Trelew, Argentina. Linear regression equations were fitted and evaluated for three cultivars and two training systems using alternatively the length, width and their product as independent variable. Regression using the product of variable length and width (r^2 = 0.994) fitted the data better than length or width (r^2 = 0.867 or r^2 = 0.787, respectively). Thus, using the product of leaf length and leaf width as the explanatory variables was more accurate to predict leaf area than using either length or width. They suggested that the equation LA = 0.6618 x L x W can be used for predicting leaf area for practical purposes, such as estimating leaf area index of commercial orchards.

Dovey and Toit (2006) measured plant area index with a LICOR LAI – 2000 plant canopy analyzer in a young stand of Eucalyptus grandis in the Kwazulu-Natal Midlands, South Africa. Destructive sampling and allometric equations were used to estimate leaf area index at 2 and 3 years age after planting. Significant correlations were found between leaf area index and plant area index for each age with different equations being generated for the two ages. The equations were developed for two years age of plant and three years age of plant (i.e. LAI = 1.0594(PAI)-0.892) and (i.e. LAI = 1.0393(PAI).

Simona *et al*. (2006) computed the fraction of light photo synthetically active radiation intercepted by mature and immature orange orchards near Lindsay, Calif, USA. Light intercepted by different canopies were related to crop coefficient values that were determined by micrometeorological measurement of crop evapotranspiration and Penman-Monteith equation for reference crop evapotranspiration. The results indicated that, shaded point at orange trees, light interception reached peak values of about 0.93, 0.74 and 0.47 for orchards characterized by 70, 47 and 20 percentage of ground cover, respectively. The leaf area indices were derived by a canopy portable digital analyzer LICOR model LAI-2000 for 5, 4 and 15 years age of orange trees and their values ranged between 3.1 to 4.0, 1.2 to 1.8 and 2.1 to 3.0, respectively.

Pokorny *et al.* (2008) investigated temporal variation of leaf area index in two young Norway spruce stands with different densities in eight consecutive growing seasons. The maximum hemi-surface leaf area index value reached 12.4. The most effective leaf area index values for maximum above ground biomass production were within the range 10-11.

In this section various methods for determining leaf area index for deciduous to evergreen fruit crops or forest species are reported. These methods are direct (i.e. destructive sampling and allometric equation) and indirect methods (i.e. litter trap, plant canopy analyzer, gap inversion, point quadrant camera and digital hemispherical photography). The LAI values ranged from 0.5 to 12.4. It is observed from these studies that direct and indirect methods are suitable for deciduous fruit crops. Based on these findings, in this study direct and indirect methods were used. The indirect method involves harvesting manually green healthy small, medium and large size leaves from the representative plant of selected orchards on weekly basis. The direct leaf area index method is generally used for verifying an estimated indirect LAI by harvesting the entire leaves of the same plant at the end of last observation and estimate true leaf area index.

Most of the studies reported in this section are concerned with measurement of evapotranspiration for determination of crop coefficient by using various methods or developing the appropriate models. (i.e. lysimetric, aerodynamic, soil moisture depletion, water balance, surface renewable, eddy covariance micro-meteorological, Bowen ratio energy balance, remote sensing, shaded area and leaf are index methods or models) for deciduous to evergreen fruit crops.

It is seen from the studies reported in this section, that very few efforts have been made for the measurement of crop evapotranspiration by using the lysimeter and aerodynamic for deciduous fruit crops. It is seen from studies, on shaded area measured at solar noon hour for deciduous fruit crops that the water use and crop coefficient are linear functions of the shaded area measured beneath the canopy for grapevine and other table fruit crops. In this study, therefore, the shaded area (at solar noon hour) method was used for pomegranate orchards for developing crop coefficient equations.

2.3 REFERENCE CROP EVAPOTRANSPIRATION

Numerous studies have been conducted during the last many years, which show the close relationship between the net radiant energy received by an irrigated crop and the rate of evapotranspiration. Where the sensible heat storage capacity is relatively small or only a small percentage of the net heat energy input is stored, the energy balance approach for estimating evapotranspiration is the most reliable and conservative method. However, a thorough understanding of the factors controlling the energy balance of a cropped soil is essential for accurate estimates of evapotranspiration. The scientific study of this process has been underway for many years. The literatures on evapotranspiration are extensive and some excellent reviews and books are available on this topic **(**Rosenberg *et al*., 1968; Doorenbos and Pruitt, 1977; Brurtsaert, 1982; Sharma, 1985; Jensen *et al.,* 1990; Allen *et al.,* 1998). Doorenbos and Pruitt (1977) defined reference evapotranspiration as the rate of evapotranspiration from an extensive surface of 8 to 15 cm, green grass cover of uniform height, actively growing, completely shading the ground and not short of water. Further this definition was revised by Allen *et al.,* (1998) as the evapotranspiration rate from a reference surface, not short of water. The reference surface is a hypothetical grass reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s/m and an albedo of 0.23. Thus, the concept of the reference evapotranspiration or reference crop evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices. A brief review on the topics related to the present study has been presented in this section.

2.3.1 Methods for Estimation of Reference Crop Evapotranspiration

Several methods have been developed to estimate reference/potential crop evapotranspiration. These methods span the spectrum from purely physically-based to purely empirically-based. This section presents the most important and widely used methods

Blanney and Morin (1942) first developed an empirical relationship between evapotranspiration and mean air temperature, average relative humidity and mean percentage of daytime's hours. They proposed an equation to estimate crop evapotranspiration. The equation is based on the principle of empirical equation. The equation needs variables to estimate ET_c. These are temperature, air humidity, day light hours and crop factor. The equation was validated for USA.

Thornthwaite (1948) developed an exponential relationship between mean monthly temperature and mean monthly consumptive use. The relationship was largely based on experience in the Central and Eastern United States. The equation needs variables to estimate ET_c are temperature, sunshine hours and correction factor. The equation is based on the principle of empirical equation. Thorntwaite formula gives a reasonable estimate of evapotranspiration in the temperate, continental climate of North America.

Penman (1948) originally proposed an equation for estimating evaporation from free water surface and then applied empirical coefficients to convert estimated evaporation to reference evapopotranspiration from vegetated surfaces. Penman assumed that the heat flux into and out of the soil is small enough to be conveniently ignored. However, he did not include a surface resistance function for water vapour transfer. For practical applications, he proposed an empirical equation for the wind function and equation to estimate ET_r. The equation is based on the principle of energy balance and mass transfer. The equation needs the climatological variables such as temperature, air humidity, dry light hours, sunshine hours/cloud cover, radiation, wind velocity etc. The equation was validated for UK.

Makkink (1957) proposed an equation to estimates ET_r. The equation is based on the principle of empirical relationships. The method needs climatological parameters such as solar radiation, air temperature, slope of the saturation vapour pressure–temperature curve and psychrometric constant. The equation was validated for Netherlands.

Turc's (1961) proposed an equation to estimates ET_r. This equation is based on the principle of empirical relationships. The method needs air temperature, solar radiation and humidity as a input climatological parameters. The equation was validated for Western Europe.

Blaney and Criddle (1962) developed and proposed an empirical formula to compute evapotranspiration using a correlation, which utilizes mean monthly air temperature, amount of daylight and a crop factor showing seasonal variation. Thus these method needs variables such as temperature, daylight hour and crop factor as an input parameters. The equation was validated for Western, USA.

Jensen and Haise (1963) estimated evapotranspiration from solar radiation using energy balance approach, based on 3,000 observations data and indicated that reasonable estimates of evapotranspiration can be made by using solar radiation as the main parameter. They presented suitable curves for different field crops in four climatic regions, as the ratio of measured evapotranspiration to solar radiation, which reflects the combination effects of short wave reflectance (albedo), and relative effects of effective thermal radiation, sensible heat flux to air and soil, and other minor energy balance components at various stages of growth. They concluded that the approach might be used for estimating mean weekly, monthly or seasonal evapotranspiration in irrigated field. The method needs the variables such as air temperature, drylight hour, sunshine hours, radiation, correction and crop factor as input parameters. The equation was validated for USA.

van Bavel (1966) formulated an equation for potential evapotranspiration by relating it with net radiation, ambient air properties and surface roughness using a combination of a surface energy balance equation and an appropriate expression of water vapour and sensiable heat transfer. The equation needs temperature, day light hours, sunshine hours, radiation and correction factor. The equation was validated for USA.

Christiansen (1968) proposed an empirical formula to estimate pan evaporation from climatic data when reliable measured pan evaporation data are not available for estimation of ET_r. This formula requires mean air temperature (^{0}C), mean wind velocity (km/day) at 0.6 m height, mean relative humidity (%), mean sunshine hours and elevation as input data. The equation was validated for USA.

Priestley and Taylor (1972) proposed a simplified version of the combination equation for use when surface areas are generally wet, which is condition required for reference evapotranspiration. The aerodynamic component was multiplied by a coefficient $\alpha_{1,}$ when general surrounding areas were wet or under humid conditions. The method needs air temperature and solar and net radiation as input parameters. The equation is based on the principle of empirical relationship and is radiation based. The method is validated for humid areas where surfaces were usually wet.

Hargreaves (1975) developed a simple empirical method requiring only temperature and radiation data for estimating evapotranspiration from eight years of cool season Altra Fescue grass used as a reference crop. The base equation was derived from grass lysimeter and climatic data from Davis, California, U.S.A. This equation is based on the principle of empirical relationship. The equation only needs temperature and radiation data as input parameters.

Morton (1976) formulated a model to permit the estimation of the evapotranspiration from large areas to be estimated from routine observation of temperature, humidity, and sunshine duration without the need of local factors or for assumptions concerning the availability of water.

Doorenbos and Pruitt (1977) provided detailed guidelines for using evaporation data to estimate reference evapotranspiration. The FAO-24 coefficients relating USWB class –A pan data to evapotranspiration from short (15-88 cm) irrigated grass turfs are given. Some adjustments would be needed to relate to K_p for a taller reference crop especially in hot, drier climates where height of crop and aerodynamic rougher crops, the values of K_p would be higher and would vary less with differences in weather conditions as compared to values for shorter and smoother grass surfaces.

Doorenbos and Pruitt (1977) proposed a modified Penman method for estimating the reference crop ET_r. This method requires relative humidity (%), mean air temperature (^{0}C), mean sunshine hours, extraterrestrial radiation (mm/day) and wind speed (km/day) at 2 m height. It is a combination equation. The equation is based on the principle of energy balance and mass transfer.

Linacre (1977) used average monthly maximum and minimum temperatures, latitude and elevation to estimate reference evapotranspiration. This method was designed to calculate lake evaporation and evapotranspiration. Method was validated for a region where average monthly precipitation is at least 5 mm/month and average difference between mean monthly air and dew point temperature is at least 4 ^{0}C.

Wright (1982) presented variable wind function coefficients for reference evapotranspiration at Kimberly, Idaho, USA, expressed as fifth – order polynomials with calendar day as the independent variable. The resulting equations were later simplified and known as Kimberly-Penman model.

Hargreaves and Samani (1985) presented a method for estimating potential evapotranspirtaion which requires only maximum and minimum temperatures data and a general knowledge of approximate percentages of relative humidity for the time periods used. The equation was derived by using Hargreaves radiation equation and empirically developed relationship for solar radiation as a function of extraterrestrial solar radiation as well as maximum and minimum temperature. The equation was validated for areas where air temperature alone is the only data available.

Jensen *et al.* (1990) proposed an equation for estimating reference evapotranspiration using solar radiation and mean air temperature.

Allen *et al.* (1998) presented Penman–Monteith equation for 24 hours calculation of reference evapotranspiration (mm/day) using daily mean data. They defined reference evapotranspiration as the evapotranspiration rate from hypothetical reference crop height (12 cm), a fixed crop surface resistance (70 s/m) and albedo (0.23), closely resembling the ET from an extensive surface of green grass cover that is of uniform height, actively growing, completely shading the ground and with adequate water supply. The equation is based on the principle of energy balance and mass transfer. It is also called as combination method. The method needs variables i.e. solar radiation, temperature, wind speed, relative humidity, altitude, latitude and crop factor. The equation was validated for USA.

This section has reviewed the studies on the methods for estimation of reference crop evapotranspiration (ET_r). ET_r estimates by different methods are based on the principle of temperature, radiation or combination of both and empirical relationships. The methods reviewed above need one or more variables from temperature, humidity, percentage of day times hours, soil heat flux, albedo, rainfall, evaporation, wind velocity, elevation and latitude. The Penman – Monteith is considered as most accurate method but involving large amount of variables for estimations of ET_r. Many a times the data are not available and there is a need of the method that need less data but estimate ET_r closely with Penman-Monteith method. Therefore in this study, it was proposed to estimate ET_r by Penman-Monteith method but compare those with other methods that need less data. These methods are Modified Penman, Hargreaves-Samani, FAO Pan Evaporation, Blanney-Criddle and FAO Radiation.

2.3.2 Applications / Modification of Methods of Evapotranspiration Estimation

Several investigators modified the equations that are reviewed in previous section for estimating reference crop evapotranspiration and applied those for various purposes. This section reviews important studies on this aspect.

Maithy and Panda (1975) conducted studies for several years on prediction of evapotranspiration from pan evaporation, taking into account the soil matric suction. For the purpose of the study the rate of daily evapotranspiration of two varieties of potato grown under four levels of soil matric suction was measured by water balance method. It was observed that at lower soil matric suction (upto 0.40 atmosphere) there was a good agreement between pan evaporation and measured evapotranspiration. They concluded that seasonal evapotranspiration can be measured with the help of seasonal coefficients when pan evaporation values are known.

Doorenbos and Pruitt (1977) presented the most fundamental revision of the Blaney – Criddle model since its introduction as the FAO24 Blaney-Criddle model. This model estimates a grass related reference crop evapotranspiration. The FAO24Blaney-Criddle model is based on general linear relationship found between measured reference evapotranspiration and Blaney-Criddle factor from many worldwide sites in various classification based on daytimes wind speed, minimum relative humidity and sunshine expressed as the ratio of actual and possible hours of bright sunshine.

Shih (1984) studied various approaches based on climatological data to estimate the evapotranspiration. He performed a multiple regression with ordinary least square analysis and observed that a model based on two variables of air temperature and solar radiation can provide a quite satisfactory estimation of the ET_r in Southern Florida, USA for irrigation requirement prediction.

Choudhary and Desai (1988) concluded that Hargreaves-Samani formula can be used in absence of large number of weather parameters which are required in modified Penman formula.

Chandra *et al.* (1996) described that the potential ET estimated by Doorenbos and Pruitt (1977) method which is based on Penman's equation, is quite rational and accurate but the computations are quite elaborate and time consuming.

Hashmi and Garcia (1998) developed a methodology to estimate regional evapotranspiration while considering spatial and temporal variability of parameters in Cache la Poudre basin, Colorado, USA. Spatial data were developed for agricultural land use, relevant climatic parameters and topographical data using GIS. A spatial simulation ET model was used to develop baseline estimation of regional ET incorporating analytical GIS functions of map algebra and map overlay to calculate ET for each field in the system and each day of growing season. Various scenarios were developed and compared to the baseline scenario. The standard deviation was 60.4%. Errors due to land use classification were 40%. The range of errors implied that maximum benefits can be achieved if the time step is reduced. This fact recognized that daily ET estimates are crucial calculations in order to reduce the error rates of regional ET measures.

Samani (2000) introduced a procedure to estimate solar radiation and subsequently reference crop evapotranspiration using 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.

Ray and Dadhwal (2001) described the use of satellite based remote sensing data and GIS for estimating seasonal crop evapotranspiration in Mahi Right Bank Canal (MRBC) command area of Gujarat. The crop coefficients map for various major crops grown in MRBC were estimated empirically, from the remote sensing derived soil adjusted vegetation index values and reference crop evapotranspiration map was generated from point meteorological observations. The crop coefficient (K_c) and reference evapotranspiration (ET_r) map were combined to generate seasonal crop evapotranspiration (ET_c) map, which highlighted spatial variation in ET_c ranging from more than 600 mm for healthy tobacco crops to less than 150 mm for very poor wheat crops.

Goyal (2005) developed regression model for the estimation of reference evapotranspiration using measured pan evaporation data without pan coefficient. Linear regression was used to describe association between computed value of ET_r (Penman- Monteith) and observed pan evaporation (E_p). The developed equation was $ET_r = 0.787+0.583\ E_p$ (r=0.982). The above mentioned equation has very high degree of association. Therefore it can be reliably used to estimate reference evapotranspiration from measured pan evaporation for the Jodhpur arid area of Rajasthan.

Salam and Mazrooe (2006) calculated reference evapotranspiration for Kuwait using FAO Penman-Monteith equation. The results revealed that the total annual ET_r of Kuwait is about 2883.0 mm. The highest monthly ET_r values (421-422 mm) were noticed during June and July (summer period). During this period, the temperature and wind speed were considerably high compared to the other months. The ET_r values were lowest during the months of December and January coinciding the cool season of Kuwait. As such, the combined effect of low temperature, low wind speed, high humidity and rainfall might have been responsible for the low values of ET_r during December and January.

O'Connell *et al.* (2006) investigated response of fruit trees to reduced irrigation in micro-irrigated peach and apple orchards in Goulburn Valley, Victoria, Australia. Irrigation regimes were 50% and 100% of current management practices where inputs were scheduled from pan evaporation and locally derived pan coefficient. Irrigation was applied to only one side of the tree root zone in the 50% treatments, while the current management practices treatment received water on both the sides of tree. Over the season, the irrigation inputs for peach and apple were equated to a crop coefficient of 0.93 and 0.87, respectively. Orchard crop evapotranspiration were predicted using ET_r and published k_c with adjustment for the fraction of shade cast by the trees on the orchards floor at solar noon. The results indicated that, the evapotranspiration of peach and apple was substantially lower than the current water scheduling practices.

Orgaz *et al.* (2005) estimated olive evapotranspiration by using crop coefficient ($k_c = ET_c/ET_r$) based on a minimum parameters. They developed functional relationships for calculating the crop coefficient for a given month of the year in any type of olive orchard, and thus its water use depth once the ET_r is known. This method calculates the monthly k_c as sum of the four components i.e. tree transpiration, direct evaporation of the water intercepted by the canopy, evaporation from the soil and evaporation from the soil wetted by the emitters.

Singh (2008) explored economic viability of drip irrigation system for growing capsicum crop based on discounted cash flow technique in West Bengal, India. Eight irrigation treatments were taken under drip with and without plastic mulch. The irrigation levels were taken as 1, 0.8 and 0.6 of the crop evapotranspiration. The pan evaporation method was used for estimation of reference evapotranspiration and water balance approach was used for irrigation scheduling. The results indicated that, the average amount of 100% irrigation supplied with drip was found to be 415 mm for whole growing season of the crop. Similarly, the amount of water was found to be

332 mm and 249 mm for the treatments of 0.8VD (80% irrigation requirement supplied with drip) and 0.6VD (60% irrigation requirement supplied with drip), respectively.

In this section some representative studies that used the different evapotranspiration methods either directly or modifying those according to the local situations were discussed. The studies indicate that evapotranspiration has definite role in water management; especially irrigation scheduling. Evapotranspiration estimation is also required for regional scale irrigation planning such as on watershed and river basin. Therefore accurate estimation of evapotranspirtaion is important.

2.3.3 Comparison of Different Methods for Estimates of Reference Crop Evapotranspiration

As reported earlier, several methods have been developed to estimate reference/potential crop evapotranspiration. Some methods are more accurate and some are less. Some methods use large data and some use less. Many researchers have compared different methods to know the suitability of these methods. The details of these studies are provided in this section.

Pramele and McGuinness (1974) compared the measured and estimated daily potential evapotranspiration in a humid region and stated that the best method of estimation is the one with the lowest absolute difference, and intercept closest to zero, a slope closest to 1.0, the smallest standard error, and the highest correlation coefficient. They concluded that a measure of estimate of Class-A pan evaporation may be good estimates of potential evapotranspiration and evapotranspiration under non-limiting moisture conditions.

Maity *et al.* (1979) compared measured and estimated evapotranspiration based on different models. Evapotranspiration rates measured by the water balance method from the wheat crop in lysimeter under the different soil moisture tension and nitrogen levels were compared with the estimated evapotranspiration rates by the Penman, Thronatewaite, Blaney-Criddle and Chritiansen models. They developed regression equations and found that when soil moisture tension is 0.75 atmospheres, there exists a close agreement between estimated and measured evapotranspiration by different methods.

Shouse *et al.* (1980) analyzed five methods to estimate potential evapotranspiration under advective condition. They found that Penman equation was superior because it accounts for wind speed, vapoure pressure deficit, solar radiation etc.

Sharda and Bhushan (1984) estimated evapotranspiration requirements for Agra region by using Radiation, Blanney-Criddle approach, Modified Penman, Throntwaite and Pan evaporation methods. The ET comes out to be 1913, 1559, 1581, 2387 and 2228 mm respectively. According to authors among these five methods, Modified Penman method seems to be more rational and realistic.

Kuruvilla *et al.* (1989) compared different methods of estimation of reference evapotranspiration using the data collected from Western Ghat region of Kerala. The results obtained by Hargreaves and pan evaporation methods compared well. Thornthwaite method has provided a higher value of evapotranspiration.

Hussain and Mushabbir (1990) compared the five methods for estimation of ET_r, in Thailand viz. Modified Blaney–Criddle, Modified Radiation, Modified Penman, Pan Evaporation, and Jensen-Haise. It was revealed that Modified Penman method gave the best performance as it provided a real correlation with observed ET_r. The Jensen-Haise method was unable to estimate a safe prediction during the wet season. The values of observed ET_r have correlation with climatological parameters. They also studied the relationship between observed and estimated crop evapotranspiration and its variation with other climatic parameters.

Michalopoulou and Papaioannou (1991) estimated reference evapotranspiration for 31 locations in Greece by using the Penman, Priestley-Taylor and Throntwaite methods. The analysis of 27 years of meteorological data indicated that the annual amount of ET_r obtained by Priestly-Taylor or Throntwaite methods do not generally agree very well with Penman ET_r predictions.

Tarantino (1992) compared measured grass evapotranspiration obtained by lysimeters and those calculated by the FAO methods and in some cases by Penman-Monteith and Thronthwaite methods. Comparisons were made on a daily basis with weighing lysimeter and on ten-days basis with drainage lysimeters.

Ismail (1993) estimated grass reference evapotranspiration by using four methods viz. Class A pan, Radiation, Jensen-Haise and Penman in Al-Qassim Region of Suadi Arbia. The radiation method overestimated the other methods, but if the adjustment factor is to be taken equal to 0.9 the Radiation method would be close to the Jensen – Haise Method. The derived seasonal average pan coefficient of 0.61 gives a more conservative value. The Penman method could be used with a local back radiation of 1.34 mm/day and albedo of crop surface of 0.35.

Chin and Zaho (1995) presented a methodology to assess the relative merits of using evaporation pan network and semi empirical function to estimate reference crop evapotranspiration (ET_r). Estimation error variance was proposed as basis of comparison. In case of Pan network, ordinary kriging and universal kriging were viable option for determination of estimation error variance. It was concluded that pan-based estimates of reference evapotranspiration are preferable to semi empirical evapotranspiration function in South Florida, USA.

Amatya and Skaggs (1995) compared six reference crop evapotranspiration methods (i.e. Penman Monteith, Makkink, Priestley Taylor, Turc's, Hargreaves-Samani and Thornthwaite) at three sites in Eastern North Carolina, USA. The Penman-Monteith method, with grass as a reference crop, was selected as the standard of comparison. Good correlation was found between the ET_r values estimated by each of the other five methods. Turc's method yielded the best average estimate of total annual ET_r. All other radiation methods and the temperature based Thornthwaite method under predicted the annual ET_r by as much as 16%. The Hargreaves-Samani method over predicted annual ET_r by 15% on the average. On the average, Turc's method was found to be the best predictor of monthly ET_r for all locations tested.

Hatfield and Allen (1997) studied different forms of reference evapotranspiration equations that included Priestly-Taylor and Penman-Monteith methods. To estimate actual evapotarnspiration, the Priestly-Taylor with an 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 equation with daily meteorological data input provided more consistent results over growing season.

Khandelwal *et al.* (1999) computed potential evapotranspiration by using the Throntwaite, Turc, Modified Penman, FAO Blaney-Criddle, Hargreaves and Penman-Monteith methods. For computation of potential evapotranspiration at weekly basis, the Hargreaves method was found to be the best (r=0.94) with the highest model ratio.

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_r) 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, Prestly-Taylor, FAO-Radiation, Hargreaves and FAO Blaney-Criddle were used to estimate the reference evapotranspiration. Performance of climatological method in estimating the ET_r 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 the1982 Kimberly-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.

Xu and Singh (2002) evaluated three categories of potential evapotranspiration methods in Switzerland. The three categories are mass-transfer based (i.e. Rohwer), radiation based (i.e. Makkink and Priestley-Taylor) and temperature based (i.e. Hargreaves and Blaney-Criddle). The Penman Monteith method as recommended by FAO was taken as a standard in evaluating the five methods. The comparison was made in two stages. In the first stage the original constant value involved in each equation were used when calculating ET_r. In the second stage the five methods were calibrated against Penman –Monteith methods to determine best parameter (constants) values for the region. The results showed that the values of α = 1.26 in Priestly-Taylor equation was too high for the study region and value of α= 0.90 was the best for Penman-Monteith method. A slight improvement was found for the Rohwer method when original constant value of a =0.44 changed to 0.47 after calibration. A further evaluation of mean monthly evapotranspiration estimated by these six methods showed that the Blaney-Criddle method is best for the region.

Gouranga and Chakravarthy (2002) computed potential evapotranspiratiion by using Penman, Papadakis, Linacre and Makkink's methods and these computed values were compared with USDA pan evaporation rate for Dehli region. The Makkink's method gave ET_r values which are consistently lower than the pan evaporation throughout the year. Penman method gave the highest correlation value (r=0.88) when compared with the pan evaporation value.

Hargreaves and Allen (2003) presented a brief history of development of the 1985 Hargreaves equation and it's comparisons to evapotranspiration predicted by FAO Penman-Monteith. It was seen that monthly ET_r by the 1985 Hargreaves equation compares closely with ET_r calculated by using a simplified reduced set Penman-Monteith that requires air temperature data only.

Magali *et al.* (2004) calculated ET_r by means of the Thonthwaite, Hargreaves-Samani and FAO Penman–Monteith equations and compared with the grass evapotranspiration measured with Lysimeter. They demonstrated the suitability about the application of FAO Penman–Monteith equation in the Altiplano, South America.

Goyal (2004) studied on the sensitivity of evapotranspiration to global warming for a arid region of Rajasthan (India). The Penman-Monteith equation was used to estimate reference evapotranspiration, and sensitivity of ET was studied in terms of change in temperature, solar radiation, wind speed and vapour pressure within a possible range of $\pm 20\%$ from the long term meteorological parameters of 32 years (1971-2002). Changes in precipitation and stomatal resistance to increased CO_2 concentration have not been considered. The study indicated an increase of 14.8% of total ET demand with increase in temperature by 20% (maximum 8 ^{0}C). ET is less sensitive (11%) to increase in net solar radiation, followed by wind speed (7%) in comparison to temperature. Increase in vapor pressure (20%) has a small negative effect on ET (-4.31%). A marginal increase in ET demand due to global warming will have a large impact on recourse poor, fragil arid zone ecosystem of Rajasthan.

Goyal (2004) developed a regional reference evapotranspiration (ET_r) model for Jodhpur in arid zone of Rajasthan. Eight standard ET_r models based on different criteria were used to arrive normal ET_r estimates of the study area. The normal ET_r (as standard value) was then used to develop regional model for estimation of $ET_{r,}$ i.e. ET_r (mm/day) = 0.206T-0.036 RH + 1.080WV + 0.223 SSH-2.33 (r=0.988) where T, RH, WV and SSH are mean temperature (^{0}C), relative humidity (%), wind velocity (m/s) and sunshine hours (hr), respectively. An attempt has also been made to understand the causative role of specific meteorological parameter (in isolation and in combinations) in expression of ET_r. Study indicated that temperature and wind velocity alone are the governing factors in arid areas to determine the evapotranspiration (r=0.89 and 0.76 respectively).

Bhakar and Singh (2005) 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. These 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_r). 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_r accurately under the climatic conditions of Udaipur region.

Lopez-Urrea *et al.* (2006) used the FAO-56 Penman-Monteith and ASCE Penman–Monteith equations for estimation of hourly ET_r under semi-arid condition of the province of Albacete. These two equations were compared with measured lysimeter ET_r. They found that Penman-Monteith equation for calculating ET_r values more accurate than ASCE Penman-Monteith method under semi-arid weather conditions in Albacete.

Alkaeed *et al.* (2006) compared six reference crop evapotranspiration methods, based on their daily performances in Western region of Fukuoka city, Japan. These are: Thorntwaite, Hargreaves, Hamon, Solar radiation, Net radiation and Penman-Monteith methods. Performance analysis for the calculated values using meteorological data of 7 years was made. The standard error of estimates was calculated on monthly basis. The estimated values by the Thornthwaite, Hargreaves, Hamon, Solar radiation and Net radiation methods were all correlated with Penman-Monteith. Proximity in ET_r estimates by the Hargreaves and Solar radiation methods showed that the solar radiation as input variable was important as the Penman-Monteith method. Also, the Thornthwaite method, which uses only temperature as input variables, has been found to have highly correlated with the Penman-Monteith method.

Villa Nova *et al*. (2007) estimated ET_r by an energy balance approach. All ET_r estimation methods refer to daily values including night evaporation losses. Night time losses are only substantial for a few days after rain or irrigation. A method is proposed for estimating ET_r based on the local energy balance from limited meteorological data monitored in an automated weather station throughout daylight periods. Regression analyses revealed that a modified Bowen method provided results similar to the Penman–Monteith method and similar to measurements made by weighing lysimeters. The modified balance energy approach tended slightly to overestimate ET_r by about 5%, whereas the Penman–Monteith method tended to underestimate atmospheric demand at a rate close to 7%.

Lu *et al.* (2007) compared six potential evapotranspiration methods and quantified the long term annual potential evapotranspiration across a physiographic gradient of 36 forest watersheds in the Southeastern United States. Three temperature based (Thornthwaite, Hamon and Hargreaves–Samani) and three radiation based (Turc’s, Makkink and Priestley-Taylor) potential evapotranspiration methods were compared. The study found that potential evapotranspiration values calculated from the six methods were highly correlated. The Priestley-

Taylor, Turc's and Hamon methods performed well than the other methods. Based on the criteria of availability of input data and correlations with actual evapotranspiration values, the Priestley-Taylor, Turc's and Hamon methods were recommended for regional applications in the Southeastern United States.

Slavisa and Vladimir (2008) compared two evaporation methods (i.e. FAO-24 pan and Christiansen) and one reference crop evapotranspiration method (i.e. Penman-Monteith) for Griffith area, New South Wales, Australia. Standard error of estimate of Christiansen and Pan methods were 1.25 and 1.39 mm/day at yearly basis, respectively. Two linear regression models were used to establish the relationship between evapotranspiration of class A pan and Penman-Monteith methods. The standard errors of estimates were 1.07 and 1.14 mm/day. Mean absolute errors of estimate were 0.77 and 0.78 mm/day, respectively. Results indicated that Christiansen method gave better agreement with Penman-Monteith method in respect to the FAO-24 pan method. One of the reasons for better agreement is usage of more climatic parameters than the FAO-24 pan method.

Saghravani *et al.* (2009) estimated and compared daily and monthly reference crop evapotranspiration by using three methods (i.e. Penman, Penman Monteith and Hargreaves) in South of Kuala Lumpur, Malaysia. The statistical analysis was done by using ANOVA to analyze the differences between three methods. The statistical analysis system (SAS) version 9.1 was used for maximum, minimum, mean, standard deviation, coefficient of variation, root mean square error and R^2 of ET_r calculation. The daily statistical analysis showed that there are significant differences between three methods. The mean daily and monthly ET_r values were 4.89, 4.42, 3.91mm/day and 118.3, 132.9, 149.0 mm/month for Penman, Penman-Monteith and Hargreaves methods, respectively. The daily and monthly mean values of Penman-Monteith and Penman methods were close in comparison with Hargreaves method.

Adeboye *et al.* (2009) evaluated reference crop evapotranspiration by using Penman-Monteith method and temperature based methods (Jensen-Haise and Hargreaves) in the South western part of Nigeria. The climatic data (1982-2000) were collected from Ogun-Osun river basin and rural development authority, Abeokuta, Nigeria. The average coefficient of determination (R^2) Hargreaves and Penman-Monteith and Jensen – Haise and Penman-Monteith were 0.7914 and 0.5158, respectively. The average root mean square error Hargreaves and Penman-Monteith and Jensen–Haise and Penman-Monteith were 1.03 and 1.79 mm/day, respectively. Results indicated that beside Penman-Monteith method, Hargreaves method is recommended for the computation of ET_r in situation where only maximum and minimum temperatures are available in Nigeria.

Lenka *et al.* (2009) estimated reference crop evapotranspiration by using five ET_r methods under Eastern Ghat highland zone of Orrisa, India. These methods are: Modified Penman FAO-24, Penman-Monteith FAO-56, Priestly-Taylor, Hargreaves and FAO-24 Blaney - Criddle. The results indicated that for the regions of limited data availability, Priestley-Taylor method can be a better alternative to Penman-Monteith method for estimation of reference crop evapotranspiration throughout the year. Among the two temperatures based methods, performance of Hargreaves method was more consistent as compared to Blanney-Criddle method. The Priestley-Taylor RMSE ranged from 0.392 in *Rabi* season to 0.558 in *Kharif* and 0.445 for the whole year, with r^2 value of 0.885 in *Kharif* to 0.964 in the complete year.

This section has reviewed the studies on the comparison of different methods of estimation of ET_r. ET_r values by different methods were either compared with measured or lysimetric ET_r or with Penman-Monteith ET_r. The reasons for comparing different methods with Penman-Monteith was that authors considered the Penman-Monteith method as the most accurate method but involving large amount of variables for estimations. Many times the data are not available and hence, there is a need of the method that needs the less data but estimates ET_r closely with Penman-Monteith method. Therefore in this study also, the Penman-Monteith method is proposed for comparison with other method.

2.4 PROBABILITY DISTRIBUTION FUNCTION

It is often required in water resources planning and designing to determine evaporation or evapotranspiration values at desired probability. In past several probability distribution functions were fitted to hydrological time series such as rainfall, runoff, evaporation and evapotranspiration. Therefore there is a necessity to fit different probability distribution function to the observed time series of evaporation or evapotranspiration and obtained these values of ET_r at desired probability. The probability distribution function is also useful to predict how often certain values may occur. Many researchers discussed the suitability of several probability distribution functions to these hydrological variables. This section presents the findings of the important studies in this regards.

2.4.1 Probability Distribution Functions for Rainfall

Gupta *et al.* (1968) gave a graphical representation of monthly, seasonal and annual rainfall data of Dehradun for 97 years. It was based on the simple array of numerical data in order of magnitude. They found that such analysis is useful to predict expected rainfall amount in a particular month, season and year for a desired recurrence interval and percent chance.

Kundu (1973) analyzed annual maximum rainfall data of Ludhiana for 48 years using different theoretical distributions namely, log-normal, log-Pearson type-III and Gumbel. It was concluded that log normal curve seemed to give the closest fit to the observed data and any of the distributions fitted, might be used for the prediction of daily maximum precipitation with a reasonable accuracy.

Jeevarathnam and Jayakumar (1979) compared the three probability distribution functions, which are widely used in hydrology viz. Gumbel, Log Pearson type-III and Log Normal distributions with observed rainfall data for Ootacamund, Tamilnadu. The Chi-square values for Gumbel, Log Pearson type-III and Log Normal distributions were found to be 16.46 (d.f.-3), 6.46 (d.f.-4) and 12.11 (d.f.-4) respectively. They observed that the Log Pearson type –III distribution was the best fit to the observed values.

Ray *et al.* (1980) analyzed statistically seven years of daily rainfall data at Gopalpur, Orissa. Weibull's method of frequency analysis was used and rainfall amounts on weekly intervals at 3 levels of probability were predicted.

Lowing (1987) recommended a procedure for selecting a probability distribution function for rainfall data which need not be extreme value data. In this procedure, information relating to the physical nature of the variable being fitted and the skew of the sample set are used to narrow down the choice of a distribution. Then goodness of fit tests were used to select the best fitting distribution from a reduced set of distributions.

Agrawal *et al.* (1988) compared the Gumbel, Log Normal and Log Pearson Type –III distributions for one day maximum daily rainfall data. They found that Log Pearson type-III distribution gave the closest fit to the observed data. On the basis of Log Pearson type-III distribution, one day maximum daily rainfalls for various return periods were worked out for 25 stations. They prepared isohyetal map for three return periods (10, 20 and 50 years), which can be used in determining one day maximum rainfall for ungauged sites in the region.

Khandelwal (1988) analyzed 25 years daily rainfall data of Canning, West Bengal and compared one day annual maximum rainfall distribution with theoretical frequency distributions of lognormal, Gumbel and log Pearson type-III. It was observed that the frequency distribution of one day annual maximum rainfall by log Pearson type-III (C_v = 0.3842) and log normal (C_v = 0.439) were close to observed distribution than by Gumbel distribution (C_v = 0.675).

Singh *et al.* (1989) carried out probability analysis of the maximum one day rainfall of Khandong in Meghalaya and Umrangsu in Assam by normal distribution method and estimated maximum one day rainfall for different return periods. It was observed that the probability of weekly normal rainfall equaling or exceeding the normal in any years is less during January to mid February, mid March to first week of April and October to December and the highest probability of normal rainfall occurrence was during May to September. Comparing the rainfall pattern and evaporation, it was observed that average rainfall during *Kharif* was 6.3 times the evaporative demand and during *Rabi* the evaporative demand exceeded 1.5 times amount of rainfall received.

Gupta and Singh (1990) worked out the frequency analysis of weekly rainfall data of 21 years and weekly evaporation data of 16 years of IIT, Kharagpur, by using modified Weibull's technique. They found that weekly frequency analysis is much more useful and provides a better planning and control than monthly, seasonal and annual analysis for planning of irrigated and rain fed agriculture. The predicated values of weekly rainfall and evaporation at 20%, 40%, 60% and 90% probability levels have been reported. Based on the frequency analysis, net irrigation requirements for different crops, which are suitable to grow in the area, have been suggested.

Singh *et al*. (1991) analyzed 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 south-west region to north-east 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.

Tambile *et al.* (1991) carried out frequency analysis of rainfall data of 45 years at Parabhani, Maharashtra on weekly basis using Weibull's method and predicted rainfall amounts at different probability levels. Considering the rainfall at 70 per cent probability, they observed that an appreciable amount of rainfall is available from 24 to 36 week and pointed out that dry sown crops may be sown during 24^{th} week, first weeding and hoeing during 29^{th} week and short duration crops have to be harvested during 40^{th} and subsequent weeks. It was concluded that *Rabi* crops should not be taken unless there is irrigation facility.

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.

Suresh and Thakur (1992) analyzed 25 years rainfall data of Pusa, Bihar statistically using Weibull's method of frequency analysis. Rainfall values on weekly basis at 3 levels i.e. 10, 50 and 99 percent probability were obtained. It was concluded that the sowing of paddy should be done, during 22nd and 25th weeks in low lands and up lands, respectively.

Dabral and Rao (1995) fitted gamma function for the weekly rainfall data (1956-89) of Mohurgong and Gulma Tea Estates, Gulma, Darjeeling (W.B.) and forecasted the weekly rainfall.

Bhatt *et al*. (1996) attempted frequency analysis of one day maximum rainfall data by analysing 24 years (1968-1991) daily rainfall data of Datia, M.P. 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's 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.

Subudhi *et al.* (1996) analyzed 28 years rainfall data at Phulbani and observed that 76 per cent of annual rainfall was received from July to October. Frequency analysis for maximum annual rainfall data was done by using Weibull's technique. They estimated the monthly, seasonal and annual rainfall at 70 per cent probability level and found that *Kharif* season received 839 mm rainfall. They suggested the crop varieties with growing period of four months from June to September for Phulbani under rainfed condition.

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 viz. 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 fit at all probability levels.

Mishra *et al.* (1999) attributed the most appropriate probability distribution to weekly rainfall amounts of 35, 10 and 10 years long data records of Kokrajhar, Dhubri and Cooch Bihar, respectively. They assigned the most appropriate probability distributions to a particular meteorological week. They used the probability density functions to forecast the weekly rainfall amounts at different probability levels of equaling or exceedence. They used the analysis for formulating the guidelines for allocating the water to various crops grown in the study region.

Kar and Singh (2002) predicted southwest and post monsoon rainfall at different probability levels using different probability models and compared those with observed values given by Weibull's formula. Chi-square test was used to obtain the best probability distribution function. It was found that log normal, log Pearson type-III and extreme values type-I distribution were the best fit probability distribution for predicating the rainfall in July, September, and August, respectively.

Suresh (2003) evaluated the 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.

Meshram *et al.* (2006) analyzed daily rainfall data for a period of 32 years by using five different theoretical distribution functions (i.e. Normal, Lognormal, Gumbel, Log Pearson Type-III and Pearson Type-III distribution functions) at Panchmahals of Central Gujarat. The analysis indicated that Log normal distribution gave the closest fit to the observed data. Chi-square test showed the lognormal distribution was the best fit distribution function for the Panchmahals region.

Ali and Sethy (2007) evaluated seven most commonly used probability distribution functions namely; normal, log-normal, gamma, extreme value type-I, log-extreme value type-I, Pearson type-III and log-Pearson type-III for selecting the best probability distribution to describe the rainfall data for south-eastern Rajasthan. The most effective and reliable probability distribution based on 48 years (1956-2003), weekly, monthly, seasonal and annual rainfall of Kota representing the south-eastern Rajasthan were derived. Two parameter log-normal distributions was found to be the best fit probability distribution function for estimating the probability of seasonal and annual rainfall, while 2-parameter gamma, log-normal and normal distributions were the best-fit for the month of June and September, July and August, respectively.

2.4.2 Probability Distribution Functions for Runoff/Stream Flow

Matalas (1963) investigated four theoretical probability distributions namely, Gumbel's limited distribution of the smallest value, 3-parameter lognormal distribution, Pearson type-III distribution and Pearson type-V distribution to low flows at United States. He carried out a study to determine the desirability of estimating parameters of probability distributions by the method of maximum likelihood. It was observed that the Gumbel and Pearson type-III distribution fitted the data equally well and that, the parameters can be best estimated by using maximum likelihood method.

Kumar (1993) made an effort to select the most representative probability density function for the annual runoff time series data obtained from the watersheds of the eastern red soil region of India. He tried seven theoretical probability functions, which are commonly used in hydrologic frequency analysis. He used Chi-square goodness of fit test to find out the best fit and method of moments to estimate the distribution parameters. He observed that the two-parameter Log normal probability density function was the most representative one for the region.

Mohan *et al.* (1998) analysed Gamma, Normal, Log Normal, Log Pearson and Square root distributions to select a suitable distribution for inflow for each month for

Chembarampakkam tank irrigation system in Tamilnadu. They compared Chi-square value fitted for the different distributions with critical Chi-square values. They determined the fitted equation of the selected distribution for each month and computed the inflows at 50%, 60%, 70% and 80% dependable levels from these cumulative distribution functions. They used these values of inflows in the optimization model for further planning.

Yue and Pilon (2005) applied L-moment ratio diagrams and average weighted distance to identify a probability distribution function of annual minimum stream flow in 11 climatic regions of Canada. Across the entire country, the Pearson type-III probability distribution function was an acceptable distribution for describing annual minimum stream flow.

2.4.3 Probability Distribution Functions for Evaporation/Evapotranspiration

Pruitt *et al.* (1972) studied the frequency distribution patterns of daily evapotranspiration and presented for those frequently irrigated, frequently mowed grass cover grown for a 10 years period at Davis, California, USA. In addition, evapotranspiration during the June-July peak requirement period was analyzed for a period of 1, 3, 7, 15 and 30 consecutive days. The distribution patterns for the various seasons of the year were discussed in relation to general climatic variations. It was reported that about 25 mm of stored soil moisture can be considered readily available; the peak design rate would be around 8.1 mm per day at 99% level. These were respectively 24% and 38% higher than the 10 years monthly mean.

Wright and Jensen (1972) studied peak water requirement for crops in Southern Idaho, USA and determined frequency distribution of evapotranspiration rates of 1,3,7,15 and 30 days averaging periods. The daily evapotranspiration computed for reference crops for Southern Idaho showed large daily variations and demonstrated the need for frequency analysis for precise planning. The results of this study provided estimates of expected peak evapotranspiration rates for the reference crops.

Bhakar (2000) performed frequency distribution of evaporation using the database of 20 years. The probability curves of evaporation were developed at 5, 10, 25, 50, and 70, 80, 90, 95 per cent levels for determination of peak crop water requirements for shorter duration. Probability distribution of daily evaporation for different consecutive day periods was also performed.

Kumar (2001) developed frequency distribution pattern of daily evapotranspiration and estimated the values at different probability levels of 5, 10, 25, 50, and 70, 80, 90, 95 per cent.

Pandey (2002) studied frequency distribution pattern of daily evapotranspiration for black gram crop. The crop evapotranspiration was estimated at different probability levels of 5, 10, 25, 50, and 70, 80, 90, 95 per cent.

Hardofa (2003) fitted weekly and monthly pan evaporation of nineteen to twenty years data of agro-climatic stations of Ethiopia to five different frequency distributions viz. Normal, Lognormal, Gamma, Gumbel and Weibull's. From the best fitted frequency distribution, dependable weekly and monthly pan evaporation at 5, 15, 25, 35, 50, 65, 78, 85 and 95 percent probability levels were obtained.

Jat and Singh (2005) formulated probability models for prediction of water deficit for Kota and Jaipur in Rajasthan. The daily meteorological data recorded at Agricultural Research Stations, Durgapura, Jaipur and Kota, Rajasthan for a period of 15 years (1981-1995) were collected for the study. Reference crop evapotranspiration was computed on weekly basis by Penman-Monteith (FAO-56) method. Weekly water balance was performed by Thornthwaite and Mather (1955, 1957) method. Three distributions namely Gumbel, Log Normal and Pearson Type-III were used. From the study, it was concluded that the Log Pearson Type-III and Log Normal distributions were found to be the best probability models for predicting weekly water deficit for Jaipur and Kota, respectively.

Wadatkar and Singh (2006) reported the frequency analysis of maximum weekly pan evaporation data of eight stations of Maharashtra using three distribution i.e. log pearson type – III, Gumbel's and Weibull's (maxima). The chi-square tests $\chi_{cal}{}^2$ for goodness of fit of the observed data to the theoretical distribution were performed. The distributions that resulted in the lowest Chi-square value while fitting the different competing distributions to the pan evaporation data were selected as the best distribution for that location and maximum weekly evaporation at 20, 40, 60, 80 and 90% probability levels were computed employing the best fit probability distribution functions. The maximum weekly pan evaporation at 70% probability level at Akola, Colaba, Dapoli, Kolhapur, Nagpur, Pune, Rahuri and Sidewahi were observed to be 17.9,5.0,6.5,5.7,10.3,10.9,12.6 and 13.9 mm, respectively.

Seung *et al.* (2008) studied design water requirement through frequency analysis of crop water requirement and reference return period for 10 years in South Korea. They determined design water requirements by using Penman-Monteith and optimal probability distribution. For finding an optimal probability distribution function, nine types of probability distribution function were tested by using K-S and PPCC goodness-of–fit methods. From the test, the generalized logistic was selected and design water requirement were estimated using the chosen optimal probability distribution function.

It is observed from the literature cited above that different probability distribution functions were studied for rainfall amount and maximum rainfall by many researchers. They estimated the values at different probability levels by the best probability distribution functions. The distribution functions that were fitted are: Normal, log normal, log Pearson type –III, gamma, 2-parameter gamma, extreme value type–I, Log extreme value–I, Gumbel's and Weibull's. They used chi-square or k-s test for testing the goodness of fit.

Similar but few studies were reported for stream flow. Rainfall and stream flow represent the water supply parameters and evaporation and evapotranspiration represents the water demand parameters. Therefore their values are required at desired probability levels. Though many studies are reported for water supply parameters, but only few for water demands parameters and that too only for evaporation. As this study is concerned with the evapotranspiration, the probability distributions analysis of evapotranspiration was performed. Based on the findings of the earlier studies reported in this section Normal, Log Normal, Gamma, Gumbel and Weibull's distributions were chosen to fit to the weekly reference crop evapotranspiration values estimated by Penman-Monteith method for Solapur, Ahmednagar, Pune and Nasik districts of Western part of Maharashtra state. The chi-square test was selected to test the goodness of fit.

2.5 STOCHASTIC MODELING

A mathematical model representing a stochastic process is called stochastic model or time series model. Stochastic processes treat sequences that are governed by law of chance. Time series are considered as a part of stochastic process. The ET_r is stochastic in nature since it is affected by climatological parameters. The stochastic nature of ET_r can be represented by the mathematical modeling. This modeling is basic tool to generate and forecast desired parameters with greater accuracy. The stochastic modeling of ET_r as time series is important for the real time irrigation scheduling and drought management planning.

The first step in stochastic model construction is to select suitable classes or families of model from which the most appropriate model to a given time series can be chosen by following the identification, estimation and diagnostic check stages of the model development. For example, when modeling of hydrological time series, one may wish to consider the Auto Regressive Moving Average (ARMA) and Auto-Regressive Integrated Moving Average

(ARIMA) family of models. The objective of this study is to fit the stochastic model to reference crop evapotranspiration (ET_r) series. Hence in this section, the brief review on stochastic model for different hydrological time series is discussed. This is followed by the desired review of the application of stochastic models for evaporation/evapotranspiration.

2.5.1 Application of Stochastic Model to Hydrological Time Series

Davis and Rappoport (1974) estimated the forecasts of the monthly Palmer Drought Severity Index using an exponential smoothing procedure and an autoregressive moving average process using monthly rainfall 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 times series and ARIMA models. Most of the recent advances in times series analysis are based on the basic work of Box and Jenkins. According to Box and Jenkins the ARIMA process has distinctly different covariance structures among their different orders which provide the covariance for a graphical comparison of the sample correlogram with that of the selected model.

Salas *et al.* (1980) presented a comprehensive discussion on time series modeling of hydrologic variables. They also discussed on many aspect of hydrologic modeling in single variate or multivariate scenario. According to them the stochastic model can be used to predict the frequency of occurrence of certain hydrological variable including water deficit.

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

Kamte and Dahale (1984) evaluated first order autoregressive AR (1) model to generate m-day minimum rainfall of different durations. The model satisfactorily explained the observed minimum rainfall of different durations. Further, the probabilities of minimum rainfall of different durations were estimated to understand how best one can delineate the area of droughts.

Hudelson *et al.* (1989) analyzed arcsine square root transformed diseases incidence values for spatial nonrandomness snap bean field by using three techniques: run analysis, autocorrelation analysis and autoregressive integrated moving average (ARIMA) modeling at

Arlington, Columbia, USA. All three techniques detected the slow, undulating change in disease incidence values: however, only ARIMA modeling detected jaggedness and could quantify both patterns. A "generalized ARIMA (1,0,1) model" was found to describe 35 of the 38 data sets. The biological mechanism generating these patterns was unknown. Theoretical characteristics of the generalized ARIMA (1,0,1) model indicated that random start systematic sampling would provide a better estimate of total or mean brown spot in a row than a simple random sampling.

Bender and Simonovle (1994) used seasonal autoregressive integrated moving average (SARIMA) models for forecasting monthly water supply. Models were developed and applied to three types of river-basin data within a sensitivity analysis of flow scenarios. Ranking of model performance for possible system scenarios suggested a set of rules to govern the choice of a single model to produce the best available forecast. SARIMA models appeared to be more flexible for natural inflows with low upstream storage capacity and high variability. According to author deseasonalized ARMA models may be better suited to natural inflow systems that have a large storage capacity, lower variability and greater response lags to precipitation events.

Gorantiwar *et al*. (1995) applied autoregressive (AR) models up to fourth order to historical annual river inflows and logarithmic transformation of the historical annual river inflows of Barkar river to generate synthetic annual river inflows. The statistical properties such as mean, standard deviation and lag one serial correlation coefficient were preserved in generated river inflows of all AR models applied to original river inflows as well as logarithmic transformation of original stream flows. The statistical properties of historical sequences fell in the 95 per cent confidence limit. However, skewness coefficient was preserved in the generated river inflows of all AR models applied to logarithmically transformed river inflows only. Diagnostic checking of residual series showed that AR model of fourth order applied to logarithmically transformed river inflows fit the annual river inflows data well in preservation of all the properties.

Narulkar (1995) used time series modeling with basic ARIMA model in its seasonal form and used a multivariate structure for four reservoirs located in hydro meteorologically homogenous areas of MRP command area, Madhaya Pradesh. The data were analyzed in single site perspective as well as multisite perspective. In multisite case, a simple seasonal time series model, the seasonal AR (1) model, was attempted and the results of forecast with all the models were compared to evolve an appropriate model for forecasting of inflows to MRP system.

Samani *et al.* (1995) applied time series techniques to Ghara–Aghaj flow records, in order to generate forecast values of the mean monthly river inflows. The autoregressive models of order one and two, AR (1) and AR (2) and autoregressive moving average model of order one ARMA (1,1) were fitted to stationary series. The AR (2) model produced results which are statistically compatible with the past records.

Srinivasan (1995) applied periodic Gaussian univariate models with different transformations to the southwest monsoon based flows of the Cauvery river in Southern India. The models considered were PAR (1), PAR (2), PARMA (1,1) and Thomas Fiering 3 –parameter model (only log transformation). The transformations attempted were natural logarithm, square root (log), Wilson–Hilferty and Log (Wilson–Hilferty). The diagnostics as well as the verification of monthly historical flow showed that the periodic model of ARMA (1,1) type with Wilson –Hilferty transformation performed the better in terms of the overall reproduction of basic statistics.

Srinivasan and Thandaveswara (1995) fitted lower order periodic autoregressive/ autoregressive moving average (PAR/PARMA) models to the monsoon-dependent river inflows of southern India, measured at Chunchanakatte (Cauvery river), Akkihebbal (Hemavathi river) and Unduwadi (Lakshmanathirtha river). Power transformation with periodic exponents (PTPE) and Wilson-Hilferty transformation (WHT) were found to be the most suited ones. In all the three cases, the more commonly used log and square-root transformations were rejected by the normality test of residuals. The periodic skewness was in general reproduced better by WHT, while periodic mean and periodic variance were better reproduced by PTPE. Even the negative skewness coefficients were reproduced by WHT. However, any of the periodic models could not reproduce the periodic skewness or preserve the periodic correlations of low flows with high skewness and low correlations. It was concluded that the most recent periodic models (PAR/PARMA) do not seem to perform to expectation in modeling a few cases of the highly variable monsoon dependent river flows.

Montanari *et al.* (1997) developed long memory model and new estimation method by using fractionally differenced autoregressive integrated moving average (FARIMA) for long term monthly and daily inflows of Lake Maggiore at Italy. They presented FARIMA framework for identification and estimation. The resulting model, which replicates the sample probability density of the data, can be used for generation of long synthetic series.

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.

Sharma (1998) evaluated various stochastic models for forecasting Jakham river monthly inflows in Southern Rajasthan. Autocorrelation, partial autocorrelation, inverse autocorrelation functions were analyzed to identify the class and order of stochastic models to represents Jakham river inflows. The parameters of the identified models were estimated by conditional least square method. Validation of the identified models suggested that only ARMA (3, 0), ARMA (2,1) and ARMA (3, 1) passed the tests. The minimum mean square error criterion was used to select the best model. It revealed that ARMA (3, 0) model was proved to be the best model amongst all.

Singh (1998) attempted stochastic modeling of monsoon rainfall data at 50 different stations across India to study the persistence structure causing inter annual variability in monsoon rainfall. The study of stochastic behavior 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 modeled by fitting auto regressive 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.

Montanari *et al.* (2000) introduced a seasonal fractional auto regressive integrated moving average (SARIMA) model, accounting both short and long term persistence. The estimation of the parameters was carried out by applying the Whittle's approximation to the Gaussian maximum likelihood function, which yielded asymptotically consistent estimates. The method was applied to the monthly flows of the Nile River at Aswan and the results were compared with ones obtained by applying heuristic procedures.

Koutosoyiannis (2001) proposed a methodology for coupling stochastic models of hydrologic processes applying to different time scales so that the time series generated by different models could be consistent. Two separate stochastic models of the same hydrologic process, each applying to different time scale, can generate two multivariate time series. A transformation was developed that appropriately modified the time series of the lower-level time scale so that this series becomes consistent with the time series of higher level and an appropriate correlation between the two time series was established.

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 was 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.

Patil (2003) performed stochastic modeling of water deficit by using 24 years (1976-1999) data. The time series was found trend free. The generated series was compared with observed water deficit series. Developed autoregressive model for Rahuri, Maharashtra state was validated by predicting two years ahead and compared with observed water deficit series. The results indicate a high degree of model fitness to observed data series.

Jha *et al*. (2003) conducted study to develop a stochastic model for the soil moisture data of 19 years (1980-1998) for an average depth of 30 cm at Udaipur region, Rajasthan. The soil moisture series was assumed to be composed of periodic and stochastic component as the trend component was found to be insignificant. The autoregressive stochastic model was fitted to the soil moisture data. By statistical analysis the closeness between generated and historical series was observed. The developed model was then validated by generating the data for the last 3 years (1999-2001) and compared it with observed data for the same years. Mean and standard deviation of the model was found to be very close to observed data, which proved the validity of the model.

Satpute (2004) developed autoregressive models for estimating weekly water deficits for different agro climatic zones of Maharashtra in India. The validation results indicated the adequacy of the fitted model.

Chhajed (2004) developed stochastic model for Mahi river inflow series. He suggested that ARMA (3,1) model can be used for one-time step ahead monthly forecasting of Mahi river inflows. Minimum mean square error (MMSE) criterion was used for selection of best model.

Verma (2004) developed stochastic model on monthly rainfall of Kota, Rajasthan. The historical data series were normalized by square root transformation. Fourier analysis was used for determination of periodic components and number of significant harmonics was determined by standardized to remove the periodic components. The parameters of AR model were estimated by the general recursive formula proposed by Kottegoda (1980) whereas the parameters of ARMA models were computed by use of Yule –Walker equations. Box-Pierce Portmanteau lack of fit test and Akaike Information Criterion were used to select the models. The performance of the models in generation and forecasting values of monthly rainfall data were evaluated quantitatively and qualitatively by comparison of historical and selected model correlograms and goodness of fit tests such as mean forecast error, mean absolute error, root mean square error and integral square error. The low values of errors suggested the applicability of AR (1) and ARMA (1,1) models for real times forecasting of monthly rainfall data of Kota, Rajasthan.

Katimon and Demun (2004) developed Auto Regressive Integrated Moving Average (ARIMA) model for monthly water uses behavior at University of Technology Campus, Johor, Malaysia. Monthly water uses series can be presented using ARIMA (2,0,0) by using ACF, PACF and AIC tests. The parameters were estimated by using maximum likelihood method. The estimated parameters of the model $\varnothing_1$ and $\varnothing_2$ are 0.2747 and 0.4194, respectively.

Bhakar *et al*. (2006) developed stochastic model for wind speed at Udaipur region, Rajasthan. Statistical test indicated that the series of the weekly wind speed data is trend free. Stochastic components of the mean weekly wind speed followed second order Markov model and correlation coefficient between generated mean weekly wind speed series and measured mean weekly wind speed series was found to be 0.997.

Rajkumar and Kumar (2007) performed time series modeling of daily rainfall during north-east monsoon season of Baptala, Andhra Pradesh. The stochastic process of daily rainfall of north-east monsoon season of Baptala was characterized by both the second order autoregressive AR(2) and autoregressive moving average ARMA (2,2) models. The goodness of fit of models was tested by Box-Pierce Portmonteau test, Akaike information criterion and by comparison of historical data and model correlograms. Performance of these models was evaluated using mean absolute error and integral square error. The performance of ARMA (2,2) model was found to be better than AR(2) model for northeast monsoon season of Baptala.

Deora *et al.* (2009) developed stochastic model for weekly water deficit series, using 28 years climatological data of S.K.Nagar, Dantiwada, Gujarat. The turning point test and Kendall's rank correlation test were applied for detecting the trend. Correlogram techniques were used to detect the periodicity, which was then analyzed by Fourier series method. Significant harmonics were also identified. Statistical properties of the generated water deficit series were compared with the observed series. Test results indicated high degree of model fitness, which may be used for representing time based structures of the water deficit time series.

It is observed from the studies reviewed in this section that the stochastic models were used to generate the synthetic sequences of mostly river inflow, soil moisture, monthly water supply, disease incidence, runoff, rainfall, drought index, wind speed and water deficit. In general the stochastic models that were fitted to these hydrological variables were Thomson-Firing, AR, MA, ARMA, ARIMA, SARIMA, PARMA and FARIMA models of different orders. SARIMA models were used to represent the seasonal variation in the variable. The model parameters were estimated by maximum likelihood, Yule Walkar equation and Whittal's approximation method. Power, Whittal's, log and square root transformation were used for tests to select the model.

Generally the models were developed to present mean, standard deviation, skewness coefficients and correlation in the generated data. Least square error, integral square error, root mean square error, Akakie Information and Box-Pierce Portmanteau criteria were used to selected the best models.

2.5.2 Stochastic Models for Evapotranspiration and Evaporation Series.

The important factor for water resources management studies is a successful prediction of water demand or evapotranspiration. In this section, the important reviews on the stochastic modeling of evaporation /evapotranspiration are presented.

The determination of irrigation water requirement for use in project planning, design, and operation commonly involves the prediction of the reference crop evapotranspiration Miguel *et al*. (1993). A time domain time series model was identified for the forecasting of reference crop evapotranspiration and compared to other simple methods of forecasting using monthly average and yearly difference approaches.

Gupta and Kumar (1994) developed the stochastic series of the weekly evaporation data of the Palanpur, Himachal Pradesh. It was concluded that there was no trend; periodicity of the periodic component was found to be 52. The stochastic component was selected on the basis of least residual variance and final relationship was developed to predict the evaporation on daily basis.

Hameed *et al.* (1994) developed a dynamic relationship between reference evapotranspiration and commonly observed climatological parameters through the utilization of multiple input transfers–function–noise modeling techniques and subsequent forecasting of evapotranspiration by such relationships.

Mohan and Arumugam (1995) studied the applicability of a seasonal ARIMA and a winter's exponential smoothing models for weekly reference crop evapotranspiration at Annamalainagar, Karnataka. They used daily meteorological data during the years 1977 – 1992 for estimating reference crop evapotranspiration. Modified Penman method was used for estimating weekly ET_r values. The differencing schemes used were d=1; D=0, d=0, D=1 and d=1, D=1, respectively. The principle of parsimony was applied to select the model. The Akaike Information Criteria and Posterior Possibility criteria were used and residual independence was checked using Port-manteau lack-of-fit test. SARIMA $(1,1,1)_{52}$ model with one autoregressive and one moving average process and with a seasonality of 52 weeks was found to be an appropriate stochastic model for forecasting the weekly ET_r values. The forecasting performance of both the model was found to be satisfactory and hence considered to be adequate for quicker and reliable estimation of evapotranspiration.

Sahoo and Mohan (1995) developed stochastic model for weekly reference crop evapotranspiration for three stations from different climatic zones in Tamilnadu. An additive model consisting of superposition of trend, cyclic and stochastic components was studied. It was found that the number of harmonies required for fitting Fourier series to the mean weekly evapotranspiration series of all the stations is less than or equal to two; accounting for more than 90% of the variance in mean weekly series. In the case of weekly standard deviation (SD) series the number of harmonies required to fit Fourier series is quite large (about 20) determining demanding a different approach to tackle this problem. The spectral density functions of weekly standard deviation series were estimated and the frequency at which the spectral density function shows peaks was found out. The cyclic decent method was used to optimize the raw frequencies thus obtained to get the exact frequencies of which the standard deviation of the weekly series is periodic. These frequencies are then used to model the standard deviation series. The stochastic component is fitted with an autoregressive model. The postulated model for evapotranspiration series has been validated by comparing the statistics of the historic series from the model and found to have close agreement.

The prediction of evapotranspiration is necessary for a reliable management of irrigation systems, project planning and operation of irrigation systems, Slavisa (1998). A seasonal ARIMA model was identified and compared with mathematical models at Nis, Yugoslavia. Monthly values of ET_r from 1961 to 1970 were used for calibrating the prediction of models and data from 1971 to 1975 were used for verifying the prediction results. The mathematical models were yearly differencing model and Monthly average model. ACF and PACF residuals series were transformed by using differencing scheme. The parameters of models were estimated by maximum likelihood method. Box-Pierce method, Portmanteau lack-of-fit and t-statistics tests are used for diagnostic checking. Akaike Information Criteria was used to select the best model. The best results were obtained using the ARIMA model. The mean square error, maximum absolute error and mean absolute error were 219.2 mm^2, 36.2 mm and 11.5 mm, respectively. The smallest statistics values were obtained using ARIMA model, which emphasizes the best agreement between the observed and the predicted evapotranspiration values. Based on the results of comparisons, it was concluded that seasonal ARIMA model provided a reasonable accurate prediction of reference crop evapotranspiration.

Bhakar (2000) developed a stochastic model for weekly evapotranspiration values using 20 years data under the climatic conditions of Udaipur, Rajasthan. Validation of the developed model was done by comparison of estimated values with historic values. The stochastic model was found to predict evaporation very accurately. Stochastic model was also developed for estimation of daily wheat evapotranspiration and daily green gram evapotranspiration using 20 years data. The developed stochastic model for wheat evapotranspiration and green gram evapotranspiration were found to predict the daily crop evapotranspiration very accurately.

Raghuwanshi and Wallender (2000) applied time-domain methodology to forecast daily ET_r values for Davis, California, USA. Stochastic process of daily crop ET was characterized by both the first order autoregressive AR (1) and auto regressive moving average ARMA (1,1) models. The ARMA (1,1) model with the least square method of estimation preserved variance and kurtosis better than the AR (1) model. For both the parameter estimation methods, ARMA (1,1) model performed better than the AR(1) model. ARMA (1,1) model with the least squares estimation method was recommended to forecast ET_r one day ahead for Davis CIMIS station, USA.

Pandey (2002) developed stochastic model for estimation of daily black gram evapotranspiration and Kumar (2003) developed stochastic model for estimation of daily Okra evapotranspiration. The developed stochastic models were found to predict daily evapotranspiration satisfactorily.

Subbaiah (2004) analyzed stochastic structure of weekly evapotranspiration time series during 1980 to 2000 from the Penman equation using an additive model at Junagadh, Gujarat. The turning point and Kendall's rank correlation tests were applied for detecting the trend. Correlogram technique was used to detect the periodicity, which was then analyzed by Fourier series method. Significant harmonics were identified. The evapotranspiration series was tested for stationarity and the dependent part of the stochastic was found to be well expressed by the second order auto regressive model. The results indicated that, the weekly evapotranspiration series is trend free and periodic and stochastic in nature. The developed model superposes a periodic deterministic process and a stochastic component. The developed periodic–stochastic model may be used for representing the time-based structure of the evapotranspiration time series. The significance of this study was to show that the past records of the data provide valuable information for determining the basic time dependent structures of evapotranspiration series.

Hamdi *et al.* (2008) described seasonal time series autoregressive integrated moving average (ARIMA) model for forecasting monthly reference crop evapotranspiration by using past historical records of pan evaporation data (1973-2002) at Central Jordan Valley, Jordan. The formulation of ARIMA model was identified based on the transformed ET_r time series data. The sample of ACF and PACF were used for detection of various types of autocorrelation. The parameters of the proposed tentatively identified models were estimated followed by estimating the values for diagnostic and adequacy checking. The parameters were estimated using maximum likelihood approach. For diagnostics checking, t-ratios, Q-stat and Akaike Information Criteria were used to check the adequacy of the tentatively identified model. The forecasting performance capability of three tentative ARIMA models was assessed using root mean square forecasting error (RMSFE), mean absolute forecasting percentage error (MAFPE) and maximum absolute forecasting percentage error (MAFPE). Upon comparison of computed ET_r from measured pan evaporation and forecast series, the developed ARIMA (1,0,0) $(0,1,1)_{12}$ model provided and acceptable forecasts. The developed model allowed local farmers and water resources managers to predict up to 60 months with a percentage error less than 11% of the mean absolute forecasting. The potential to make such predictions is crucial in optimization of the needed resources for effective management of water resources. Furthermore, the developed model offered a forecasting of short and long term forecasting.

It is seen from this section, that very few attempts have been made on the stochastic modeling of evaporation and evapotranspiration. The models developed so far indicate that mostly ARMA or ARIMA classes of models were used for evaporation and evapotranspiration. In this study therefore, ARIMA class of models were used for the forecasting of weekly evapotranspiration series for Solapur, Ahmednagar, Pune and Nasik districts of Western part of Maharashtra state.

Concluding Remarks

The various studies conducted for estimation of crop coefficient values for deciduous fruit crops were through lysimeter approach. It is difficult to conduct the lysimeter studies for pomegranate fruit crop. Therefore under this study shaded area approach was considered for developing crop coefficient values for 1^{st} to 5^{th} year's pomegranate fruit crop. Further, the reported studies have indicated that the direct and indirect methods are suitable for deciduous fruit crops for estimation of leaf area index. The similar approach has been inducted for pomegranate fruit crop as well.

The reference crop evapotranspiration estimated by various investigators have indicated that Penman-Monteith method requires more climatological data hence, it becomes difficult to estimate the same in absence of availability of data, however the other methods requiring lesser data can be compared with Penman-Monteith method and it has been conducted in present study also.

The probability distribution functions studies were reported for rainfall, runoff, stream flow and evaporation series but few study mentioned for evapotranspiration time series. As this study is concerned with evapotranspiration, the probability distributions analysis of evapotranspiration was performed at different probability levels.

It is observed from the studies reviewed that stochastic models have been developed and fitted for various hydrological variables, but few studies reported for generating and forecasting of reference crop evapotranspiration. In this study the ARIMA classes of model have been used for analysis. The analysis carried out in this study has not been reported for crop like pomegranate. Therefore, considering the above facts and pomegranate as a main fruit crop of Western part of Maharashtra, the present study was undertaken for Solapur, Ahmednagar, Pune and Nasik districts of the state.

CHAPTER-III

MATERIAL AND METHODS

This study involved taking measurements in the laboratory and field on certain parameters and collection of data on several meteorological parameters over a location area. This chapter describes the location of the study area and other pertinent details. Further the chapter describes the methodologies that were adopted for measuring the biometric data required for developing k_c values and curve, and leaf area indices for 1^{st} to 5^{th} year of Pomegranate orchard. The sources of meteorological data are also described in the chapter.

The different procedures/models that were used for the estimation of reference crop evapotranspiration (ET_r) values along with the software developed for the estimation are presented in this chapter. Further the probability distribution function used for fitting ET_r values and the procedure for fitting of probability distribution function and obtaining the values of ET_r at various probability levels are also described in this chapter. The procedure for fitting the stochastic model for generation and forecasting of ET_r values are presented in this chapter.

3.1 GENERAL FEATURES OF THE STUDY AREA

The major pomegranate growing districts of Maharashtra state are the study area. The details and general features of the study area are presented in this section.

The study was carried out for the Western part of water scarcity zone of the state of Maharashtra. The four districts of the Western region of the state of Maharashtra were considered for estimation of ET_r and fitting probability distribution functions and stochastic models to ET_r values. The name of districts and their details, and location map of the study area are presented in Table 3.1 and Fig. 3.1; respectively.

Table 3.1 The details of the districts that were considered for the study

Sl.No.	Districts	Latitude	Longitude	Altitude (amsl)	Period of meteorological data available
1.	Solapur	$17^0 40^'$N	$75^0 54^'$E	483.50 m	1983-2007(25 Years)
2.	Ahmednagar	$18^0 32^'$N	$73^0 51^'$E	559.00 m	1975-2007(33 Years)
3.	Pune	$19^0 24^'$N	$74^0 39^'$E	514.00 m	1987-2006(20 Years)
4.	Nasik	$20^0 08^'$N	$73^0 55^'$E	608 .00 m	1985-2007(23 Years)

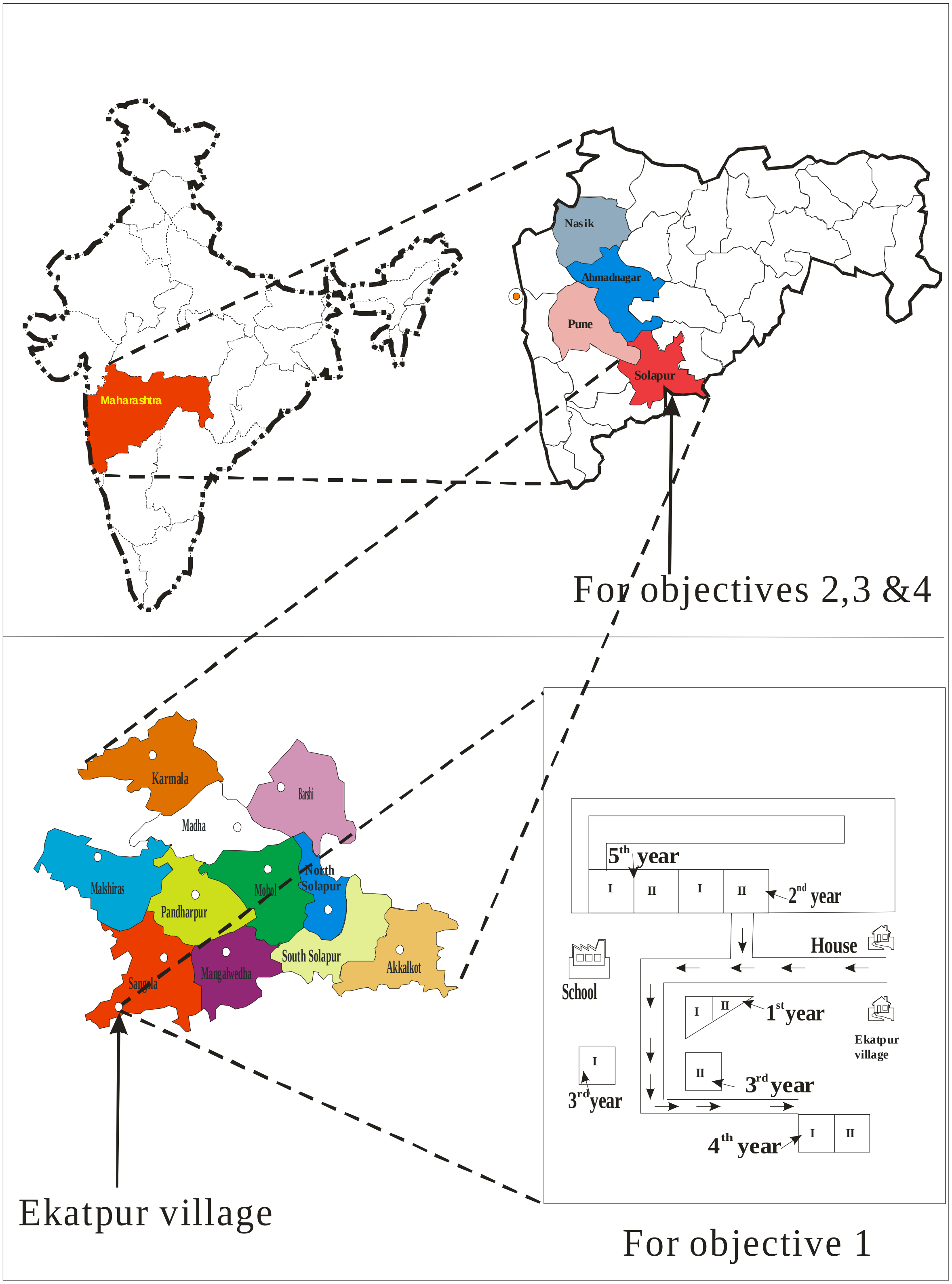

Fig. 3.1 Location map of the study area

3.2 DEVELOPMENT OF CROP COEFFICIENT VALUES FOR POMEGRANATE

The objectives of this study were to develop crop coefficient values/curves for 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} year's age of pomegranate fruit crop and estimate pomegranate evapotranspiration (ET_c) for major pomegranate growing region of Maharashtra state. There are several methods available for developing k_c values/curves for pomegranate tree. However as stated in chapter-I and chapter–II, the shaded area method was used in this study. There was necessity of information on percentage/fraction of shaded area of pomegranate at solar noon for this purpose.

The details of selection of pomegranate plantations, their inventory for soil, water and nutritional status, water applied to plantation and the procedure for measuring shaded area are described in this section.

3.2.1 Selection of Plantation

Pomegranate is the perennial plant, which stabilizes often after 3-4 years. Therefore, it is necessary to know the crop coefficient (k_c) values up to five years. To establish the separate plantation and obtain the crop coefficient (k_c) values of the same plantation over five years i.e. from 1^{st} to 5^{th} year is out of scope for this study. Hence, it was proposed to select the commercial orchards of different ages (i.e. 1^{st} to 5^{th} years) and develop k_c values for these plantations. Therefore, the two commercial orchards having ages of 1, 2, 3, 4 and 5 year were selected. In this way 10 orchards were selected. As the purpose of the selection of orchards was to obtain the information for the development of k_c values, the due care was taken to select the plantations that were growing potentially, disease free and not short of water.

3.2.2 Inventory of the Pomegranate Orchards

The inventory of orchard in terms of plant geometry and layout of irrigation system is described in Table 3.2.

3.2.3 Water Applied

It is important to know the quantity of water applied for each irrigation. This information is useful to compare the quantity of water applied by the farmers with those estimated from the ET_r and k_c values developed in this study. For this purpose the forms were designed in a specific format and plantation owners were requested to fill the information in the forms. The format of the form and analysis report are presented in Appendix-A (Tables A-1 and A-2). The training was provided to owners to fill the forms. The forms constituted predominately the information on irrigation scheduling i.e when, how and how much water was applied to the plantations. The information on water applied that was collected from the experimental orchards is presented in Table 3.3.

Table 3.2 Pomegranate tree inventories for selected orchards

Basic observations	Age of the orchards (years)									
	1		2		3		4		5	
	I	II	I	II	I	II	I	II	I	II
Spacing(m)	4.5x3	4.5x3	4.5x3	4.5x3	4.5x3	4.5x3	4.5x3	4.5x3	4.5x3	4.5x3
Plantation year	2007	2007	2006	2006	2005	2005	2004	2004	2003	2003
Nos. of plant per ha	740	740	740	740	740	740	740	740	740	740
Irrigation application method	Drip	Drip	Drip	Drip	Drip	Drip	Drip	Drip	Drip	Drip
Nos. of dripper per tree	1	1	2	2	4	4	6	6	8	8
Nos. of lateral per row	1	1	1	1	2	2	2	2	2	2
Dripper capacity (l/hr)	4	4	4	4	4	4	4	4	4	4
Irrigation Interval	AD	AD	AD	AD	AD	AD	AD	AD	AD	AD

(Note: AD-Alternate day)

Table 3.3 Water applied to experimental pomegranate tree in different months

Months (2008-2009)	Rainfall (mm)	Age of the orchards									
		1 (l/d/tree)		2 (l/d/tree)		3 (l/d/tree)		4 (l/d/tree)		5 (l/d/tree)	
		I	II	I	II	I	II	I	II	I	II
July	50.0	68	68	104	104	208	208	528	528	448	448
August	65.5	78	78	104	104	392	392	648	648	432	432
September	253.2	24	24	32	32	232	232	348	348	384	384
October	157.7	78	78	104	104	624	624	936	936	1040	1040
November	125.9	84	84	84	84	704	704	924	924	1176	1176
December	0.0	93	93	124	124	992	992	1860	1860	2232	2232
January	0.0	93	93	124	124	868	868	1674	1674	1984	1984
February	0.0	108	108	162	162	864	864	1296	1296	1512	1512
March	0.0	124	124	248	248	992	992	1302	1302	1488	1488
April	0.0	120	120	300	300	960	960	1080	1080	1635	1635
May	0.0	155	155	310	310	992	992	1488	1488	1567	1567
June	0.0	155	155	310	310	868	868	1302	1302	1438	1438
Total(l/y/t)	652.2	1180	1180	2006	2006	8696	8696	13386	13386	15336	15336

3.2.4 Soils

3.2.4.1 Soils of the study area

The typical soil physical properties for the selected districts were taken from the report of National Bureau of Soil Survey and Land Use Planning, Nagpur (Challa *et al.* 1999) and are presented in Table 3.4.

Table 3.4 Physical properties of the soils of the study area

Districts	Texture	Depth(cm)	Average AWC (%)	Climatic region
Solapur	Clay loam to Clay	15-200	85	Semi-arid (dry)
Pune	Clay loam to Clay	15-200	80	Semi-arid (dry)
Ahmednagar	Clay loam to Clay	30-125	100	Semi-arid (dry)
Nasik	Clay loam to Clay	32-130	100	Semi-arid (dry)

(Note: AWC-Available water content)

The soils of the study area are dominantly clayey in texture (61.1%) followed by loamy (38.9%). The deep and very deep soil constitutes 33.4%, shallow soils 14.4% and slightly deep soils 15.3% (Challa *et al.* 1995).

3.2.4.2 Soils of the experimental plots

The chemical properties of soil of the experimental plot are presented in Table 3.5a. The soils of the experimental plots are stony in nature and hence, classified as marginal land, which is not suitable for cultivation (Sehgal, 1996). The soil pH is alkaline and EC value is normal for both the orchards. The values of organic carbon are in medium to high range and $CaCO_3$ is slight to medium low at depths 30, 60 and 90 cm for all the orchards.

The status of major nutrients, nitrogen at depths 30 cm is medium for 1st, 2nd and 5th and low for 3rd and 4th year's (I and II) orchards at depths 30, 60 and 90 cm. Phosphorus and potassium at depths 30, 60, and 90 cm are high for 1st, 2nd, 3rd, 4th and 5th year's (I and II) orchards. The status of micro nutrients (Fe, Mn, Zn and Cu) are high at depths 30, 60 and 90 cm for 1st, 2nd, 3rd, 4th and 5th year's (I and II) orchards.

The physical properties of soil of the experimental plot are presented in Table 3.5b. It is indicated that, the percentage of sand, silt and clay vary from 35.61 to 59.60, 6.78 to 19.60 and 14.58 to 52.70%. The bulk density varies from 1.50 to 1.60 Mg/m^3.

Table 3.5a Chemical soil properties of the plots of experiment orchards

A) I Orchard

Ages (years)	**1**			**2**			**3**			**4**			**5**		
Depths (cm)	30	60	90	30	60	90	30	60	90	30	60	90	30	60	90
pH	8.31	8.32	8.36	8.31	8.32	8.36	8.29	8.48	8.59	8.18	8.26	8.11	8.31	8.32	8.36
EC(dSm^{-1})	0.33	0.39	0.28	0.35	0.48	0.41	0.32	0.37	0.31	0.40	0.37	0.31	0.25	0.58	0.50
OC(%)	0.95	0.45	0.48	0.98	0.48	0.55	0.92	0.47	0.36	0.28	0.32	0.28	0.54	0.43	0.38
$CaCo_3$ (%)	5.41	4.88	11.2	3.22	3.88	8.58	4.41	4.66	3.68	1.96	0.74	1.96	7.35	7.60	13.9
Available major nutrients(kg/ha)															
N	285	210	120	290	205	185	268	215	157	163	163	198	372	407	140
P	100	65	45	87	112	63	98	80	60	96	78	113	55	50	9
K	765	730	422	352	365	652	785	724	451	348	452	754	637	522	483
Available micro nutrients(ppm)															
Fe	3.19	3.65	4.43	3.22	3.55	3.25	3.17	3.49	4.83	3.77	3.48	3.65	3.17	3.49	4.83
Mn	9.10	6.33	6.90	6.08	6.85	6.95	9.06	6.32	6.80	6.86	6.06	6.73	6.83	6.53	5.19
Zn	4.54	1.36	1.16	1.08	1.54	1.44	4.43	1.34	1.14	1.05	1.24	1.41	2.15	1.30	0.55
Cu	15.6	4.58	5.64	6.88	6.20	3.58	19.48	6.58	5.54	6.44	6.18	4.77	8.55	5.16	2.76

B) II Orchard

Ages (years)	**1**			**2**			**3**			**4**			**5**		
Depths (cm)	30	60	90	30	60	90	30	60	90	30	60	90	30	60	90
pH	8.45	8.96	8.22	8.32	8.36	8.38	8.20	8.41	8.53	8.22	8.22	8.12	8.30	8.39	8.3
EC(dSm^{-1})	0.32	0.34	0.27	0.33	0.42	0.45	0.31	0.34	0.30	0.47	0.36	0.38	0.26	0.54	0.5
OC(%)	0.96	0.47	0.42	0.92	0.44	0.55	0.93	0.49	0.35	0.23	0.34	0.27	0.55	0.44	0.4
$CaCo_3$ (%)	5.45	4.67	11.3	3.32	3.98	8.65	4.42	4.88	3.72	1.98	0.75	1.89	7.25	7.62	13
Available major nutrients (kg/ha)															
N	298	225	140	295	250	198	278	220	168	165	168	197	378	408	185
P	110	72	52	98	120	75	102	88	65	99	85	118	50	45	15
K	785	720	430	365	378	665	788	735	496	384	465	763	665	536	485
Available micro nutrients (ppm)															
Fe	3.14	3.58	4.45	3.28	3.56	3.22	3.47	3.65	4.98	3.95	3.84	3.68	3.25	3.52	4.85
Mn	9.15	6.44	6.95	6.12	6.88	6.59	9.12	6.35	6.88	6.74	6.12	6.78	6.45	6.25	5.16
Zn	4.56	1.38	1.16	1.09	1.56	1.55	4.62	1.47	1.21	1.15	1.20	1.65	2.21	1.36	0.58
Cu	15.5	4.57	5.65	6.89	6.22	3.68	19.12	6.65	5.46	6.45	6.88	4.98	8.58	5.45	2.25

Table 3.5b Physical soil properties of the plots of experiment orchards

A) I Orchard

Properties	**Age of the orchards (years)**				
	1	**2**	**3**	**4**	**5**
Sand (%)	35.61	43.37	59.66	54.45	38.33
Silt (%)	19.60	7.82	10.11	6.78	10.90
Clay (%)	14.58	20.0	35.5	30.8	52.7
Bulk density(Mg/m^3)	1.50	1.55	1.56	1.54	1.60
Field Capacity (mm/m)	145	156	164	170	177
Permanent wilting point (mm/m)	40	43	55	62	65

B) II Orchard

Properties	**Age of the orchards (years)**				
	1	**2**	**3**	**4**	**5**
Sand (%)	38.61	47.47	58.66	58.45	28.33
Silt (%)	19.62	6.97	11.16	5.68	16.90
Clay (%)	13-43	19.8	33.43	32.8	51.70
Bulk density(Mg/m^3)	1.53	1.54	1.56	1.53	1.59
Field Capacity(mm/m)	143	154	166	173	175
Permanent wilting point(mm/m)	38	41	54	64	67

3.2.5 Irrigation Water

The properties of irrigation water of the experimental plots were measured and are presented in Table 3.6. The irrigation water from well number-I was used for 1st, 2nd and 5th year's pomegranate orchards, well number-II for 3rd year pomegranate orchards and well number-III for 4th year pomegranate orchards. As per guideline of water quality for agriculture given by FAO (Ayers and Westcot, 1994) and the classification of irrigation water based on properties of irrigation water, the irrigation water under study was classified as class 2, which is good for irrigation. The pH, EC, SAR and RSC values were all within the recommended limits by FAO and permissible for irrigation of pomegranate orchards. Others properties of irrigation water are in safe limit for irrigating pomegranate orchards.

3.2.6 Nutrient analysis of leaf or petiole

The pomegranate leaf or petioles from the experimental plots were analysed for the nutritional status. The results of the analysis are presented in Table 3.7. As per nutritional diagnosis norms developed for pomegranate (Raghupathi and Bhargava, 1999), it is indicated that, Nitrogen (%) is high, Phosphorous (%) is excess, Potassium (%) is optimum and Manganese (ppm), Zinc and Copper (ppm) are in excess for both experimental orchards of all ages.

Table 3.6 Properties of the water used for irrigation in experimental orchards.

Sl.No.	Particulars	Well No.-I	Well No. II	Well No.-III	Remarks
1.	pH	7.37	7.85	7.98	Permissible
2.	EC (dsm^{-1})	0.93	0.95	0.94	
3.	CO_3^{-2} ($meqL^{-1}$)	Absent	Absent	Absent	safe
4	HCO_3^- ($meqL^{-1}$)	5.73	5.85	5.97	
5	Cl^- ($meqL^{-1}$)	3.60	3.70	3.20	
6	SO_4^{2-} ($meqL^{-1}$)	0.24	0.34	0.22	
7	Ca^{2+} ($meqL^{-1}$)	5.18	5.22	5.35	
8	Mg^{2+} ($meqL^{-1}$)	2.30	2.45	2.54	
9	Na^{2+} ($meqL^{-1}$)	2.17	2.32	2.35	
10	K^+ ($meqL^{-1}$)	0.015	0.018	0.019	
11	SAR	1.22	1.23	1.26	
12	RSC	0.00	0.00	0.00	
13	Mg:Ca Ratio	0.44	0.47	0.41	

Table 3.7 Nutrient status of leaves of pomegranate trees from the experimental orchards.

A) I Orchard

Sl.No.	Nutritional parameters	Age of the orchards (years)					Remarks
		1	2	3	4	5	
1	N (%)	1.55	1.53	1.62	1.93	1.52	High
2	P (%)	0.298	0.258	0.250	0.232	0.352	Excess
3	K (%)	1.59	1.52	1.49	1.38	1.54	Optimum
4	Mn (ppm)	115.12	112.1	119.00	161.00	234.5	Excess
5	Zn (ppm)	140.2	138.90	136.75	97.75	77.25	Excess
6	Cu (ppm)	835.25	845.25	842.25	672.25	705.00	Excess

B) II Orchard

Sl.No.	Nutritional parameters	Age of the orchards (years)					Remarks
		1	2	3	4	5	
1	N (%)	1.58	1.52	1.67	1.98	1.51	High
2	P (%)	0.299	0.255	0.290	0.238	0.365	Excess
3	K (%)	1.65	1.53	1.42	1.35	1.25	Optimum
4	Mn (ppm)	115.32	112.15	115.00	162.00	235.65	Excess
5	Zn (ppm)	140.28	138.98	138.75	98.75	79.25	Excess
6	Cu (ppm)	835.45	845.45	849.25	678.25	710.20	Excess

3.2.7 Estimation of Shaded Area of Pomegranate Trees and Determination of k_c

As stated earlier, two commercial pomegranate orchards each of 1st, 2nd, 3rd, 4th and 5th years were selected. Five numbers of representative plants were randomly selected from each orchard. Plywood boards of 1.5 x 1.5 m, 2.5 x 2.5 m and 3.5 x 3.5 m sizes with grid marking of size 10 x 10, 20 x 20 and 30 x 30 cm were prepared for the estimation of shaded area. These are shown in Plate 3.1. Shaded area was measured at solar noon hour. To measure the shaded area, a plywood board was kept below the canopy as shown in Plate 3.2; and the total number of grids that were shaded area measured. The shaded area was then calculated as the total number of grids times the area of each grid. The crop coefficient value was then computed by using following procedure.

		Example
Measure row to row spacing (A)		= 4.5 m
Measure plant to plant spacing (B)		= 3.0 m
Calculate area occupied by a pomegranate tree (C= A x B)	= 4.5 x 3 m^2	= 13.5 m^2
Measure average length of shaded area at solar noon (D)		= 0.95 m
Measure average width of shaded area at solar noon (E)		= 0.82 m
Shaded area of Pomegranate (F = D x E)		= 0.78m^2
Calculate percentage of shaded area (x) = (F/C) x100, %		= 5.8 %

Calculate the crop coefficient $$k_c = 0.014x + 0.08 \quad (3.1)$$

The crop coefficient values were determined by using the above stated procedure, which was developed for deciduous fruit crop (Williams and Ayars, 2005) on weekly basis.

3.2.8 The Growth Stages of Pomegranate

Doorenbos and Pruitt (1977) have provided the k_c values for deciduous fruit and nut trees for different growth stages. There are:

Initial stage: For perennials crops, the planting date or the start of new leaves to 10% ground cover.

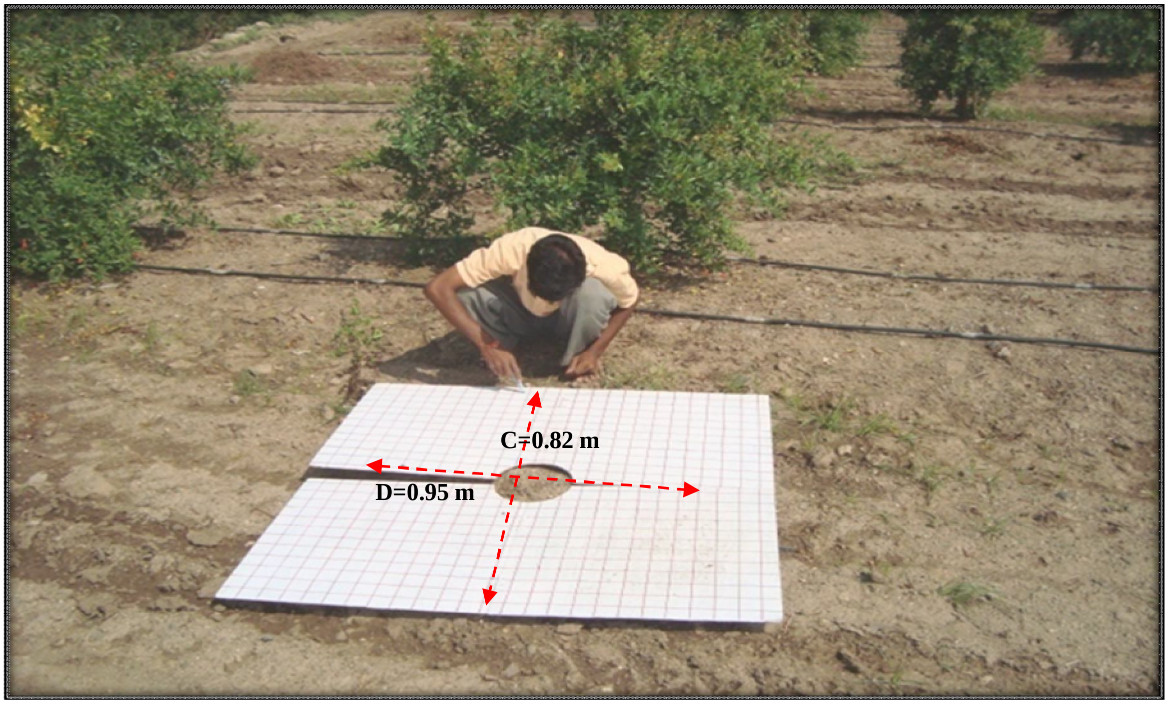

Plate 3.1 Plywood board used for the estimation of shaded area

Plate 3.2 Plywood board kept below the canopy for the estimation of shaded area

Crop development stage: From 10% ground cover to effective full cover, which often occurs at the initiation of flowering or when leaf area index reaches 3.

Mid Season: From effective full cover to start of maturity, which is often indicated by the beginning of the ageing, yellowing, senescence of leaves, leaf drop, or the bowing of the fruit.

Late Season: From start of maturity to harvest or full senescence.

The length of these growth periods depends on climate, altitude, latitude and the date of new leaf initiation. Therefore the observations were recorded to determine the length of these growth periods according to the definition of these growth periods as stated above.

The crop coefficient curves were then constructed using the locally determined length of growth period and corresponding k_c values obtained from the FAO by using the procedure described in guideline for predicting crop water requirements (Doorenbos and Pruitt, 1977). The daily values of k_c were then obtained from the curve. These values were then used for comparing with k_c values determined in this study using shaded area approach.

3.3 LEAF AREA INDEX OF POMEGRANATE

As stated in chapter-II, the k_c values and LAI are dependent on each other. Therefore in this study, the leaf area indices were correlated with crop coefficient values. These correlations will be helpful to know the crop coefficient values from leaf area index values. The LAI values were measured using two approaches. These are described below.

3.3.1 Indirect Leaf Area Index Method

Five representative plants were randomly selected from each of 10 orchards for the estimation of leaf area index. For this purpose the total leaves of a representative plant were divided into small, medium and large size leaves. The numbers of leaves from small, medium and large size were measured. Five representative leaves were then selected from each size and harvested. The area of the harvested leaves was measured by using LI-3000 Licor instrument. This instrument uses an electronic method of rectangular approximation. The area of leaf was measured as the leaf was drawn through the scanning head as shown in Plate 3.3. The total leaf area was estimated by multiplying the average leaf area of each range (i.e. small, medium and large) with the numbers of leaves in these ranges. The leaf area index is estimated as the ratio of total leaf area to shaded area. The leaf area index was calculated for each of the representative plant from the selected orchard. The average of LAI of all the representative plant is the LAI value of the selected orchard. The leaf area indices were measured on weekly basis during the period of 31st to 30th meteorological week (August, 2008 to July, 2009) for 1, 2, 3, 4 and 5 year's plants of pomegranate.

3.3.2 Direct Leaf Area Index Method

In this method all leaves were removed from representative plant after harvesting of fruits and the pomegranate tree after harvesting of all the leaves is shown in Plate 3.4. All leaves were then removed from representative plants. All exercised leaves were immediately transported to a nearby indoor facility; they were weighed on a laboratory balance (Model EK-1200 A, A & D Co. Ltd, Tokyo). A sample of each representative plant was weighed, placed in the sealed bag and stored in a refrigerator. One leaf area was measured with the help of electronic leaf area meter (Model LI-3000, LI-COR, Inc.) within 24 hours.

The total leaf area (m^2) per sample was calculated as under

$$\mathbf{TLA} = \frac{\mathbf{W_t \times SLA}}{\mathbf{P}} \tag{3.2}$$

Where,

TLA- Total leaf area of pomegranate tree (m^2)

W_t – Total weight of all the leaves removed from pomegranate tree

SLA - Specific leaf area (m^2/g) of the subsample.

P – Estimated portion of leaves (1.0)

The leaf area index for each representative plant in the study plot was then calculated as under

$$\mathbf{LAI} = \frac{\mathbf{TLA}}{\mathbf{SA}} \tag{3.3}$$

Where,

LAI – Leaf area index of pomegranate, (m^2/m^2)

TLA – Total leaf area of pomegranate, (m^2)

SA – Shaded area at solar noon, (m^2)

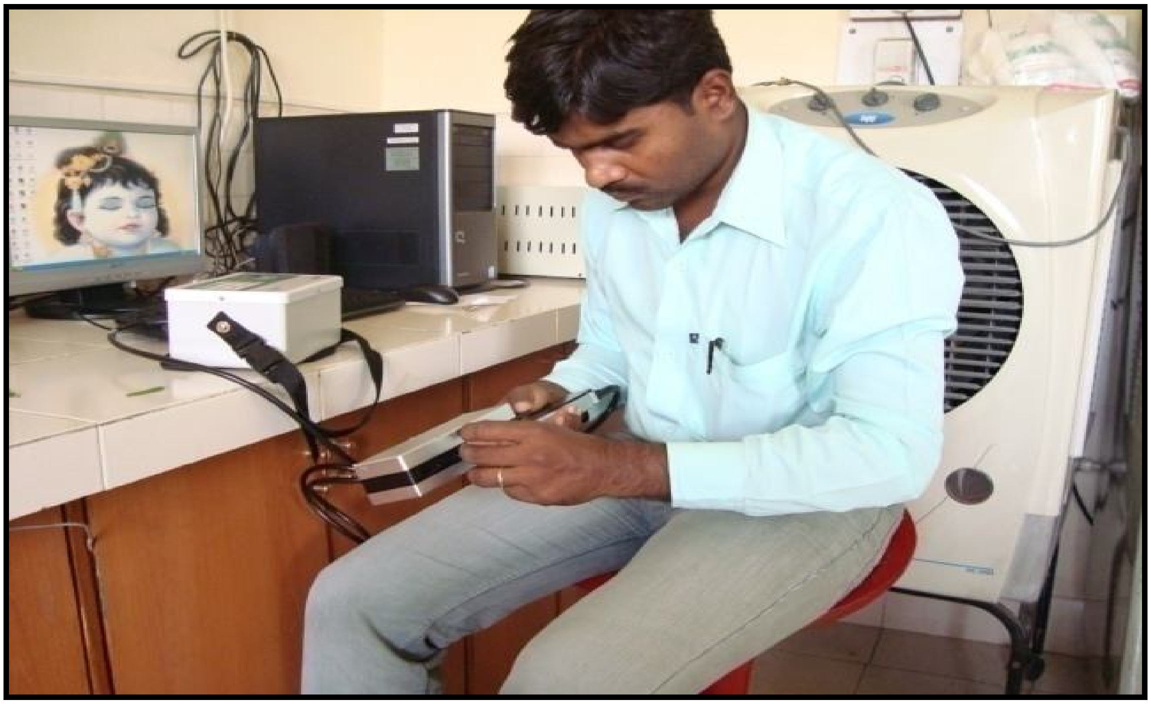

Plate 3.3 Leaf area measured through Leaf area meter

Plate 3.4 Pomegranate tree after harvesting of all leaves for the estimation of true leaf area index

3.4 ESTIMATION OF REFERENCE CROP EVAPOTRANSPIRATION

One of the objectives of this study consists of estimating reference crop evapotranspiration (ET_r) for major pomegranate growing regions of Maharashtra state by using different methods, and then perform the probability distribution analysis and stochastic modeling of estimated ET_r values. There was necessity of past meteorological data for this purpose. The details of these data are described in this section.

3.4.1 Collection of Historical Meteorological Data

The daily values of meteorological parameters, viz maximum temperature (T_{max}), minimum temperature (T_{min}), maximum relative humidity (RH_{max}), minimum relative humidity (RH_{min}), pan evaporation (E_p), wind speed at height of 2m (U_2), actual sun shine hours (n) and rainfall (R) were collected from the Indian Meteorological Department, Pune, National Research Center on Pomegranate, Solapur and MPKV, Rahuri for a period of 20 to 33 years (1975-2007). For Solapur station, the data were obtained from 1983 to 2007, for Ahmednagar from 1975 to 2007, for Pune from 1988 to 2006 and for Nasik from 1985 to 2007. Other parameters viz, latitude, longitude and altitude were also obtained for respective districts.

The average weekly variation of maximum and minimum air temperature (^{0}C), maximum and minimum relative humidity (%), actual sunshine hour (hours), wind speed (Km/hr), pan evaporation (mm) and rainfall (mm) in respect of these districts are presented in this section.

3.4.1.1 Maximum and minimum temperature

The variation of mean weekly maximum temperature (T_{max}) and minimum temperature (T_{min}) for Solapur, Ahmednagar, Pune and Nasik districts over the years based for which the data were available are shown in Figs.3.2 and 3.3; respectively.

The observations of maximum and minimum temperature data for Solapur, Ahmednagar, Pune and Nasik districts showed that the highest values of maximum temperature are 41.2, 38.9, 38.1 and 38.3 ^{0}C, whereas the lowest values of maximum temperature are 29.9, 28.3, 27.3 and 27.7 ^{0}C. The highest values of minimum temperature are 23.1, 22.9, 23.4 and 23.1 ^{0}C, whereas the lowest values of minimum temperature are 10.2, 9.9, 10.1 and 10.0 ^{0}C.

3.4.1.2 Maximum and minimum relative humidity

The variation of mean weekly maximum relative humidity (RH_{max}) and minimum relative humidity (RH_{min}) for Solapur, Ahmednagar, Pune and Nasik districts over the years for which the data were available are shown in Figs. 3.4 and 3.5; respectively.

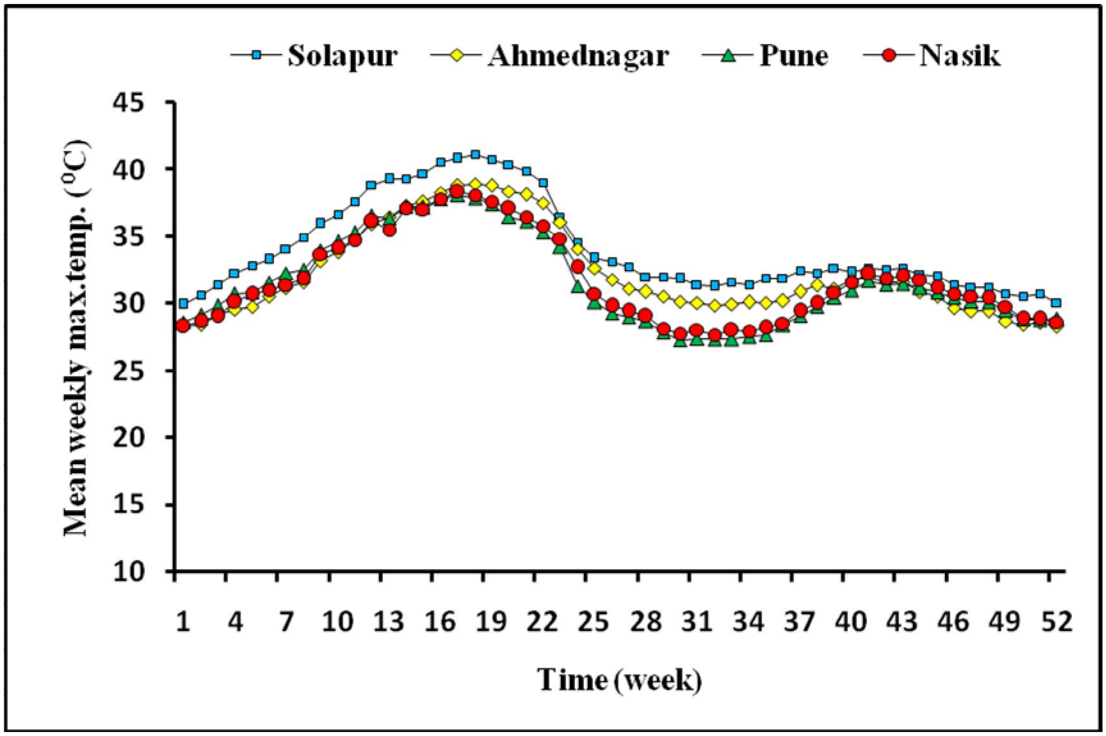

Fig. 3.2 Annual variation of maximum temperature (^{0}C)

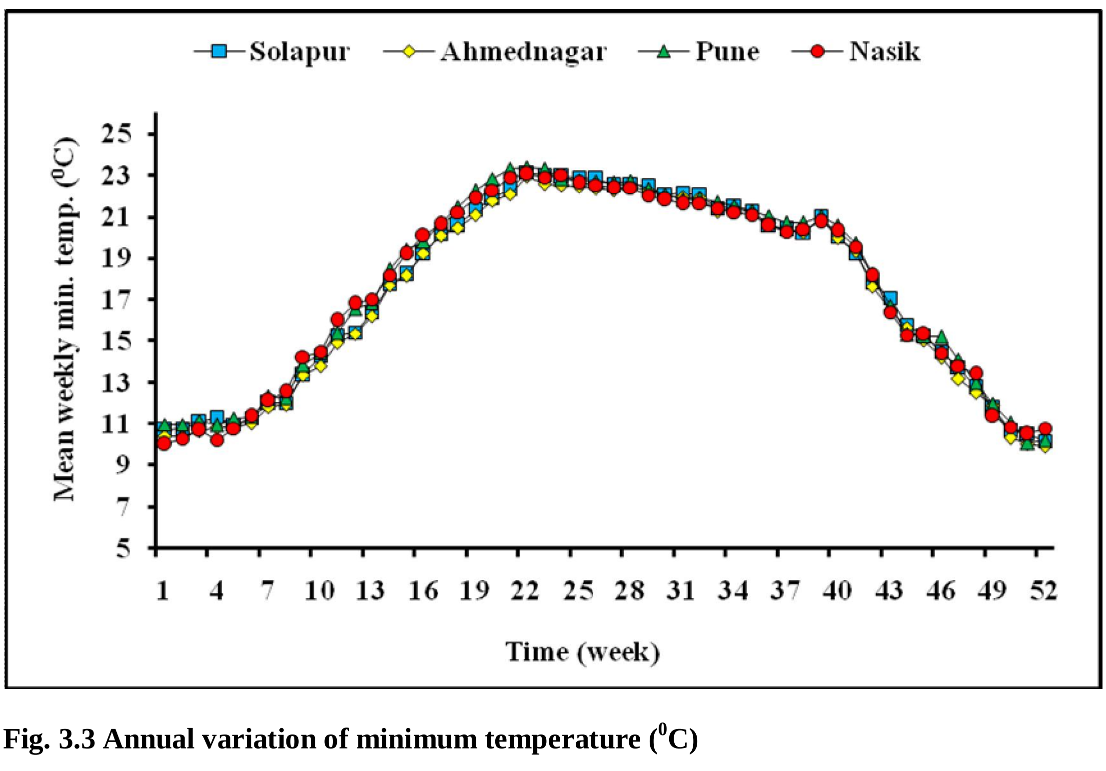

Fig. 3.3 Annual variation of minimum temperature (^{0}C)

The observations of maximum and minimum relative humidity data for Solapur, Ahmednagar, Pune and Nasik districts showed that the highest values of maximum relative humidity are 88.4, 88.9, 89.6 and 89.0%, whereas the lowest values of relative humidity are 53.9, 57.9, 47.9 and 45.6%. The highest values of minimum relative humidity are 62.7, 63.3, 79.9 and 79.6%, whereas the lowest values of minimum relative humidity are 20.3, 21.3 19.7 and 18.3%.

3.4.1.3 Actual sunshine hours

The variation of mean weekly actual sunshine hour (hours) for Solapur, Ahmednagar, Pune and Nasik districts over the years for which the data were available are shown in Fig. 3.6.

The observation of maximum and minimum actual sunshine data for Solapur, Ahmednagar, Pune and Nasik districts showed that the highest value of maximum sunshine hours are 12.0, 11.7, 10.2 and 10.2 hours , whereas the lowest value of actual sunshine hour are 3.7, 3.8, 2.1 and 2.3 hours.

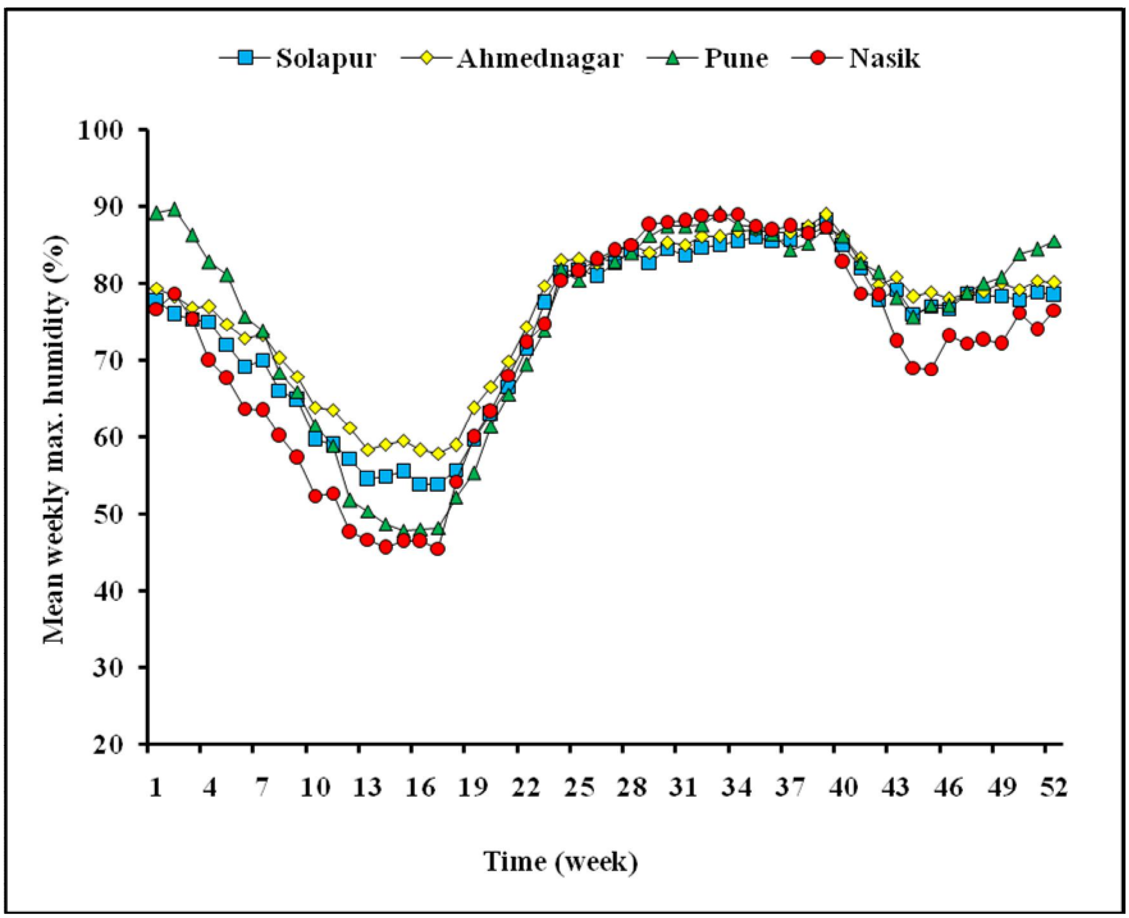

Fig. 3.4 Annual variation of maximum humidity (%)

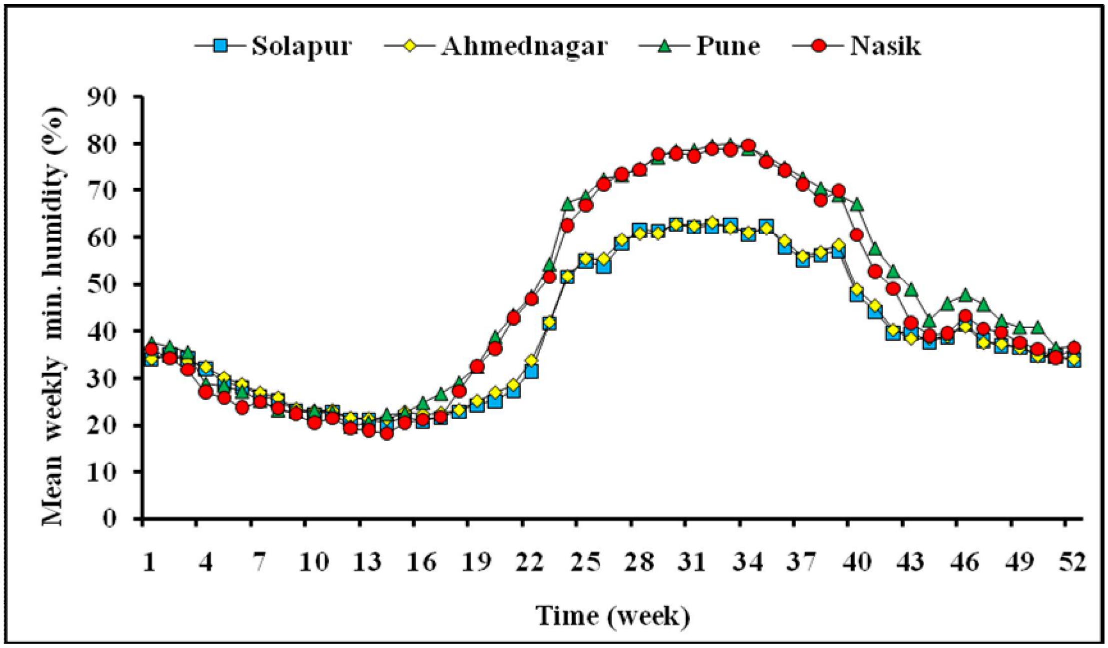

Fig. 3.5 Annual variation of minimum humidity (%)

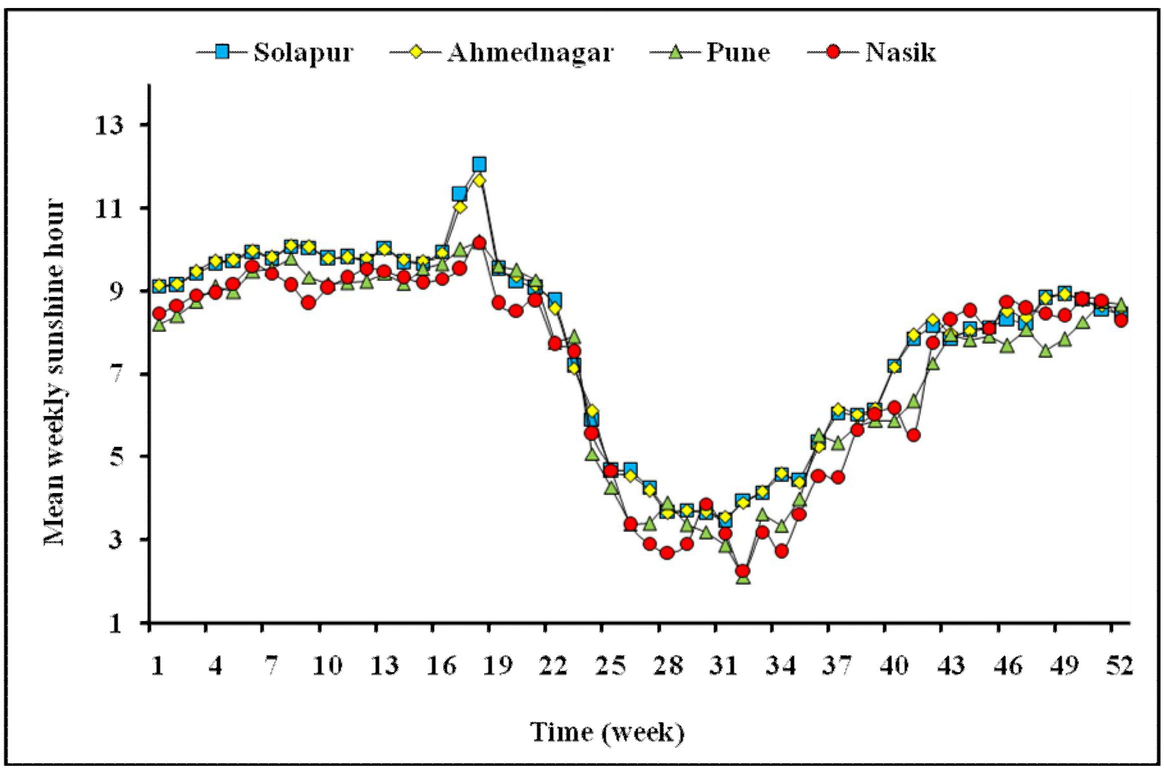

Fig. 3.6 Annual variation of sunshine hours

3.4.1.4 Pan evaporation

The variation of mean weekly pan evaporation (E_p) for Solapur, Ahmednagar, Pune and Nasik districts over the years for which the data was available are shown in Fig.3.7.

The observations of pan evaporation data for Solapur, Ahmednagar, Pune and Nasik districts showed that the highest values of pan evaporation are 12.2, 9.8, 9.5 and 7.4 mm/day , whereas the lowest values of pan evaporation are 3.9, 3.0, 3.4 and 3.3 mm/day.

3.4.1.5 Wind speed

The variation of mean weekly wind speed (km/hr) for Solapur, Ahmednagar, Pune and Nasik districts over the years for which the data was available are shown in Fig. 3.8.

The observations of wind speed data for Solapur, Ahmednagar, Pune and Nasik districts showed that the highest values of wind speed are 11.8,13.2, 9.3 and 12.5 km/hr, whereas the lowest values of wind speed are 4.2, 3.3, 2.2 and 3.5 km/hr.

3.4.1.6 Rainfall

The variation of mean weekly maximum rainfall (mm/week) for Solapur, Ahmednagar, Pune and Nasik districts over the years for which the data was available are shown in Fig.3.9.

The observation of maximum and minimum rainfall data for Solapur, Ahmednagar, Pune and Nasik districts showed that the highest value of maximum rainfall are 44.9, 47.0, 64.5 and 54.3 mm/week, whereas the lowest values of rainfall are 0.0 mm/week.

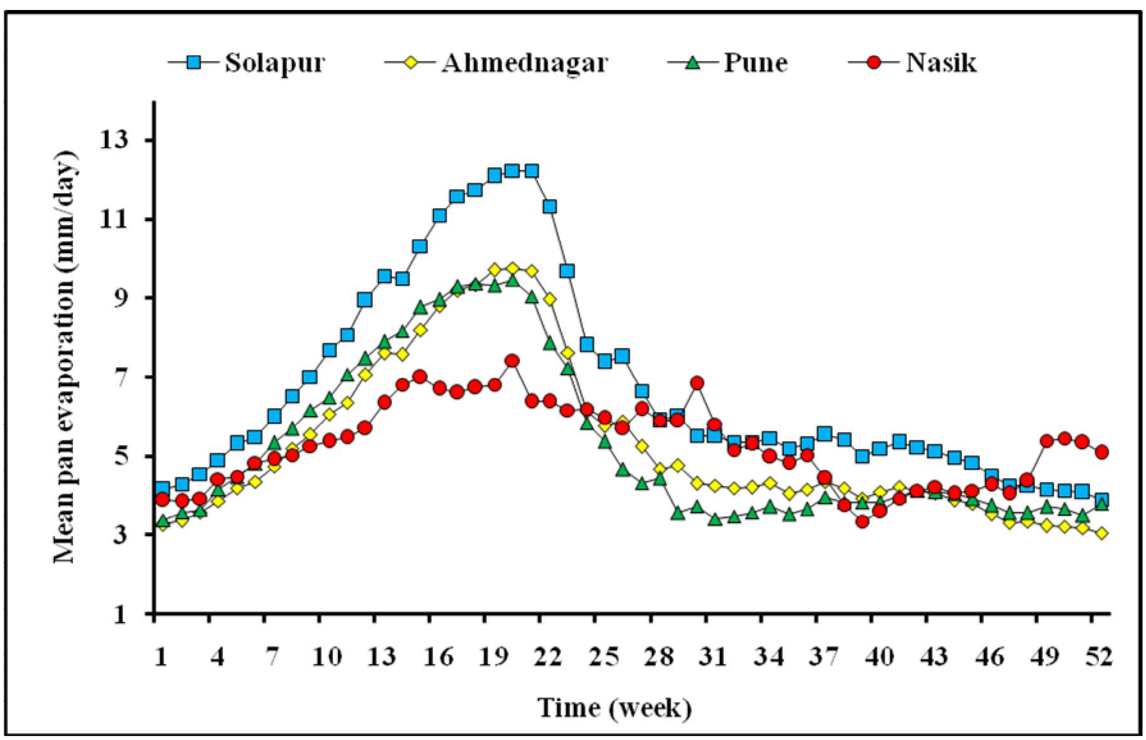

Fig. 3.7 Annual variation of pan evaporation (mm/day)

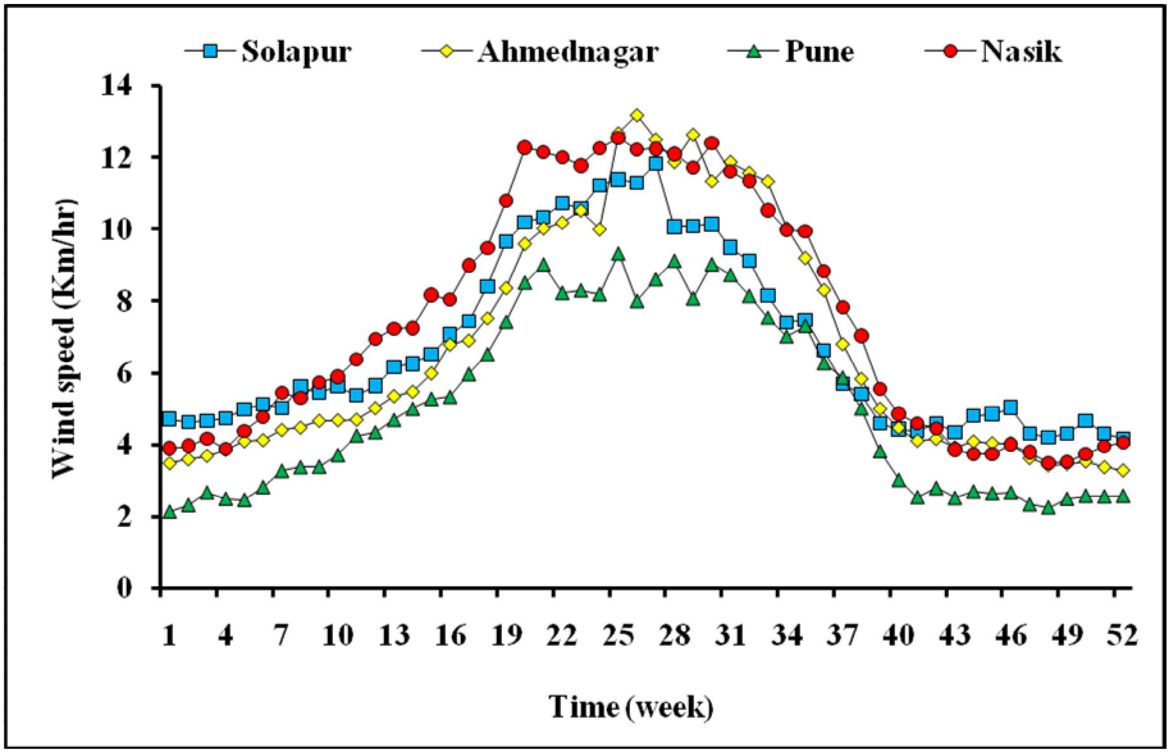

Fig. 3.8 Annual variation of wind speed (Km/hr)

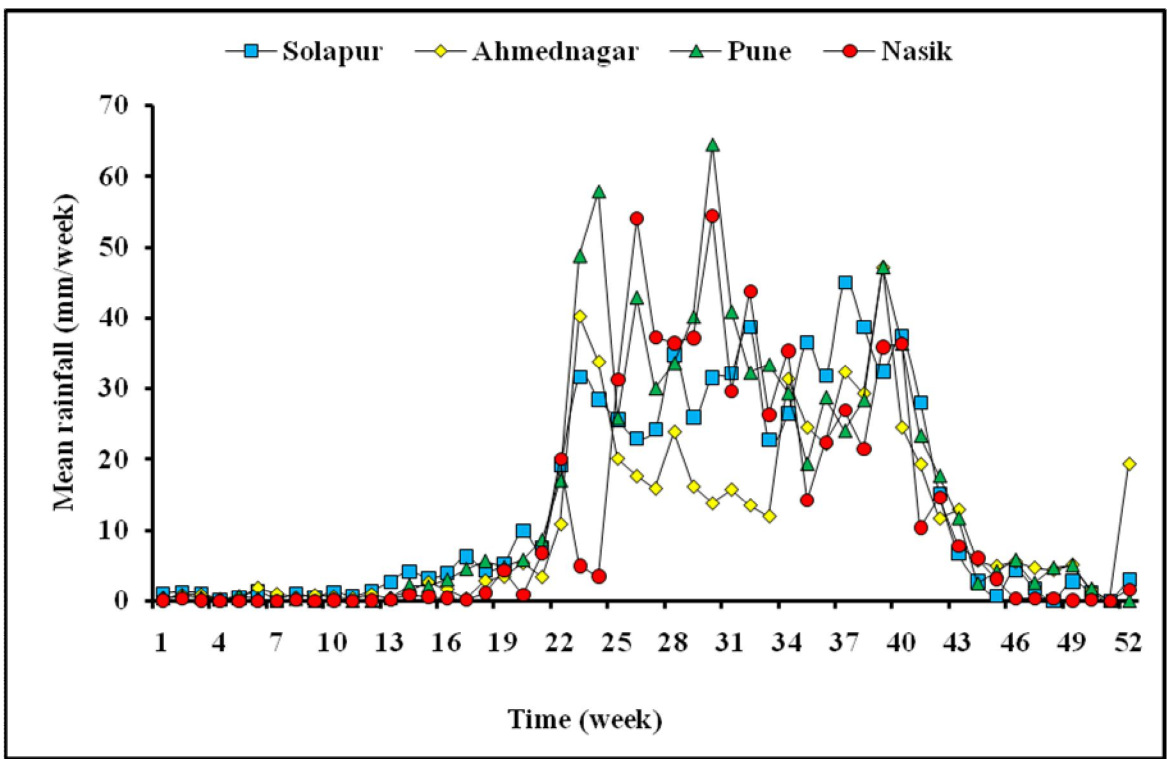

Fig. 3.9 Annual variation of rainfall (mm/week)

3.5 METHODS FOR ESTIMATION OF ET_r

In this study, it was proposed to estimate daily ET_r values by using Penman-Monteith, Modified Penman, Hargreaves-Samani, FAO Pan Evaporation, Blanney-Criddle and FAO Radiation methods. The procedure/formula to estimate ET_r by these methods are described in this section.

3.5.1 Penman-Monteith Method

The analysis of the performance of the various calculation methods revealed the need for formulating a standard method for the computation of ET_r. The Penman-Monteith method has been recommended as the sole standard method. It is a method with strong likelihood of correctly predicting ET_r in a wide range of location and climates and has provision for application in data – short situations (Allen *et al.,* 1998).

A consultation of experts and researchers was organized by FAO in May 1990, in collaboration with ICID and WMO, to review the FAO methodologies on crop water requirements and to advice on the revision and updates of procedures. The panel of experts recommended the adoption of Penman-Monteith combination method as a new standard for reference evapotranspiration and advised on procedures for calculation of the various parameters. By defining the reference crop as a hypothetical crop with an assumed height of 12 cm having a surface resistance of 70 s/m and an albedo of 0.23, closely resembling the evaporation of an extension surface of green grass of uniform height, actively growing and adequately watered, the FAO Penman-Monteith method was developed. The method overcome shortcomings of the previous FAO Penman method and provides values more consistent with actual crop water use data worldwide. The most common FAO56 Penman-Monteith equation was use for the estimating reference crop evapotranspiration for the present study.

The daily values of reference crop evapotranspiration (ET_r) were calculated by equation (3.4)

$$ET_r = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T+273}\right)u_{2(e_s - e_a)}}{\Delta + \gamma(1 + 0.34u_2)} \qquad (3.4)$$

Where,

ET_r = reference evapotranspiration, (mm/day)
G = soil heat flux density, (MJ/m^2 /day)
R_n = net radiation, (MJ/ m^2/day)
T = mean daily air temperature, (^0C)

γ = Psychometric constant, (kPa/^{0}C)

Δ= Slope of saturation vapour pressure function, (kPa/^{0}C)

e_s = saturation vapour pressure at air temperature T, (kPa)

e_a= actual vapour pressure at dew point temperature, (kPa)

u_2= average daily wind speed at 2 m height, (m/sec)

3.5.2 Modified Penman Method

The daily values of ET_r by modified Penman method (Doorenboss and Pruitt, 1977) were estimated by equation (3.5)

$$ET_r=\left(\frac{\Delta}{(\Delta+\gamma)}\right)(R_n+G)+\left(\frac{\gamma}{\gamma+\Delta}\right)f(u)(e_s-e_a) \quad (3.5)$$

Where,

ET_r – Reference crop evapotranspiration, (mm/day)

Δ - Rate of change of the saturated vapor pressure

γ - Psychometric constant, (kPa / ^{0}C)

e_s - Saturated vapor pressure at the mean air temperature in ^{0}C, (mbar)

e_d – Mean actual vapor pressure, (mbar)

$RH_{mean=}\frac{RHmax+RHmin}{2}$

RH_{max} – Maximum relative humidity, (%)

RH_{min} – Minimum relative humidity, (%)

f (u) – Wind related function = $0.27(1+W_2/100)$

W_2 – Wind speed, (km/day)

W – Temperature and elevation related weighing factor for the effect of radiation on ET_r $= \frac{\Delta}{\Delta+\gamma}$

$(1-W)$ -Temperature and elevation related weighing factor for the effect of wind and humidity on ET_r.

R_n - Net radiation, (mm/day) = R_{ns} - R_{nl}

R_{ns} – Net incoming shortwave solar radiation = $R_A(1-\alpha)(0.25 + 0.50\ n/N)$

R_A – Extraterrestrial radiation, equivalent evaporation, (mm/day)

α – Refection coefficient = 0.25

n/N – Ratio between actual and possible hours of bright sunshine

R_{nl} – Net long wave radiation = f(t).f(e_d).f(n/N)

f (t) – Correction for temperature = $\sigma T k4$

σ - Stefan – Boltzmann constant

T – Mean temperature, (^{0}C)

k – Constant

f (e_d) – Correction for vapor pressure = $0.34 - \frac{0.444}{\sqrt{e_d}}$

f(n/N) –Correction for the ratio of actual and maximum bright sunshine hours=0.1+ .9n/N

3.5.3 Hargreaves- Samani Method

The daily values of reference crop evapotarnspiration by Hargreaves-Samani method (Hargreaves and Samani, 1985) were estimated by equation (3.6).

$$\mathbf{ET_r = 0.0023(T_{max} - T_{min})^{0.5}(T_{mean} + 17.8)R_a} \qquad (3.6)$$

Where,

ET_r – Reference crop evapotranspiration, (mm/day)

T_{max} and T_{min} – Mean monthly maximum and minimum temperature, (^{0}C)

T_{mean} – Mean air temperature, (^{0}C)

R_a – Extra terrestrial radiation, (MJ/m^2/ day)

3.5.7 FAO Pan Evaporation Method

The formula for estimating reference crop evapotranspiration by FAO Pan evaporation method (Doorenbos and Pruitt 1977) is given by the equation (3.7).

$$\mathbf{ET_r = K_p \times E_{pan}} \qquad (3.7)$$

Where,

ET_r – Reference crop evapotranspiration, (mm/day)

K_p – Coefficient related to evaporation

E_{pan} – Evaporation from USWB class A pan, (mm)

3.5.5 Blanney-Criddle Method

Doorenboss and Pruitt (1975, 1977) presented most fundamental equation (3.8) of Blanney Criddle method which is given as:

$$\mathbf{ET_r = \{a + b[p(0.46T + 8.13)]\}\left(1 + \frac{0.1E}{1000}\right)} \qquad (3.8)$$

Where,

ET_r - Estimated evapotranspiration for a growing season, (mm/day)

P – Mean daily percentage of annual daytime's hour, (%)

T – Mean air temperature, (^{0}C)

a and b – Empirical factors, (dimensionless)

E – Altitude of the station, (m)

3.5.6 FAO - Radiation Method

Doorenboss and Pruitt (1975, 1977) reported an equation (3.9), which is called FAO Radiation method and is given as

$$\mathbf{ET_r = c\left(\frac{\Delta}{\Delta+\gamma}\frac{R_s}{\lambda}\right)} \qquad (3.9)$$

Where,

ET_r - Reference crop evapotranspiration, (mm/day)

c – Adjustment factor which depends of mean humidity and daytimes wind

Δ - Slope of vapor pressure curve, (kPa/^{0}C)

γ - Psychrometric constant, (kPa/ ^{0}C)

R_s – Mean Solar radiation, (MJ/ m^2/day)

λ - Latent heat of evaporation, (MJ/kg)

3.5.7 Computer Programme

The computer program was written in **FORTRAN 90** language to calculate reference crop evapotranspiration by using Penman-Monteith, Modified Penman, Hargreaves-Samani, FAO Pan Evaporation, Blanney-Criddle and FAO Radiation methods with the help of meteorological data collected required for these methods.

3.5.8 Comparison

The daily reference crop evapotranspiration values were estimated for each method for all years of data and station by using the computer programme. After calculating ET_r by different methods the linear regression analysis was performed by considering Penman-Monteith as the standard method. For this purpose ET_r by Penman-Monteith method was considered as independent variable and ET_r by one of the remaining five methods as dependent variable. The method with the highest value of regression coefficient was considered as the closest method to Penman-Monteith method. Similarly, root mean square error was calculated between the ET_r values estimated by Penman-Monteith method and the other method by the following equation.

$$\mathrm{RMSE} = \sqrt{\sum_{i=1}^{n} \frac{\left(ET_r^{\,p} - ET_r^{\,i}\right)^2}{n}} \qquad (3.10)$$

Where,

ET_r^{p} – Estimated ET_r by various methods (i.e. equation 3.5 to 3.9)

ET_r^{i} – Estimated ET_r by Penman- Monteith method (i.e. equation 3.4)

n – Number of observation

3.6 PROBABILITY DISTRIBUTION FUNCTIONS

The values of ET_r at desired probability are required for the irrigation planning. For this purpose it was proposed in this study to investigate the appropriate probability distribution functions for the ET_r values estimated by Penman-Monteith method. The daily ET_r values were estimated for all the 4 selected districts by Penman-Monteith method for 24, 32, 19 and 22 years ET_r data for Solapur, Ahmednagar, Pune and Nasik districts and daily values then were converted to weekly values. The probability distribution analysis was then performed for weekly ET_r values for 52 standard meteorological weeks.

3.6.1 Probability Distributions

The following five most commonly used probability distribution functions were selected and the distribution that best fitted the data has been used for determining the ET_r values at different return periods (i.e. probabilities).

- Normal probability distribution function
- Log normal probability distribution function

- Gamma probability distribution function
- Gumbel probability distribution function
- Weibull's probability distribution function

3.6.1.1 Normal probability distribution function

This is a symmetrical bell shaped probability density function of random continuous variable and is known as Gaussian distribution which is given as:

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \qquad (3.11)$$

Where,

x= variable of the sample

μ= population mean

σ= standard deviation

3.6.1.2 Log normal probability distribution function

This is transformed normal distribution in which the variable is replaced by logarithmic value. The equation is expressed as:

$$f(x) = \frac{1}{x\sqrt{2\pi\sigma^2}} e^{-\frac{(\ln x-\mu)^2}{2\sigma^2}} \qquad (3.12)$$

Where,

x= variable of the sample

μ= population mean

σ= standard deviation

3.6.1.3 Gamma probability distribution function

The density function of this distribution is given by

$$f(x) = \frac{\beta^{-\alpha} x^{\alpha-1} e^{-\frac{x}{\beta}}}{\Gamma(\alpha)} \qquad (3.13)$$

Where,

x= variable of the sample

α= shape parameter

β= scale parameter

3.6.1.4 Gumbel probability distribution function

The density function of Gumbel distribution to fit on observed data can be expressed as:

$$f(x) = \frac{e^{\frac{(x-\gamma)}{\beta}} e^{-e^{\frac{(x-\gamma)}{\beta}}}}{\beta} \qquad (3.14)$$

Where,

x= variable of the sample

γ = location parameter

β= scale parameter

3.6.1.5 Weibull's probability distribution function

The density function of Weibull's distribution to fit on observed data can be expressed as:

$$f(x) = \frac{\alpha}{\beta}\left(\frac{\gamma - x}{\beta}\right)^{\alpha-1} e - \left(\frac{\gamma-x}{\beta}\right) \alpha \qquad (3.15)$$

Where,

x= variable of the sample

γ = location parameter

β= scale parameter

α= shape factor

3.6.2 Test for Goodness of fit of Probability Distribution Functions

To know the probability distribution function that fit the ET_r data most, chi-square test was performed. The chi-square statistic $\chi_{cal}{}^2$ has been estimated by the following expression:

$$(\chi_{cal}{}^2) = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i} \qquad (3.16)$$

Where,

k is the number of observation,

O_i is the observed values

E_i is the expected values.

χ_{cal}^2 were calculated for each week and probability distribution functions. The calculated Chi-square value (χ_{cal}^2) was compared with tabulated value χ_{tab}^2 at 5% level of significance. If the calculated Chi-square value is less than the tabulated value, the probability distribution function under consideration fits to the data. If more than one probability distribution function fits to data, the probability distribution function with lowest value of calculated chi square were considered as the best function. Once the probability distribution function is obtained, the reference crop evapotranspiration values was found at 10, 20, 30, 40, 50, 60, 70, 80, and 90 per cent probability levels for each week.

The weekly reference crop evapotranspiration (ET_r) data were analyzed by a computer based routine, VTFIT, packag*e* for fitting probability distribution functions which provides goodness of fit tests and expected values.

3.7 STOCHASTIC MODEL

One of the objectives of this study was to develop and validate the stochastic model for generating and forecasting of reference crop evapotranspiration of major pomegranate growing districts of Maharashtra state.

Often the length of historic series of climatological data based on which evapotranspiration values are estimated is short and hence the length of the evapotranspiration series is also short. However, while planning and management of water resources, whenever the variability in evapotranspiration needs to be considered, the short term evapotranspiration data is not adequate and evapotranspiration series needs to be extended. For this purpose, the evapotranspiration data needs to be generated from the available historical evapotarnspiration data.

In addition to this, an important factor for proper irrigation management study is a successful prediction of climatological variables which have the influence upon the behavior of the irrigation systems. This is particularly important for the irrigated agricultural areas where the evapotranspiration prediction guarantees a reliable planning, design and operating of irrigation systems.

In literature, there are various methodologies and models available for the generation of climatological and hydrological data. These are elaborately discussed by Box and Jenkins (1976). Normally for the generation of climatological and hydrological data, Autoregressive (AR), Moving Average (MA), Auto Regressive moving Average (ARMA), Thomas-Fiering, Auto

Regressive Integrated Moving Average (ARIMA), Seasonal ARIMA and harmonic class of models are used (Gorantiwar *et al.,* 1995; Samani *et al.,* 1995 and Bhakar, 2000). Amongst these models ARIMA class of models were found to be more suitable for the generation of seasonal (weekly or monthly) climatological data. ARIMA class of models is also one of the most widely used time series prediction methods in practice (Changnon, 1988 and Elango *et al.,* 1996).

In this study, therefore, for the generation of evapotranspiration the ARIMA classes of models were used. As the evapotranspiration series is the seasonal, seasonal ARIMA models were proposed for the generation and forecasting of the ET_r series. This model is discussed in the next section.

3.7.1 Seasonal ARIMA Model

Seasonal autoregressive integrated moving average (SARIMA) are useful for modeling seasonal time series in which the mean and other statistics for a given season are not stationary across the year. The basic ARIMA model in its seasonal form is described as (Box and Jenkins, 1994; Hipel *et al.,* 1977) a straightforward extension of the nonseasonal ARMA and ARIMA models.

Auto regressive (AR) models estimate values for the dependent variable x_t as a regression function of previous values $x_{t-1}, \ldots, x_{t-p}$ plus some random error e_t. Moving average (MA) models give a series value x_t as a linear combination of some finite past random errors, $e_{t-1} \ldots e_{t-q}$. p and q are referred as orders order of the models. AR(p) and MA(q) models can be combined to form an ARMA (p,q) model. This model can provide additional flexibility in describing the time series.

However, a large number of time series is nonstationary and for modeling such time series, simple AR, MA or ARMA models are not appropriate. Box and Jenkins (1976) suggested that a nonstationary series can be transformed into a stationary one by differencing. The ARMA models applied to the differenced series are called integrated ARMA models, denoted by ARIMA (Auto Regressive Moving Average Models)

ARIMA model is essentially a device for transforming a highly dependent series into a sequence of independent random deviates. An underlying principle of this approach is the “Principle of Parsimony” or of representing a time series by a minimum number of parameters possible. Most time series, especially the hydrological time series are ‘non-stationary’ meaning that the level or variance of the series changes over time. Differencing is often used to remove the trend component of a time series before the model building to describe the series.

A time series involving seasonal data will have relations at a specific lag s which depends on the nature of the data, e.g. for monthly data s = 12 and weekly s = 52. Such series can be successfully modeled only if the model includes the connections with the seasonal lag as well. Such models are known as multiplicative or seasonal ARIMA (SARIMA) models. The general multiplicative seasonal ARIMA (p, d, q) $(P,D,Q)_s$ model has the following form.

Let $Z_{1,}$ Z_2 --------Z_n be a discrete time series measure at approximately equal time intervals. An ARIMA model is given as

$$\varphi(B)\Theta(B)^s w_t = \theta\left(B^S\right)e \qquad (3.17)$$

Where, w_t is a stationary series obtained by differencing the original series, Z_t

Equation 3.17 can also be written as

$$\varphi(B)\Theta(B)^s \nabla^d {\nabla_S}^D z_t = \theta\left(B^S\right)e_t \qquad (3.18)$$

Where, e_t is normal independently distributed white noise residual series with mean zero and variance σ^2, B is the backward shift operator, Φ *and* Θ describe an ARIMA structures between seasonal observations, ϕ *and* θ describe a within period ARIMA structure which accounts for week to week dynamics. $\phi(B)$ is the non seasonal autoregressive operator or polynomial of order p and is represented by

$$\varphi(B) = 1 - \varphi_1 B - \varphi_2 B^2 - \ldots\ldots\ldots\ldots\ldots\ldots\ldots - \varphi_P B^P \qquad (3.19)$$

Similarly,

$$\Phi(B^s) = 1 - \Phi_1 B^S - \varphi_2 B^{2S} - \cdots\ldots\ldots\ldots\ldots \Phi_P B^{ps} \qquad (3.20)$$

$\theta(B)$ is the non seasonal moving average (MA) operator or polynomial of order q;

$\Theta(B^s)$ is the seasonal MA operator of order Q. $\theta(B)$ and $\Theta(B)$ are expressed as:

$$\theta(B) = 1 - \theta_1 B - \theta_2 B^2 - \ldots\ldots\ldots. - \theta_q B^q \qquad (3.21)$$

$$\Phi(B^s) = 1 - \theta_1 B^s - \theta_2 B^{2s} - \ldots\ldots\ldots. - \theta_Q B^{QS} \qquad (3.22)$$

∇^d and $\nabla^D{}_S$ are the non seasonal and seasonal differencing operators of order d and D, respectively, and are represented by

$$\nabla^{d} = (1 - B)^{d} \tag{3.23}$$

$$\nabla^{D}{}_{S} = \left(1 - B^{S}\right)^{D} \tag{3.24}$$

s indicates the length of seasonality and is equal to 52 for weekly ET_r series.

3.7.2 Procedure to Develop ARIMA Model

Box and Jenkins (1994) and Hipel and McLeod (1994) formalized the modeling process comprising of following steps.

- Standardization and normalization of time series variables
- Identification of the models
- Determination of the parameters of selected models
- Diagnostic checking
- Selection of the model

3.7.2.1 Standardization and normalization of time series variables

The first step in time series modeling is to standardize and transform the times series. This process is required to ensure normalcy of data sequence and residuals. Many procedures are available in the literature for this purpose. In general the standardization is proposed by normalizing the series as follows.

$$y_{i,j} = \frac{x_{i,j} - x_i}{\sigma_i} \tag{3.25}$$

Where,

$y_{i,j}$ – stationary stochastic component in the mean and variables for week i of the year j;

$x_{i,j}$ – weekly evapotranspiration in the week i of the year j;

x_i – weekly mean and

σi – weekly standard deviation

However in this study as the ARIMA model wherein there is a provision to differentiate the series is used, the standardization or normalization is not performed.

3.7.2.2 Identification of the model

The first and foremost important step in the modeling is the identification of the tentative model type to be fitted to the data set. It is also to be understood that identification is necessary inexact. In the proposed study the procedures stated by Hipel and McLeod (1994) were adopted for identifying the possible ARIMA models. A time series with the seasonal variation may be considered stationary if the theoretical autocorrelation function (ρ_k) and theoretical partial autocorrelation function (ρ_{kk}) are zero after a lag k = 2s + 2 (Where‘s’ is the seasonal period; in this study, s=52).

The requirement of identification procedure is as follows

- Plot of the original series
- Plot of the standardized series
- Autocorrelation function (ACF) analysis
- Partial autocorrelation function (PACF) analysis

The estimates of theoretical autocorrelation function (e_k) i.e. r_k is given by equation (3.26). The autocorrelation function will vary between -1 and +1, with values near ± 1 indicating stronger correlation.

$$r_m = \frac{\sum_{i=1}^{n-m}(x_i - \bar{x})(x_{i+m} - \bar{x})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{3.26}$$

Where,

n – the number of observations

$\bar{x}$ - the average of the observations

r_m -autocorrelation function at lag m

The estimate of theoretical partial autocorrelation function (e_{kk}) i.e. Φ_{mm} is given by the equation (3.27). The partial autocorrelation function will vary between – 1 and +1, with values near ± 1indicating stronger correlation. The partial autocorrelation function removes the effect of shorter lag autocorrelation from the correlation estimates at longer lags.

$$\Phi_{mm} = \frac{r_m - \sum_{j=1}^{m-1} \Phi_{m-1,j} r_{m-1}}{1 - \sum_{j=1}^{m-1} \Phi_{m-1,j} r_j} \tag{3.27}$$

Where

Φ_{mm} –Partial autocorrelation function at lag k

It is considered that ρ_k and ρ_{kk} equal to zero if (Maier and Dandy, 1995)

$$\rho_k = 0 \text{ i.e. } |r_k| \le \frac{2}{T^{0.5}} \tag{3.28}$$

$$\rho_{kk} = 0 \text{ i.e. } |r_{kk}| \le \frac{2}{T^{0.5}} \tag{3.29}$$

Where,

r_k - sample autocorrelation at lag k;

r_{kk} - sample autocorrelation at lag k; and

T – Number of observation

If the sample autocorrelation function (ACF) of analyzed series does not meet the above condition, the time series needs to the transformed into a stationary one using different differencing schemes. For example, for (d = 0, D = 1, s = 52) according to the expression given by equation

$$y_t = (1 - B)^d (1 - B^x)^D x_t = (1 - B^{12}) ET_{0,t} \tag{3.30}$$

The time series y_t is stationary if the ACF and PACF cut off at lags less than k = (2s + 2) seasonal periods. Thus, it is necessary to test the stationarity of the transformed time series obtained by differencing the original times series according to different orders of differencing (non seasonal and seasonal). The differenced series that pass the stationary criteria needs to be considered for further analysis.

The following guidelines are used for selecting the orders of AR and MA terms (Gorantiwar, 1984):

- If the autocorrelation function cuts off, fit ARIMA (0,d,q) $(0,1,Q)_{52}$ model to the data, where q is the lag after which the autocorrelation function first cuts off, and Q is the after which seasonal ACF cutoff.
- If the autocorrelation function cuts off, fit ARIMA (p,d,0) $(P,1,0)_{52}$ model to the data, where data, where p is the lag after which the partial autocorrelation function first cuts off, and p is the lag after which the partial autocorrelation function first cuts off, and P is the lag after which seasonal PACF cuts off.
- If neither the autocorrelation or partial autocorrelation functions cuts off, fit the ARIMA (p,d,q) $(P,1,Q)_{52}$ model for a grid of values of p, P, q and Q.

Thus on basis of information obtained from the ACF and PACF, several forms of the ARIMA model need to the identified tentatively.

3.7.2.3 Estimation of parameters of the model

After the identification of model, the parameters of the selected models were estimated. The parameters of the identified models were estimated by the statistical analysis of the data series. The most popular of the approaches of the parameters estimation are:

- The method of maximum likelihood
- The method of moments
- The method of least – squares

Box and Jenkins, (1994) have discussed these methods in detail. The first method is most exact method of parameter estimation, since it utilizes full information from the data set. Therefore, the first method was used for the parameters estimation.

3.7.2.4 Diagnostic checking of the model

Once a model has been selected and parameters calculated, the adequacy of the model has to be checked. This process is called diagnostic checking. There are number of diagnostic checking methods to test the suitability of the estimated model. These include Box-Pierce method; Portmanteau lack–of–fit test and t-statistics, standard error of the models parameters, observing ACF and PACF of the residuals, Akaike Information Criteria (AIC) and Bayes Information Criteria. However, in this study following three tests were used.

3.7.2.4.1 Examination of standard error

A high standard error in comparison with the parameter values points out a higher uncertainty in parameter estimation which questions the stability of the model. The model is adequate if it meets the following condition.

$$t = \frac{cv}{se} > 2 \qquad (3.31)$$

Where,

cv – parameter value

se – standard error

3.7.2.4.2 ACF and PACF of residuals

If the model is adequate at describing behavior of evapotranspiration time series, the residuals of the model should not be correlated i.e. all ACF and PACF should lie within the limits calculated by equations (3.26) and (3.27) after lag $k = 2s + 2$, where s = number of periods.

3.7.2.4.3 Akaike Information Criteria (AIC)

The Akaike Information Criteria (Akaike, 1974) are computed as

$$\mathbf{AIC} = 2\mathbf{k} + \left(\ln\left(\frac{2\,\pi v_r}{T}\right) + 1\right)\mathbf{T} \tag{3.32}$$

Where,

AIC – akaike information criteria

k – number of model parameters

vr – residuals variance

T – total number of observations.

3.7.2.5 Selection of the most appropriate model

The RMSE criteria was used for selecting the most appropriate model of ARIMA amongst all the models that passed the adequacy test or diagnostic checking (see section 3.7.2.4) in the present study. RMSE shows how close the actual values of ET_r are with predicted ET_r. Lower the values of RMSE, better is the model. The actual and forecast values were compared by RMSE. The root mean square error (RMSE) were estimated for each models by using the equation (3.33)

$$\mathbf{RMSE} = \frac{\sqrt{\sum_{i=1}^{n}(ET_{act} - ET_{for})^2}}{n} \tag{3.33}$$

Where,

RMSE – root mean square error

ET_{act} – actual value of reference evapotranspiration (ET_r)

ET_{for} – forecast value of reference evapotranspiration (ET_r)

n – total number of observation used for computing RMSE

The model that gives the least values of RMSE was selected as the most appropriate model.

CHAPTER-IV
RESULTS AND DISCUSSION

The study was undertaken with the broad objective of generating the information on water requirement of pomegranate for major pomegranate growing districts of Western part of Maharashtra viz. Solapur, Ahmednagar, Pune and Nasik. Hence, the study required the determination of reference crop evapotranspiration for these districts and crop coefficient values for pomegranate.

The Penman-Monteith method is recommended by FAO. Hence the ET_r values were estimated by using this method. However as Penman-Monteith methods needs large amount of data and as these data might not be available, the study also focused on investigating the methods that give ET_r estimates close to ET_r estimates of Penman-Monteith method and need less data.

Determination of k_c values need actually conducting the lysimetric experiments. The experimental set up for lysimetric studies for fruit crops like pomegranagate is expensive and time consuming. In absence of such experiments the k_c values would not be available. Hence the k_c values were determined in this study with the help of percentage of shaded area covered by the canopy of the tree. The approach involved taking the observations on shaded area during different growth stages of pomegranate trees of different ages and estimating k_c values with the help of regression equiation between k_c and percentage shaded area already developed for other deciduous fruit trees with the help of lysimetric study. Through this approach involves certain assumption, nevertheless in absence of lysimtric studies, the information would be useful.

Often the leaf area indices are more convientaly measurable parameters. Hence in this study the attempts were made to relate k_c with LAI, so that upon the availability of information on LAI, k_c values can be estimated.

Further as for irrigation planning it is necessary to know the water requirement of pomegranate at certain desired probability levels, the appropriate probability distribution functions were obtained for ET_r and based on the probability distribution function, the water requirement of values pomegranate were estimated at different levels of probability.

The real time operation of any water resources systems needs the forecast of the hydrological variable such as evapotranspiration. For this purpose the stochastic modeling of ET_r was performed to investigate the suitable model. ARIMA class of seasonal models of different orders were used to provide the one year ahead forecast of ET_r from which estimates of water requirement of pomegranate for these districts were obtained.

The methodologies used for the above stated tasks are described in chapter-III. This chapter provides the results of the study which would be useful for the irrigation planning for pomegranate.

4.1 CROP COEFFICIENT OF POMEGRANATE

Crop coefficients are needed to estimate crop evapotranspiration (ET_c) with reference crop evapotranspiration (ET_r). These coefficients are dimensionless numbers that are multiplied by the ET_r values to know crop evapotranspiration. It varies with crops, phenological stages of the growth of the crop, elevation the crop is being grown, by time of the years and specific cultural or management practices. The crop coefficient generally varies from very small around 0.15 for early season and very large around 1.2 for mid seasons for deciduous fruit crops (Johnson *et al.,* 2005). The resulting crop evapotranspiration would be of help to an irrigation manager to schedule when irrigation should occur and how much water should be put back into the soil.

As stated in chapter-III, the k_c values were determined by measuring the shaded area at solar noon of pomegranate tree weekly for the trees of different ages (1 to 5 years) and using the regression equation (3.1) proposed by Ayars *et al.,* (2003) that relates the k_c with shaded area. The percentages of shaded area for different meteorological weeks of pomegranate tree of different ages are presented in Appendix-B (Table B-1). The k_c values for pomegranate tree of different ages are reported in Appendix-B (Table B-2).

In this section the variation of k_c over the season for pomegranate tree of different ages are discussed.

4.1.1 Crop Coefficient Curve for Pomegranate Tree in 1st Year

The crop coefficient curve for pomegranate tree in 1st year is presented in Fig. 4.1. Figure indicates that the values of crop coefficient increases from 0.17 to 0.30 due to the development, maturation of the leaf surface and increased number of leaves; foliage and water sprout of the tree during first year. The k_c values increases linearly from 31st to 12th weeks due to increases in number of leaves, water sprout, luxors and shaded area as observed from the representative trees. The crop coefficient reduced in the 13th week due to removal of the flowers, disease fruits, excess water sprout, foliage clumping and management practices (i.e. thinning, pruning and training of the tree).

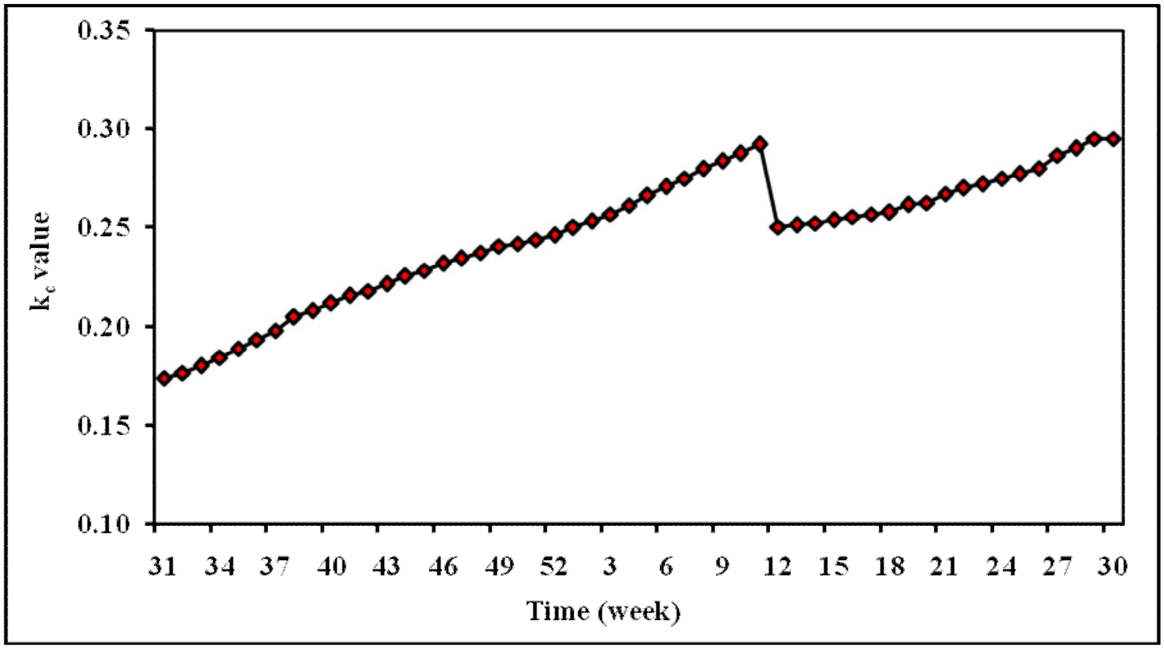

Fig. 4.1 Crop coefficient curve for 1st year pomegranate tree

4.1.2 Crop Coefficient Curve for Pomegranate Tree in 2nd Year

The crop coefficient curve for pomegranate tree in 2nd year is presented in Fig.4.2. Figure shows four distinct phases of k_c. The k_c increases from 0.22 in 31st week to 0.50 in 44th week due to increases in number of leaves, flowers, foliage, water sprout, maturation of the leaf surface, luxor and fruits. The k_c shows the constant value of 0.50 from 45th to 52nd weeks. K_c value reduces from 0.50 in 52nd week to 0.28 in 15th week due to harvesting of fruit, removal of number of leaves, foliage, flowers, fruits, water sprouts and luxor. The crop coefficient again increases from 16th to 30th weeks (i.e. from 0.29 to 0.35) due to increasing the irrigation quantity for maintaining the tree health for next season.

4.1.3 Crop Coefficient Curve for Pomegranate Tree in 3rd Year

The crop coefficient curve for pomegranate tree in 3rd year is presented in Fig.4.3. Figure shows four distinct phases of k_c. The k_c increases from 0.13 in 31st week to 1.01 in 44th week due to increases in number of leaves, flowers, foliage, water sprout, maturation of the leaf surface, luxor and fruits. The k_c shows the constant value of 1.08 from 45th to 52nd weeks. K_c value reduces from 1.08 in 52nd week to 0.65 in 15th week due to harvesting of fruit, removal of number of leaves, foliage, flowers, fruits, water sprouts and lux. The crop coefficient again increases from 16th to 30th weeks (i.e. from 0.66 to 0.72) due to increasing the supply of irrigation water for maintaining the tree health for next season.

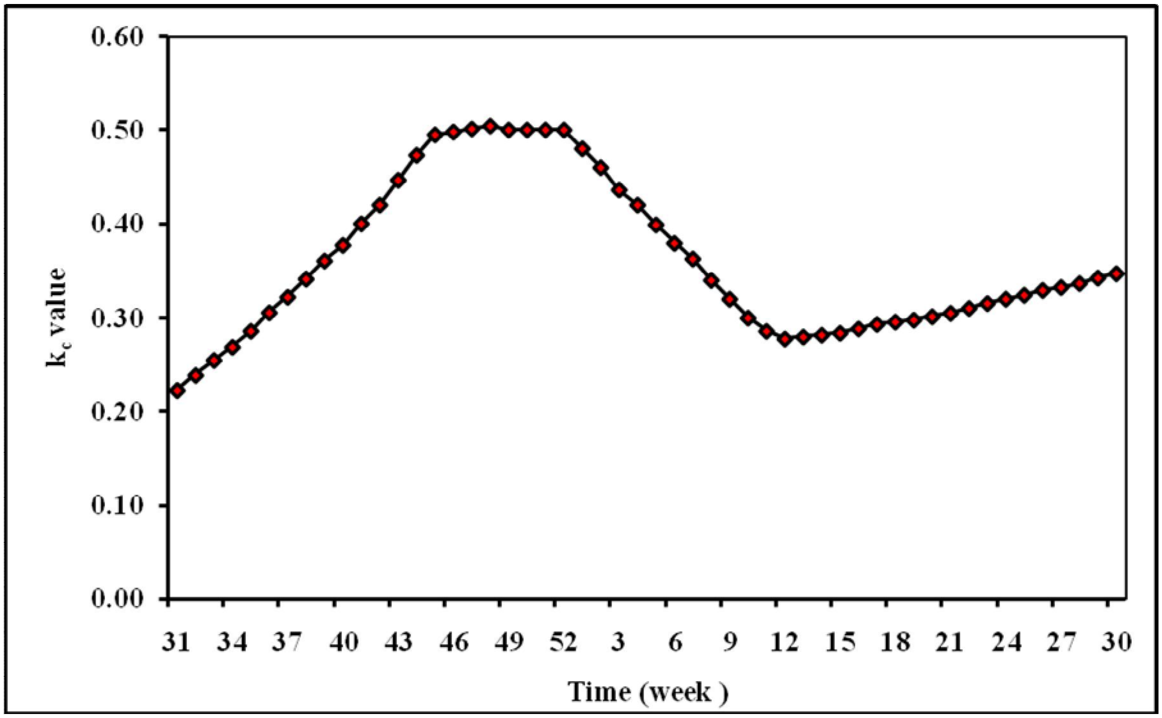

Fig. 4.2 Crop coefficient curve for 2nd year pomegranate tree

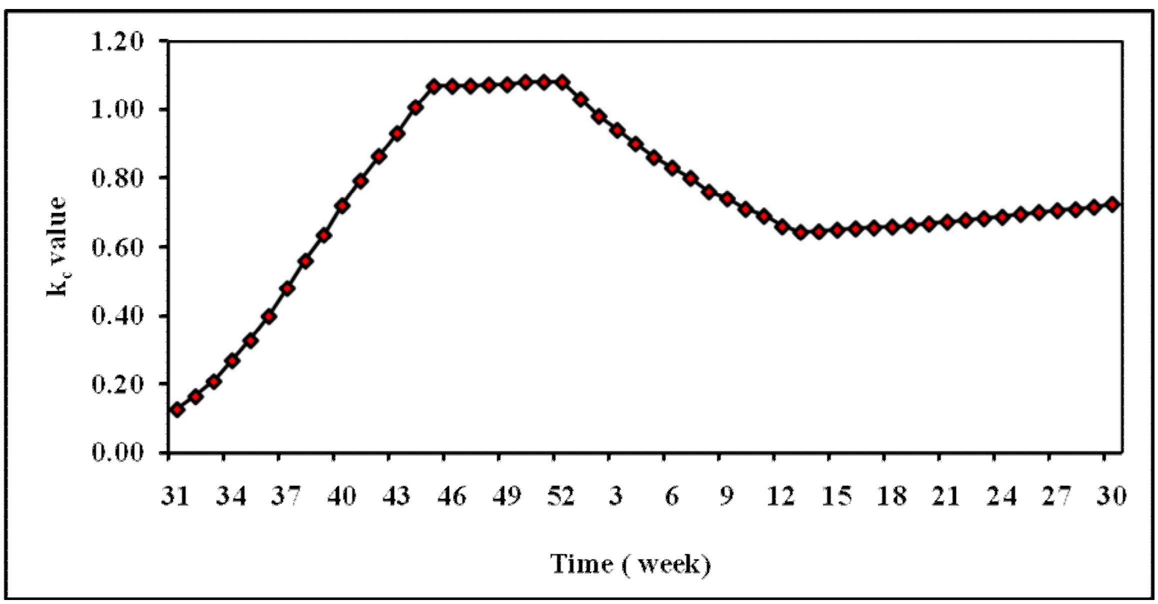

Fig. 4.3 Crop coefficient curve for 3rd year pomegranate tree

4.1.4 Crop Coefficient Curve for Pomegranate Tree in 4th Year

The crop coefficient curve for pomegranate tree in 4th year is presented in Fig.4.4. Figure shows four distinct phases of k_c. The k_c increases from 0.14 in 31st week to 1.08 in 44th week due to increases in number of leaves, flowers, foliage, water sprout, maturation of the leaf surface, luxor and fruits. The k_c shows the constant value of 1.15 from 45th to 52nd weeks. K_c value reduces from 1.15 in 52nd week to 0.74 in 15th week due to harvesting of fruit, removal of number of leaves, foliage, flowers, fruits, water sprouts and luxor. The crop coefficient again increases from 16th to 30th weeks (i.e from 0.75 to 0.80) due to increasing the supply of irrigation water for maintaining the tree health for next season.

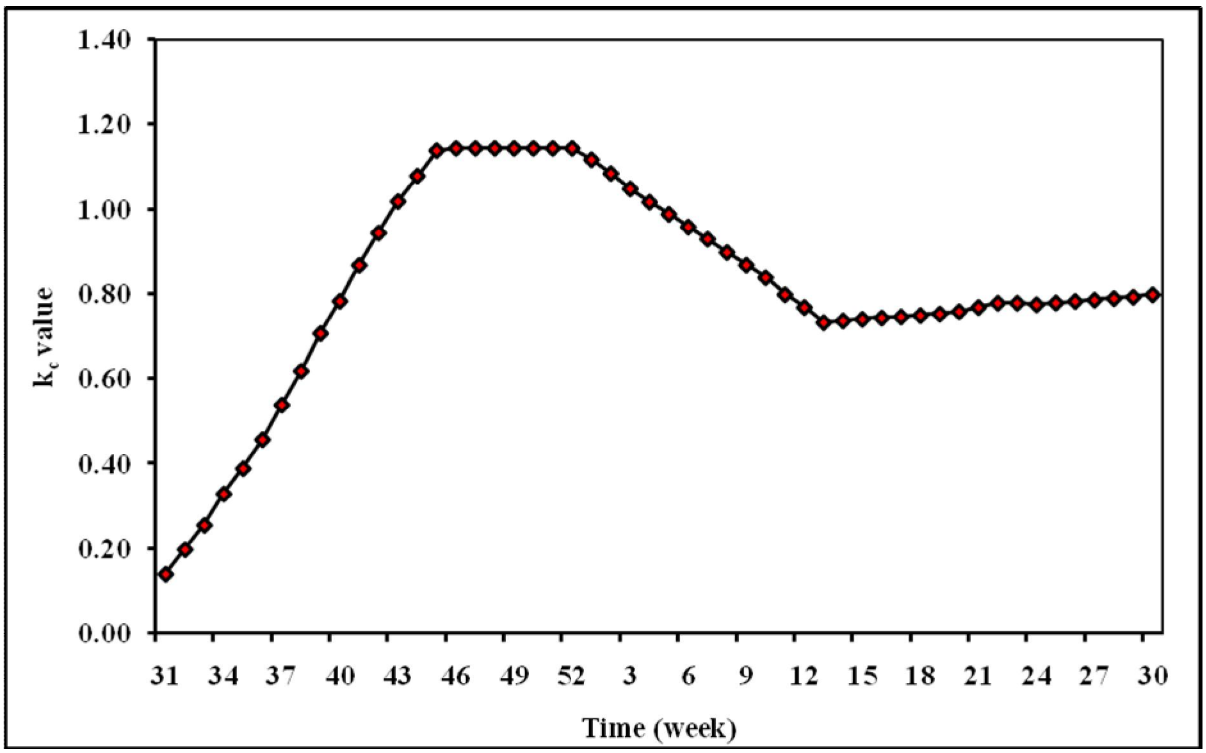

Fig. 4.4 Crop coefficient curve for 4th year pomegranate tree

4.1.5 Crop Coefficient Curve for Pomegranate Tree in 5th Year

The crop coefficient curve for pomegranate tree in 5th year is presented in Fig.4.5. Figure shows four distinct phases of k_c. The k_c increases from 0.15 in 31st week to 1.11 in 44th week due to increases in number of leaves, flowers, foliage, water sprout, maturation of the leaf surface, luxor and fruits. The k_c shows the constant value of 1.18 from 45th to 52nd weeks. K_c value reduces from 1.18 in 52nd week to 0.83 in 15th week due to harvesting of fruit, removal of number of leaves, foliage, flowers, fruits, water sprouts and luxor. The crop coefficient again increases from 16th to 30th weeks (i.e from 0.83 to 0.92) due to increasing the supply of irrigation water for maintaining the tree health for next season.

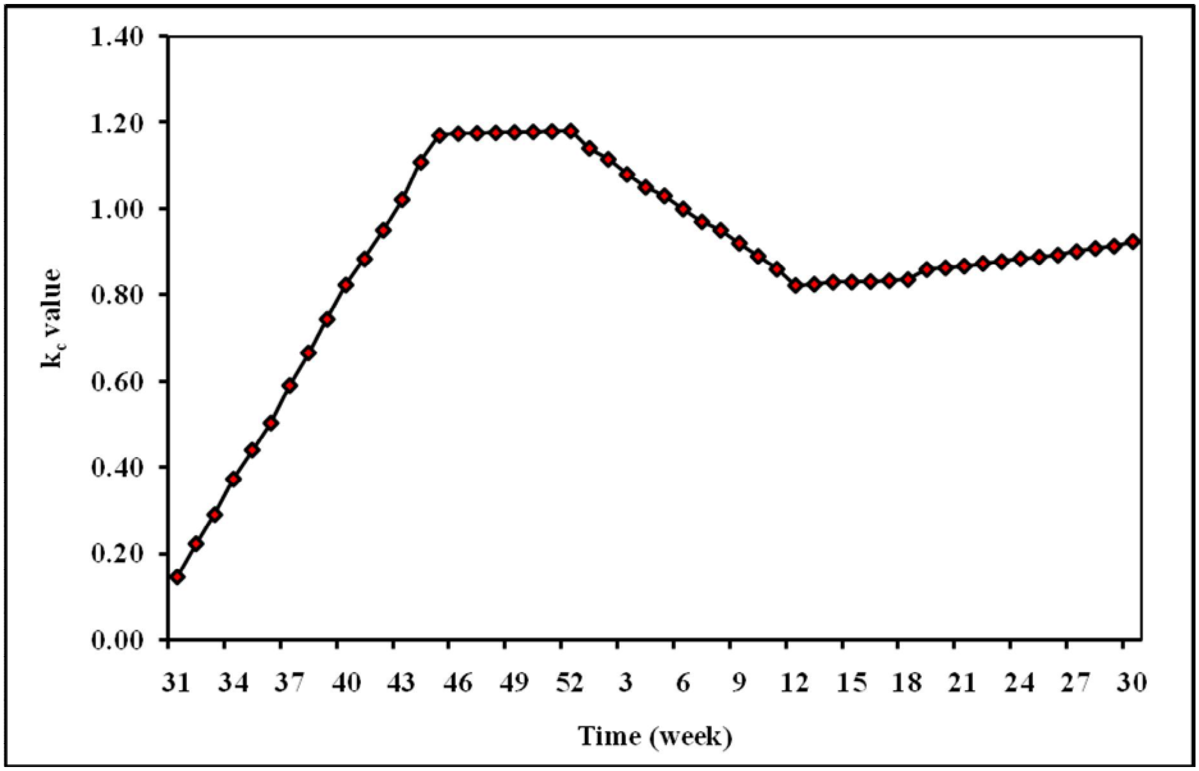

Fig. 4.5 Crop coefficient curve for 5th year pomegranate tree

4.1.6 K_c Values of Matured Pomegranate Tree According to Local Observation on Growth Stages

The crop coefficient curve of mature pomegranate tree obtained from local information is presented in Fig. 4.6. The lengths of the difference growth stages of mature pomegranate tree were obtained as discussed in section 3.2.8. These are:

1. Initial stage: 31st to 33rd meterological week (21 days)
2. Crop development stage:34th to 44th meterological week (77 days)
3. Mid Season: 45th to 52nd meterological week (57 days)
4. Late Season: 01st to15th meterological week (105 days)
5. Rest of period: 16th to 30th meterological week (105 days)

The k_c values of FAO were used to develope the k_c curves by using procedure given in section 3.2.8

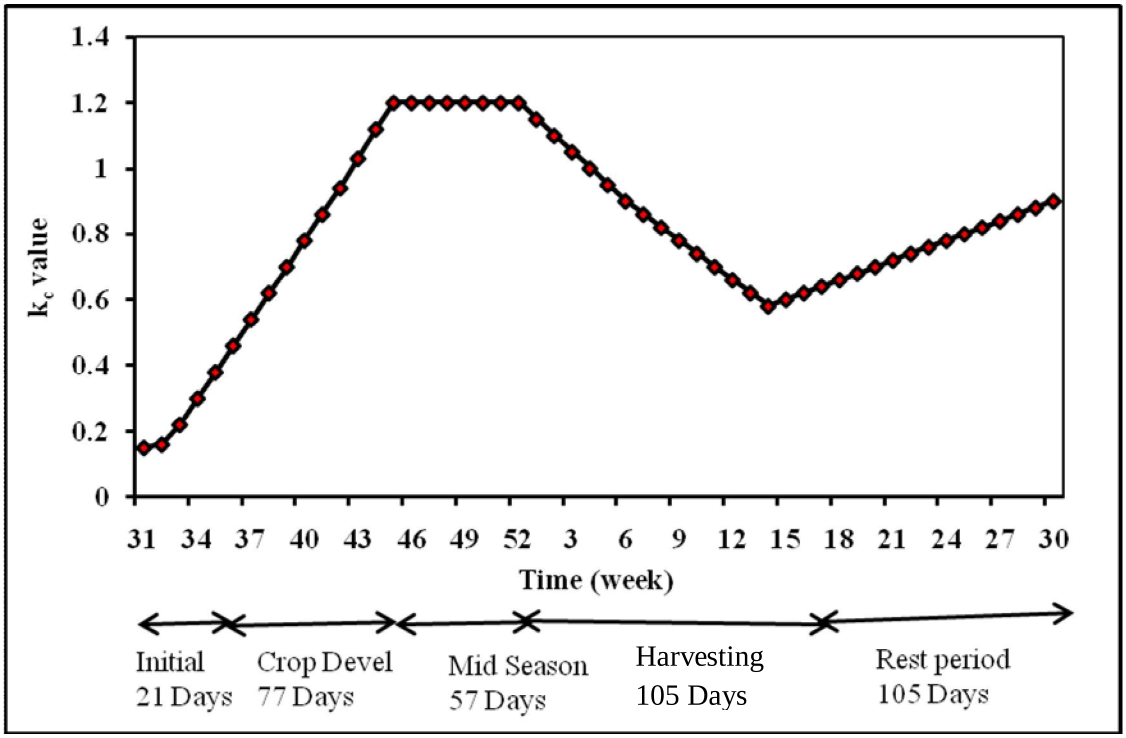

Fig. 4.6 Crop coefficient curve developed from local information on growth stages of mature Pomegranate tree and k_c values of FAO.

4.1.7 Leaf Area Index of Pomegranate by using Indirect Method

Leaf area index (LAI) and tree height are the basic growth parameters of tree. The leaf area index, a dimension less quantity is the leaf area (upper side only) per unit area of soil below it. It is expressed as m^2 leaf area per m^2 of ground area. It also represents upper sunlit portion of a dense canopy. The active leaf area index actively contributes to the surface heats and vapour transfer. The leaf areas of the selected leaves from the selected trees from the orchards of different ages were measured with the help of an (LAI-3000 LICOR) electronic leaf area meter by using the procedure described in section 3.3.

As described in sections 3.3.1 and 3.3.2, the LAI_{SN} was computed as proportion of total leaf area with respect to shaded area at solar noon hour (LAI_{SN}) and as proportion of total leaf area with respect to total area of tree (LAI_{APP}). The weekly values of LAI_{SN} and LAI_{APP} for the pomegranate plantation of different years are presented in Table B-3 of Appendix-B. Generaly LAI_{APP} are less than LAI_{SN} as shaded areas were always less than the total tree area (4.5 x 3) m^2.

4.1.7.1 Leaf area index for pomegranate tree in 1st year

The variation of LAI_{SN} and LAI_{APP} for the pomegranate tree of 1st year with respect to meteorological week is presented in Fig. 4.7. It is seen from the figure that leaf area index increases rapidaly from 31st to 12th weeks (3.51 to 6.84 for LAI_{SN} and 0.20 to 0.70 for LAI_{APP}) due to increase in foliage, number of leaves and its area. The increase in LAI_{APP} is more pronounced compared to LAI_{SN} as during this period shaded area also increased. After 13th week LAI decreases due to removing of water sprout, leaves, foliage crumbling as a result of management practices. Later LAI slowely increases because of emergence of new leaves as a result of application of inputs including irrigation water.

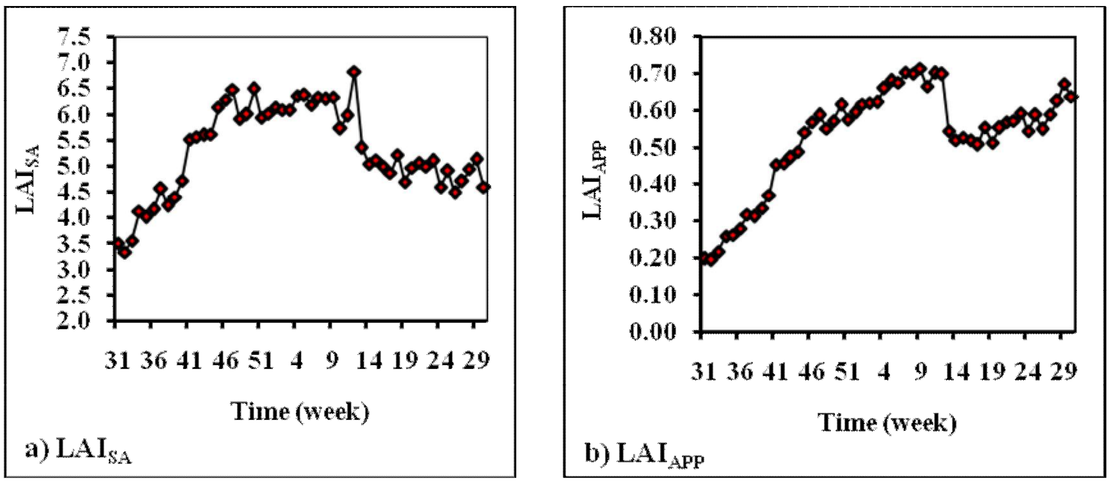

Fig. 4.7 Leaf area index of 1st year pomegranate tree

4.1.7.2 Leaf area index for pomegranate tree in 2nd year

The variation of LAI_{SN} and LAI_{APP} for the pomegranate tree of 2nd year with respect to meteorological week is presented in Fig. 4.8. It is seen from the figure that leaf area index increases rapidaly from 31st to 12th weeks (4.85 to 9.22 for LAI_{SN} and 0.49 to 1.36 for LAI_{APP}) due to increases in foliage, number of leaves and its area. The increase in LAI_{APP} is more pronounced compared to LAI_{SN} as during this period shaded area also increases. After 13th week LAI decreased due to removing of water sprout, leaves, foliage crumbling as a result of management practices. Later LAI slowely increases because of emergence of new leaves as a result of application of inputs including irrigation water.

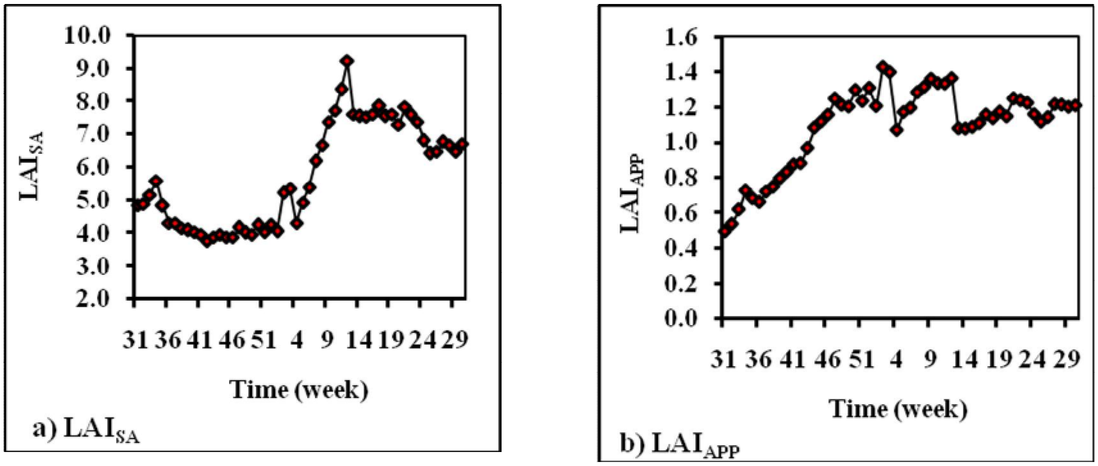

Fig. 4.8 Leaf area index of 2nd year pomegranate tree

4.1.7.3 Leaf area index for pomegranate tree in 3rd year

The variation of LAI_{SN} and LAI_{APP} for the pomegranate tree of 3rd year with respect to meteorological week is presented in Fig. 4.9. It is seen from the figure that leaf area index increases rapidaly from 31st to 12th weeks (3.98 to 5.62 for LAI_{SN} and 0.13 to 2.50 for LAI_{APP}) due to increases in foliage, number of leaves and its area. The increase in LAI_{APP} is more pronounced compared to LAI_{SN} as during this period shaded area also increases. After 13th week LAI decreases due to removing of water sprout, leaves, foliage crumbling as a result of management practices. Later LAI slowely increases because of emergence of new leaves as a result of application of inputs including irrigation water.

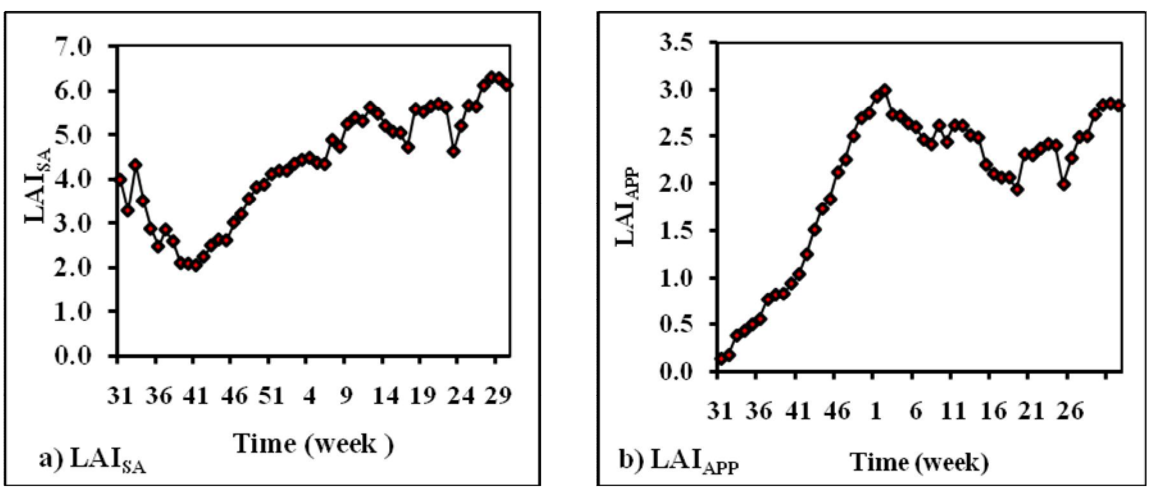

Fig. 4.9 Leaf area index of 3rd year pomegranate tree

4.1.7.4 Leaf area index for pomegranate tree in 4th year

The variation of LAI_{SN} and LAI_{APP} for the pomegranate tree of 4th year with respect to meteorological week is presented in Fig. 4.10. It is seen from the figure that leaf area index increases rapidaly from 31st to 12th weeks (3.96 to 4.56 for LAI_{SN} and 0.17 to 2.34 for LAI_{APP}) due to increases in foliage, number of leaves and its area. The increase in LAI_{APP} is more pronounced compared to LAI_{SN} as during this period shaded area also increases. After 13th week LAI decreases due to removing of water sprout, leaves, foliage crumbling as a result of management practices. Later LAI slowely increases because of emergence of new leaves as a result of application of inputs including irrigation water

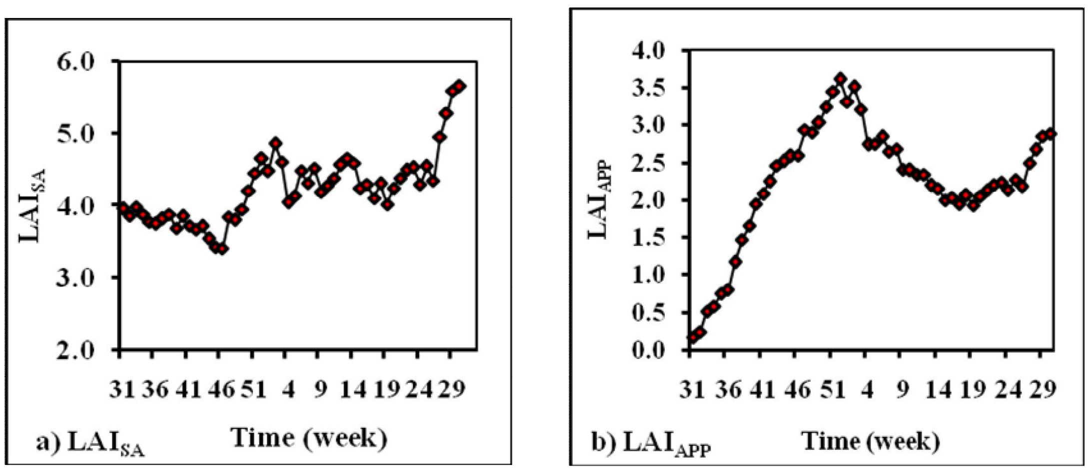

Fig. 4.10 Leaf area index of 4th year pomegranate tree

4.1.7.5 Leaf area index for pomegranate tree in 5th year

The variation of LAI_{SN} and LAI_{APP} for the pomegranate tree of 5th year with respect to meteorological week is presented in Fig. 4.11. It is seen from the figure that leaf area index increases rapidaly from 31st to 12th weeks (4.93 to 5.73 for LAI_{SN} and 0.23 to 3.33 for LAI_{APP}) due to increases in foliage, number of leaves and its area. The increase in LAI_{APP} is more pronounced compared to LAI_{SN} as during this period shaded area also increases. After 13th week LAI decreases due to removing of water sprout, leaves, foliage crumbling as a result of management practices. Later LAI slowely increases because of emergence of new leaves as a result of application of inputs including irrigation water

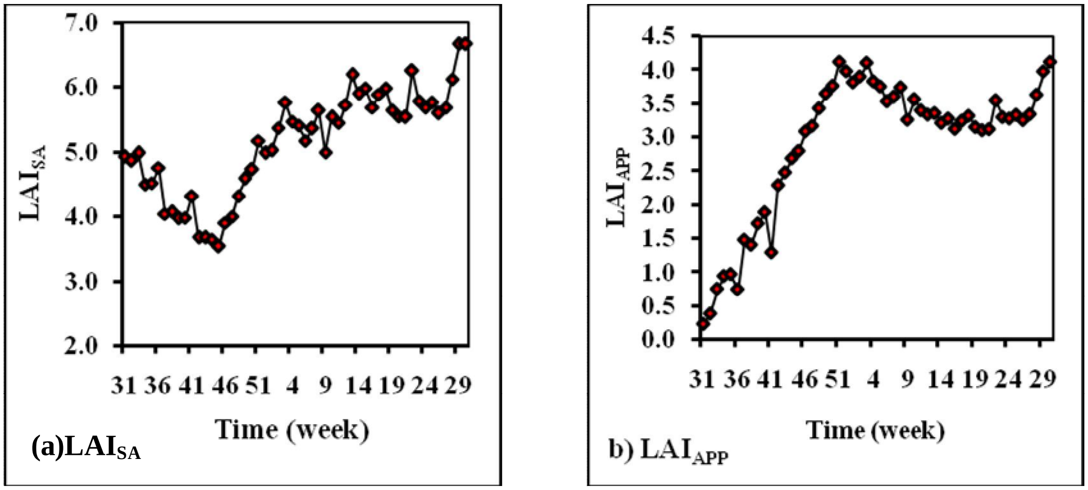

Fig. 4.11 Leaf area index of 5th year pomegranate tree

4.1.8 Leaf Area Index of Pomegranate by using Direct Method

The LAI values based on the area of all the leaves at the end of each year as calculated by using the procedure described in section 3.3.2 are presented in Table 4.1. It is seen from the table that the leaf area index based on total area increases from 0.68 for 1st year to 3.41 for 5th year. This is obiviously due to increases foliage with age. Leaf area index based on shaded area increases from 4.55 for 1st year to 6.28 for 2nd year. However LAI decreases for 3rd year and then increases for 4th and 5th years. This is because the LAI_{SN} is estimated based on shaded area and 2nd year orchard showed more canopy/foliage, compared to 3rd year orchard.

Table 4.1 Average leaf area indices based on area of total leaves for 1st to 5th year pomegranate trees

Tree No	**Year**									
	1		**2**		**3**		**4**		**5**	
	LAI_{SN}	**LAI_{APP}**	**LAI_{SN}**	**LAI_{APP}**	**LAI_{SN}**	**LAI_{APP}**	**LAI_{SN}**	**LAI_{APP}**	**LAI_{SN}**	**LAI_{APP}**
	A) I Orchard									
1	4.89	0.63	5.04	0.93	4.93	2.19	3.96	2.02	4.79	2.87
2	4.90	0.63	7.07	1.30	4.12	1.89	5.28	2.71	5.84	3.50
3	4.82	0.64	4.49	0.85	4.92	2.18	4.77	2.48	6.31	3.81
4	4.38	0.56	6.98	1.34	4.65	2.03	4.36	2.24	6.35	3.84
5	3.95	0.66	6.28	1.22	6.25	3.00	5.13	2.63	5.19	3.15
Av.LAI	4.55	0.62	5.98	1.13	4.99	2.26	4.70	2.42	5.70	3.43
Tree No	**B) II Orchard**									
1	6.68	1.11	5.61	1.11	4.14	1.94	5.09	2.60	4.48	2.69
2	6.09	0.97	7.42	1.45	4.34	2.04	6.08	3.12	6.53	3.92
3	3.75	0.60	4.93	0.95	5.25	2.48	4.39	2.29	8.14	4.92
4	3.11	0.48	7.90	1.50	4.54	2.18	5.04	2.58	5.15	3.11
5	3.11	0.52	7.09	1.35	4.90	2.36	5.76	2.96	3.84	2.33
AV.LAI	4.55	0.73	6.58	1.27	4.64	2.20	5.27	2.71	5.63	3.39
Ave.(A&B)	4.55	0.68	6.28	1.20	4.81	2.23	4.98	2.56	5.66	3.41

4.1.9 Relationship between Crop Coefficient and Leaf Area Index

Crop coefficient values are required to obtain ET_c from ET_r. ET_c values are required to estimate water requirement which is needed for irrigation planning. As stated in the beginning of the chapter-III, k_c values are often not available and expensive to determine. The literature has shown the definite relationship between k_c and LAI for field crop (Orgaz *et al.* 2005; Williams and Ayars *et al.* 2005; Johnson *et al.* 2005 and Netzer *et al.* 2008). LAI values can be measured with relatively more ease than k_c. Hence the relationships between LAI and k_c were developed; which can be used to estimate k_c from measured values of LAI.

In this study LAI values were developed on the basis of viz. total area of tree (LAI_{APP}) and shaded area (LAI_{SN}). However, for the purpose of developing the relationship LAI_{APP} was used as LAI_{APP} considers total area and its trend resembles properly with k_c (Grantz and Williams, 1993; Villlalobos *et al.* 1995; Oliveira and Santos, 1995; Coops *et al.* 2000; Cittadini and Peri 2006 and Simona *et al*. 2006). K_c- LAI relationships for the pomegranate tree of different ages were developed and are discussed in this section.

4.1.9.1 Relationships between crop coefficient values and leaf area index for 1st to 5th year tree

The graph showing the variation of k_c with leaf area index for the pomegranate tree of different ages is shown in Fig. 4.12. It is seen from the graphs that k_c linearly increases with LAI. The results are in agreement with those obtained by Ayars *et al.*, 2005.

The relationship between k_c and LAI were also developed for the pomegranate trees of different ages and are given below along with the values of regression coefficient.

Years	Equations	R^2
1st	k_c=0.181LAI+0.128	0.815
2nd	k_c=0.335LAI+0.164	0.751
3rd	k_c=0.363LAI+0.144	0.725
4th	k_c=0.289LAI+0.169	0.872
5th	k_c=3.489LAI-0.129	0.692

As the values of r^2 are more than 0.60 for all the relationships, there relationships can be used to obtain k_c from LAI.

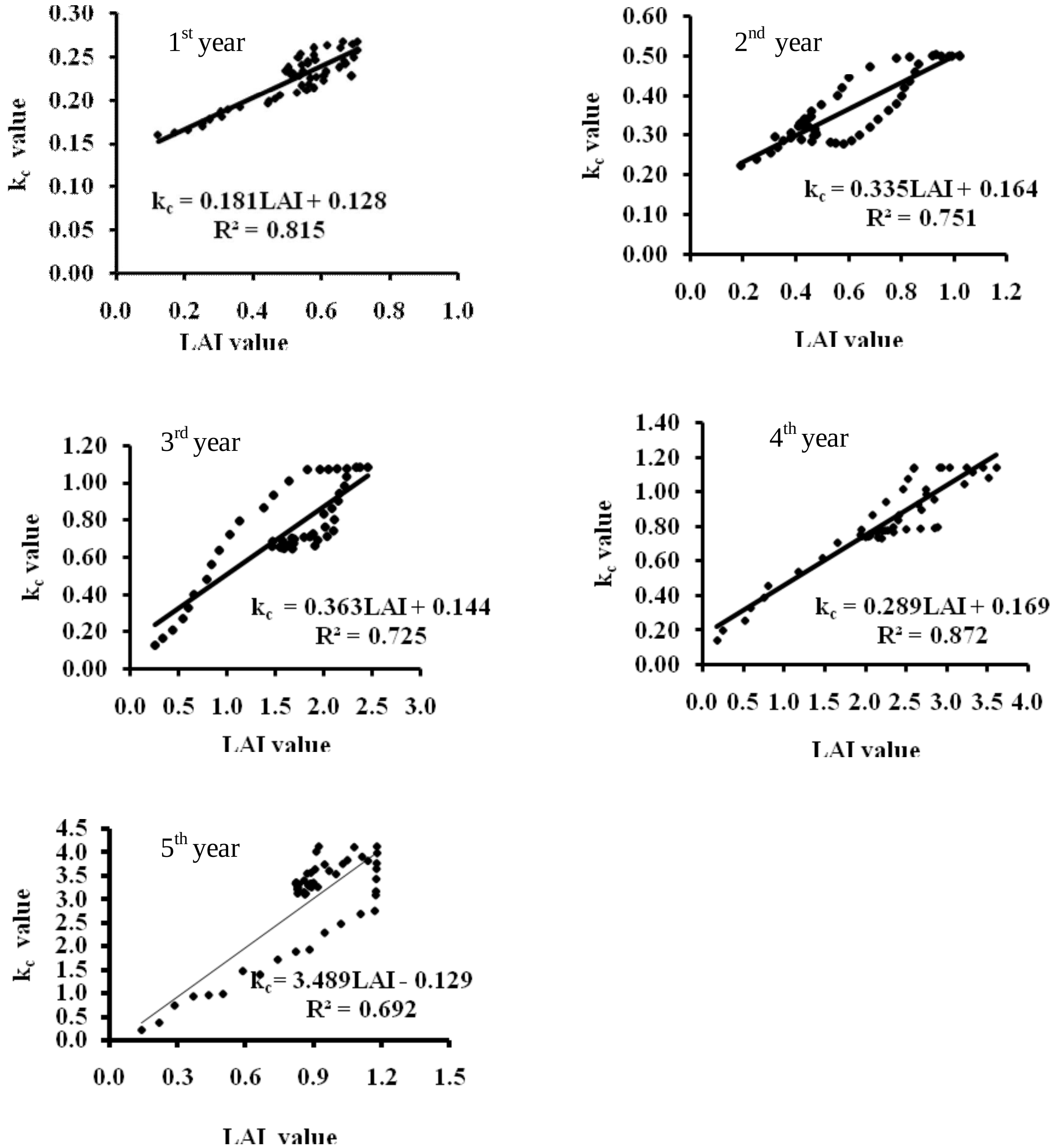

Fig. 4.12 Relationship between LAI and k_c values of 1st to 5th year pomegranate trees

4.1.9.2 Relationship between crop coefficient values and leaf area index for pomegranate tree

The relationship between k_c and LAI for the pomegranate tree for all the ages together was also obtained and show in Fig.4.13. The relationship is given below.

Equation	R^2
$k_c = 0.261LAI + 0.189$	0.837

As r^2 more than 0.60, this single relationship would also provide the k_c values for known values of LAI.

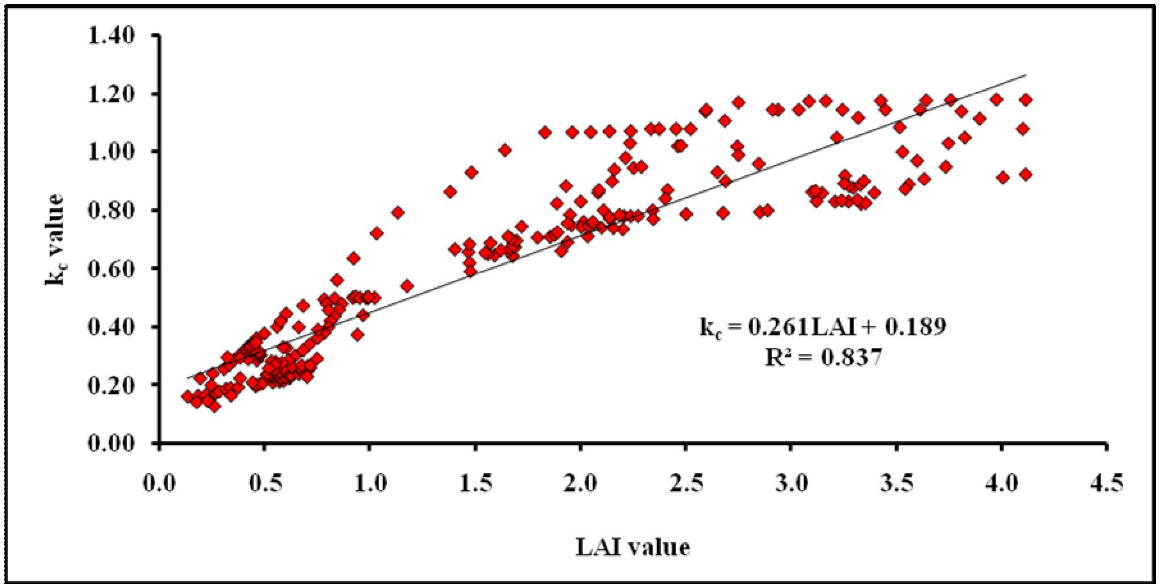

Fig. 4.13 Relationship between LAI and k_c values for pomegranate trees of all the ages together

4.2 DEVELOPEMNT OF SOFTWARE FOR ESTIMATIOMATION OF ET_r

The study involves comparing the ET_r by different methods, fitting of different probability distributions to ET_r series and stochastic modeling of ET_r. For this purpose, it is necessary to estimates the ET_r values by different methods using historical climatic data of available years (in this study 24 years for Solapur, 33 years for Ahmednagar, 20 years for Pune and 23 years for Nasik districts). Therefore the computer programe was written to estimate ET_r on daily basis by using following methods.

Penman-Monteith,
Modified Penman,
Hargreaves-Samani,
FAO Pan Evaporation,
Blanney-Criddle and
FAO Radiation Method

This programme has been coded in FORTRAN – 90 language. The detail flowchart of the programme is presented in Appendix-C (Fig. C-1). The details of the required input data, methodology used and output of the results are described in this section.

4.2.1 Input Data

The programme needs following input data

1. Option for the estimation of ET_r or both ET_r

    Option = 1 for estimating only ET_r

    Option = 2 for estimating both ET_r

2. Year, altitude, latitude
3. Option for the method of estimation of ET_r

    Option = 1 if the reference evapotranspiration is to be estimated by all six methods

    Option = 2 if the reference evapotranspiration is to be estimated by Penman-Monteith method

    Option = 3 if the reference evapotranspiration is to be estimated by Modified Penman method

    Option =4 if the reference evapotranspiration is to be estimated by Hargreaves–Samani method

    Option = 5 if the reference evapotranspiration is to be estimated by pan evaporation method

    Option = 6 if the reference evapotranspiration is to be estimated by Blanney-Criddle method

    Option = 7 if the reference evapotranspiration is to be estimated by Radiation method

4. The daily values of climatological data according to the options in (3)

    Option = 1, the value of α, a_1, b_1, pan coefficient, daily values of maximum temperature(^{0}C), Minimum temperature (^{0}C), maximum relative humidity (%), minimum relative humidity (%), wind speed (km/hr) , sunshine hours (hr), pan evaporation (mm), rainfall (mm)

    Option = 2 & 3, the values temperature (^{0}C), maximum of α, a, b, daily values of maximum temperature (^{0}C), minimum temperature (^{0}C), minimum relative humidity (%), wind speed (km/hr), sunshine hours (hr).

    Option = 4, daily values of maximum temperature (^{0}C), minimum temperature (^{0}C).

    Option = 5, the values of pan coefficient, daily values of pan evaporation (mm).

    Option = 6, the daily values of air temperature (^{0}C), mean daily % of day time hour.

    Option =7, daily values of solar radiation (MJ/m^2/day)

    The typical input file is shown in Appendix-C (Table C-1)

4.2.2 Methodology Used in Programme

The programme estimates the daily ET_r by all six methods at a time or by using any one method. The procedure used for estimating ET_r by Penman-Monteith, Modified Penman, Hargreaves- Samani, FAO Pan Evaporation, Blanney-Criddle, and FAO Radiation methods are described in sections 3.5.1, 3.5.2, 3.5.3, 3.5.4, 3.5.5 and 3.5.6, respectively. The programme further computes the weekly values of ET_r from daily values.

4.2.3 Output

The outputs are obtained in the following forms:

- Daily reference crop evapotranspiration (ET_r) by different methods
- Weekly reference crop evapotranspiration (ET_r) by different methods

The typical output files in the form of daily and weekly basis are shown in Appendix-C (Table C-2 and Table C-3).

4.3 ESTIMATION AND COMPARISON OF REFERENCE CROP EVAPOTRANSPIRATION (ET_r)

The values of ET_r by using Penman-Monteith, Modified Penman, Hargreaves-Samani, FAO Pan Evaporation, Blanney-Criddle, and FAO Radiation methods were estimated with the help of software explained in section 4.2 and data discussed in chapter-III. The average weekly values of ET_r obtained by above mentioned methods are discussed and compared for Solapur, Ahmednagar, Pune and Nasik districts of Western part of Maharashtra region.

4.3.1 Solapur District

The daily climatic data for the period of January, 1984 to December, 2007 (i.e.24 years) were used to determine daily and weekly reference crop evapotranspiration (ET_r). The average weekly ET_r values are presented in Appendix-D (Table D-1) and Fig. 4.14. Figure shows that the trend of variation of average ET_r values over the year for all the methods is same. However none of the methods shows the same results. The difference in values of ET_r is due to different climatological variables used in each method. The mean yearly reference crop evapotranspiration (ET_r) obtained are 1803.5, 2211.8, 1900.5, 1949.5, 2056.6, and 2239.8 mm for Penman-Monteith, Modified Penman, Hargreaves-Samani, FAO Pan Evaporation, Blanney-Criddle, and FAO Radiation methods, respectively. It is observed from the average weekly values of ET_r that the estimates of ET_r by FAO radiation method are higher, followed by modified penman method, Blanney-Criddle, pan evaporation, Hargraeves-Samani and Penman-Monteith methods.

As one of the objectives of the study was to find out the method of estimation of ET_r that is close to Penman-Monteith method, the estimates of ET_r by different methods were compared with estimates of ET_r by Penman-Monteith method by regression analysis and computing root mean square error as discussed in section 3.5.8.

4.3.1.1 Regression analysis

The correlation between Penman-Monteith and other methods by regression analysis is shown in Fig. 4.15. The regression coefficient (r^2) between Penman-Monteith method and

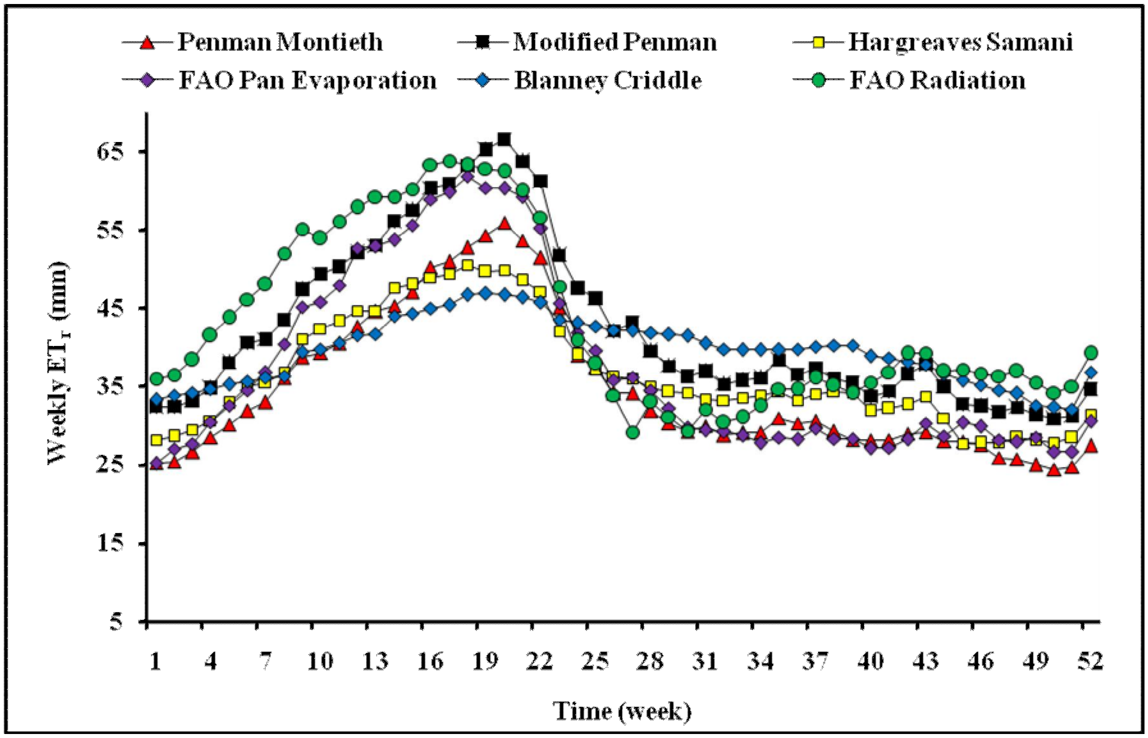

Fig. 4.14 Average weekly reference crop evapotranspiration for Solapur district (1984-2007)

Modified Penman method, Hargreaves-Samani, Pan Evaporation, Blanney-Criddle, and FAO Radiation are 0.962, 0.644, 0.542, 0.477 and 0.744, respectively. Modified Penman method shows the highest correlation with Penman-Monteith method. This is evidant due to the fact that both the methods use the same set of data and is based on similar principle. These values of r^2 indicate the estimates of Modified Penman, Hargreaves-Samani and FAO Radiation are significantly correlated with ET_r estimates of Penman-Monteith method. Hence on the basis of regression analysis all the three methods can be used in lieu of Penman-Monteith method. However user needs to decide to select the appropriate method out of these three on the basis of data availability.

4.3.1.2 Root mean square error (RMSE)

The root mean square error between the daily ET_r estimates of Penman-Monteith method and other methods were compared for each year. The RMSE value for each year and average yearly values are presented in Table 4.2. The table shows that the lowest value of RMSE i.e. 1.025 mm/day is obtained for Hargreaves-Samani, followed by 1.25 mm/day for Modified Penman, 1.43 mm/day for Pan Evaporation, 1.46 mm/day for Blanney-Criddle and 1.788 mm/day for FAO Radiation methods. Thus on the basis of RMSE, Hargreaves-Samani method is recommended for use in leiu of Penman-Monteith method for Solapur district.

The high correlation of ET_r by the Hargreaves-Samani method with Penman-Monteith method clearly reflects the importance of the incident solar radiation as they are calculated by using the temperature and solar radiation. This fact is also supported by many studies which reveal that the Hargreaves-Samani method is nearly as accurate as the Penman-Monteith method for estimating ET_r. Therefore, it is recommended to use the Hargreaves method in the case of other reliable data is not available or only temperature data is available.

Table 4.2 Root mean square error (RMSE) between ET_r estimates of Penman-Monteith method and other methods for Solapur district (1984-2007)

Years	Root mean Square error (mm/day)				
	MP	**HAR**	**E_{pan}**	**BLC**	**RAD**
1984	1.19	0.97	1.31	1.43	1.49
1985	1.37	0.92	1.21	1.26	1.96
1986	1.39	0.85	1.29	1.14	1.74
1987	1.38	1.18	1.34	1.49	1.46
1988	2.02	1.83	1.12	1.94	1.98
1989	1.47	1.11	1.34	1.28	2.02
1990	1.28	0.86	1.38	1.26	1.86
1991	1.23	0.83	1.29	1.22	1.72
1992	1.15	0.71	1.26	1.05	1.38
1993	1.06	0.87	2.58	1.37	0.501
1994	1.07	1.02	1.50	1.46	1.53
1995	1.03	1.14	1.22	1.49	1.45
1996	1.24	1.01	1.23	1.46	1.79
1997	1.16	0.906	1.36	1.48	1.65
1998	0.97	1.23	1.74	1.76	1.32
1999	1.09	1.24	2.56	1.81	1.48
2000	1.06	1.25	2.25	1.64	1.38
2001	1.24	1.14	1.56	1.59	1.67
2002	1.26	1.00	1.49	1.48	1.74
2003	1.32	0.95	1.11	1.39	1.72
2004	1.09	0.89	0.898	1.33	1.50
2005	1.20	0.93	1.10	1.56	1.60
2006	1.75	1.24	1.30	1.63	6.62
2007	1.07	1.07	0.925	1.48	1.39
Total	30.16	25.23	34.41	35.07	42.92
Average	1.25	1.025	1.43	1.46	1.788

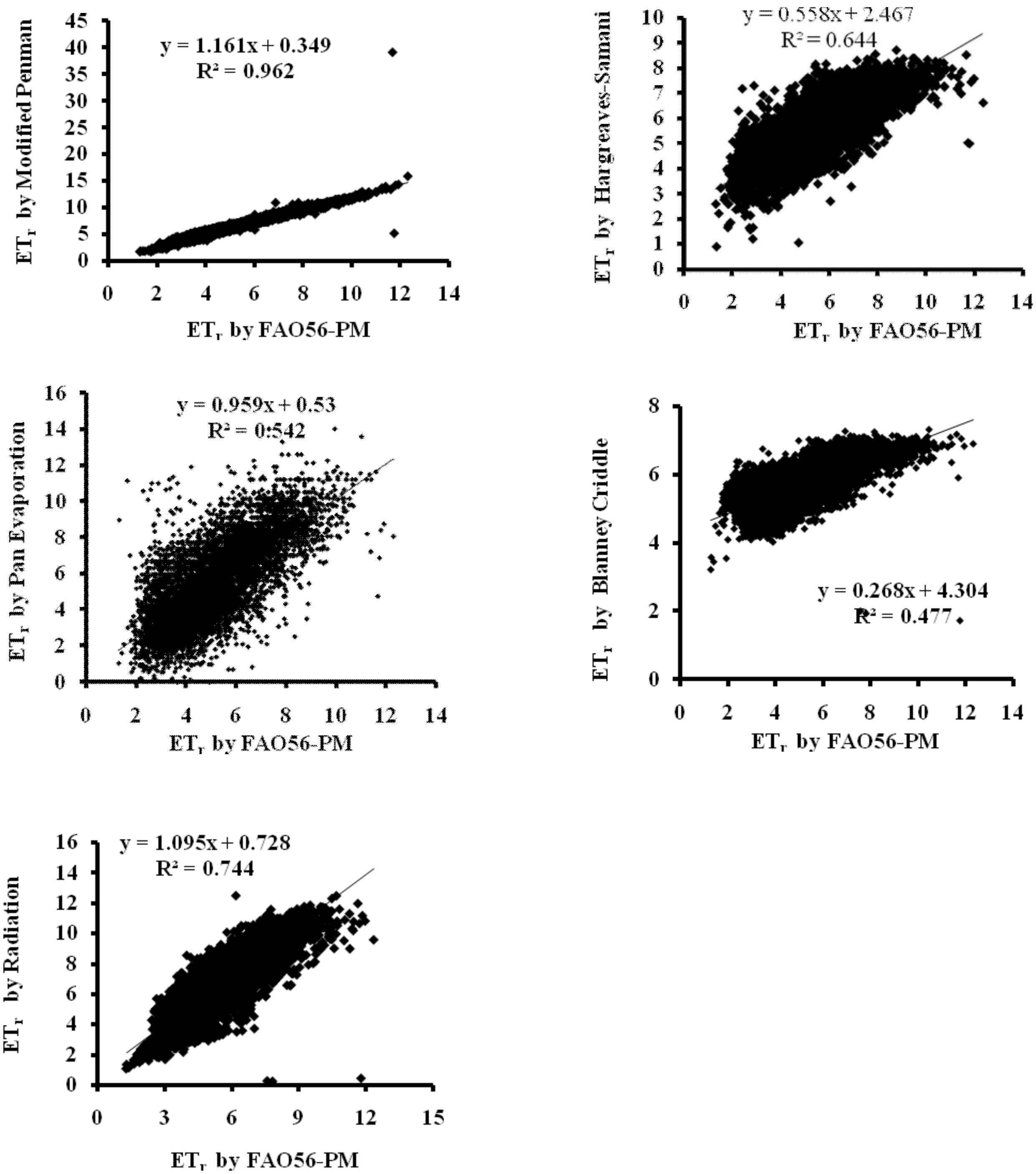

Fig. 4.15 Regression analysis of ET_r (mm/day) estimates between Penman-Monteith method and Modified Penman, Hargreaves, Pan Evaporation, Blanney-Criddle and FAO Radiation methods for Solapur district

4.3.2 Ahmednagar District

The daily climatic data for the period of January, 1975 to December, 2007 (i.e.33 years) were used to determine daily and weekly reference crop evapotranspiration (ET_r). The average weekly ET_r values are presented in Appendix-D (Table D-2) and Fig. 4.16. Figure shows that the trend of variation of average ET_r over the year for all the methods is same.However none of the methods shows the same results. The difference in values of ET_r is due to different climatological variables used in each method. The mean yearly reference crop evapotranspiration (ET_r) obtained are are 1692.1, 2066.5, 1851.3, 1788.3, 1944.5, and 2166.6 mm for Penman-Monteith, Modified Penman, Hargreaves-Samani, FAO Pan Evaporation, Blanney-Criddle, and FAO Radiation methods, respectively. It is observed from the average weekly values of ET_r that the estimates of ET_r by FAO radiation method are higher, followed by modified penman method, Blanney-Criddle, Hargraeves-Samani, pan evaporation, and Penman-Monteith methods.

As one of the objectives of the study was to find out the method of estimation of ET_r that is close to Penman-Monteith method, the estimates of ET_r by different methods was compared with estimates of ET_r by Penman-Monteith method by regression analysis and computing root mean square error as discussed in section 3.5.8.

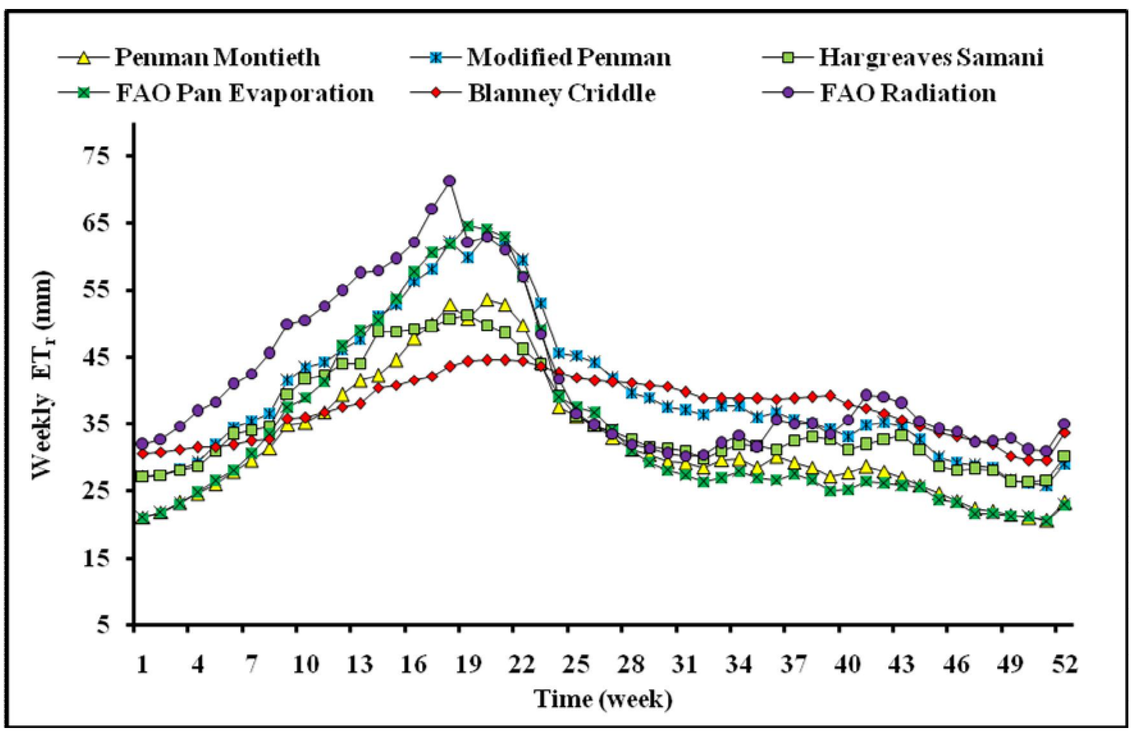

Fig. 4.16 Average weekly reference crop evepotranspiration for Ahmednagar district (1976-2007)

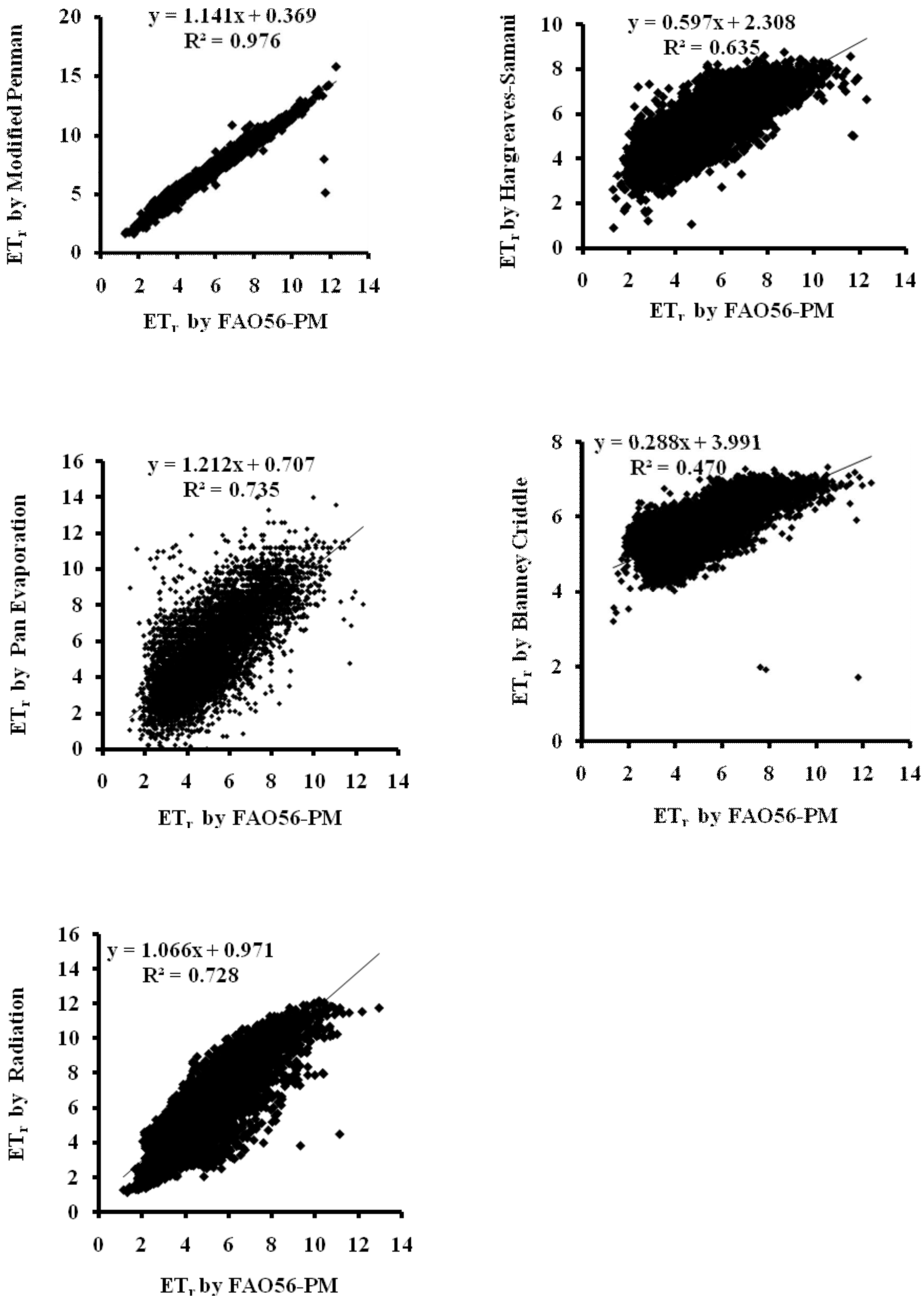

Fig: 4.17 Regression analysis of ET_r (mm/day) estimates between Penman-Monteith method and Modified Penman, Hargreaves-Samani, Pan Evaporation, Blanney-Criddle and FAO Radiation methods for Ahmednagar district

4.3.2.1 Regression analysis

The correlation between Penman-Monteith and other methods by regression analysis is shown in Fig. 4.17. The regression coefficient (r^2) between Penman-Monteith and Modified Penman, Hargreaves-Samani, Pan Evaporation, Blanney-Criddle, and FAO Radiation methods are 0.976, 0.635, 0.735, 0.470 and 0.720, respectively. Modified Penman method shows the highest correlation with Penman-Monteith method. This is evidance due to the fact that both the methods use the same set of data and is based on similar principle. These values of r^2 indicate the estimates of Modified Penman, Hargreaves-Samani and FAO Radiation are significantly correlated with ET_r estimates of Penman-Monteith method. Hence on the basis of regression analysis all the three methods can be used in lieu of Penman-Monteith method. However user needs to decide to select the appropriate method out of these three on the basis of data availability.

4.3.2.2 Root mean square error (RMSE)

The root mean square error between the daily ET_r estimates of Penman-Monteith method and other methods were compared for each year. The RMSE value for each year and average yearly values are presented in Table 4.3. The table shows that the lowest value of RMSE i.e. 1.08 mm/day is obtained for Modified Penman, followed by 1.116 mm/day for Hargraves-Samani, 1.29 mm/day for Pan Evaporation, 1.47 mm/day for Blanney-Criddle and 1.77 mm/day for FAO Radiation methods. Thus on the basis of RMSE, Modified Penman method is recommended for use in leiu of Penman-Monteith method for Ahmednagar district.

The high correlation of ET_r by the Modified Penman method with Penman-Monteith method clearly reflects the importance of the incident solar radiation as they are calculated by using the temperature and solar radiation. This fact is also supported by many studies which reveal that the Modified Penman method is nearly as accurate as the Penman-Monteith method for estimating ET_r. Therefore, it is recommended to use the Modified Penman method in the case of other reliable data is not available or only temperature data is available.

4.3.3 Pune District

The daily climatic data for the period of January, 1988 to December, 2006 (i.e.19 years) were used to determine daily and weekly reference crop evapotranspiration (ET_r). The average weekly ET_r values are presented in Appendix-D (Table D-3) and Fig. 4.18. Figure shows that the trend of variation of average ET_r over the year for all the methods is same. However none of the methods shows the same results. The difference in values of ET_r is due to different climatological variables used in each method. The mean yearly reference crop evapotranspiration (ET_r) obtained

Table 4.3 Root mean square error (RMSE) between ET_r estimates of Penman-Monteith method and other method for Ahmednagar district (1976-2007)

Years	Root mean Square error(mm/day)				
	MP	HAR	EPan	BLC	RAD
1976	1.25	1.13	1.09	1.66	1.78
1977	1.22	0.92	1.12	1.34	1.68
1978	1.23	0.99	1.27	1.38	1.63
1979	1.29	1.15	1.33	1.65	1.73
1980	1.13	1.07	1.15	1.28	1.31
1981	1.27	1.06	1.23	1.44	1.71
1982	1.28	0.93	1.08	1.19	1.67
1983	1.18	1.02	1.37	1.58	1.52
1984	1.27	1.01	1.50	1.37	1.56
1985	1.18	0.88	1.31	1.20	1.54
1986	1.15	0.87	1.28	1.24	1.62
1987	1.12	0.85	1.30	1.22	1.44
1988	1.04	0.96	0.95	1.46	1.75
1989	1.12	0.96	1.09	1.40	1.93
1990	1.01	0.85	1.16	1.45	1.78
1991	1.05	1.06	1.11	1.42	1.79
1992	1.02	1.03	1.30	1.24	1.59
1993	0.97	1.22	1.63	1.57	0.64
1994	0.99	1.32	1.36	1.65	1.45
1995	1.03	1.07	1.25	1.41	1.70
1996	1.00	1.19	1.39	1.58	1.78
1997	0.94	1.21	1.21	1.53	1.58
1998	1.14	1.44	0.90	1.69	2.29
1999	0.99	2.65	2.25	2.91	5.52
2000	0.94	1.22	0.76	1.44	1.63
2001	1.02	0.63	1.24	1.13	1.27
2002	0.98	0.75	1.23	1.02	1.32
2003	1.07	1.28	1.47	1.51	2.12
2004	0.92	1.23	1.36	1.39	1.63
2005	1.15	1.22	1.35	1.43	2.00
2006	0.89	1.34	1.83	1.83	2.23
2007	0.62	1.06	1.59	1.53	1.42
Total	34.6	35.7	41.5	47.29	56.65
Average	1.08	1.116	1.29	1.47	1.77

are 1428.7, 1782.5, 1744.5, 1334.6, 1936.6, and 1984.4 mm for Penman-Monteith, Modified Penman, Hargreaves- Samani, FAO Pan Evaporation, Blanney-Criddle, and FAO Radiation methods, respectively. It is observed from the average weekly values of ET_r that the estimates of

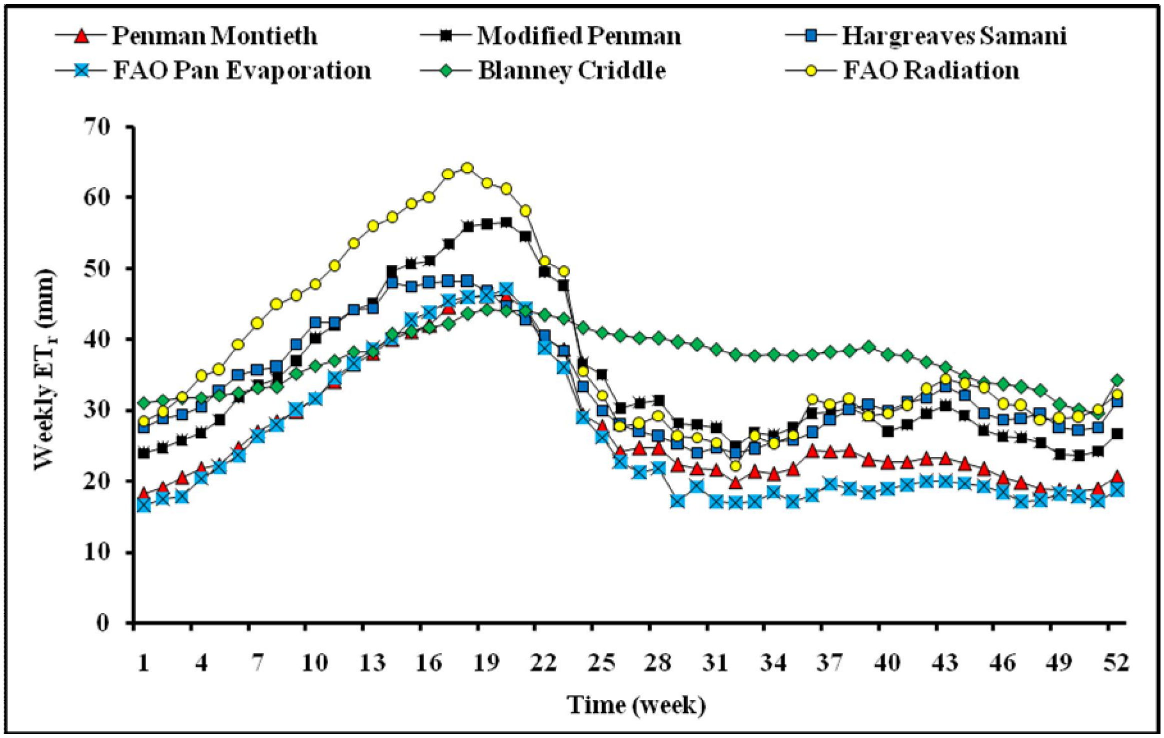

Fig. 4.18 Average weekly reference crop evepotranspiration for Pune district. (1988-2006)

ET_r by FAO radiation method are higher, followed by Blanney-Criddle, modified penman method, Hargraeves-Samani, Penman-Monteith, and pan evaporation methods.

As one of the objectives of the study was to find out the method of estimation of ET_r that is close to Penman-Monteith method, the estimates of ET_r by different methods was compared with estimates of ET_r by Penman-Monteith method by regression analysis and computing root mean square error as discussed in section 3.5.8.

4.3.3.1 Regression analysis

The correlation between Penman-Monteith and other methods by regression analysis is shown in Fig. 4.19. The regression coefficient (r^2) between Penman-Monteith method and Modified Penman method, Hargreaves-Samani, Pan Evaporation, Blanney-Criddle, and FAO Radiation are 0.985, 0.599, 0.674, 0.391 and 0.846, respectively. Modified Penman method shows the highest correlation with Penman-Monteith method. This is evidance due to the fact that both the methods use the same set of data and is based on similar principle. These values of r^2 indicate the estimates of Modified Penman, FAO Radiation and Pan Evaporation are significantly correlated with ET_r estimates of Penman-Monteith method.

4.3.3.2 Root mean square error (RMSE)

The root mean square error between the daily ET_r estimates of Penman-Monteith method and other methods were compared for each year. The RMSE value for each year and average yearly values are presented in Table 4.4. The table shows that the lowest value of RMSE i.e. 1.022 mm/day is obtained for Modified Penman, followed by 1.045 mm/day for Pan Evaporation, 1.260 mm/day for Hargraves-Samani, 1.818 mm/day for Blanney-Criddle, and 1.814 mm/day for FAO Radiation methods. Thus on the basis of RMSE, Modified Penman method is recommended for use in leiu of Penman-Monteith method for Pune district.

Table 4.4 Root mean square error (RMSE) between ET_r estimation of Penman-Monteith and other methods for Pune district (1988-2006)

Years	Root mean Square error (mm/day)				
	MP	HAR	EPan	BLC	RAD
1988	1.17	1.04	1.24	1.55	1.83
1989	1.02	1.10	1.23	1.58	1.79
1990	0.96	0.95	1.28	1.67	1.51
1991	0.97	1.11	1.16	1.64	1.57
1992	1.00	1.23	0.88	1.61	1.62
1993	0.98	1.05	1.23	1.53	1.57
1994	1.04	1.03	1.51	1.54	1.74
1995	0.98	1.16	0.99	1.67	1.53
1996	0.96	1.08	1.08	1.83	1.56
1997	1.05	1.24	0.94	1.77	2.03
1998	1.01	1.25	0.88	2.04	1.73
1999	0.985	1.43	0.81	2.01	1.85
2000	0.99	1.45	1.10	1.89	1.88
2001	1.08	1.70	0.80	2.16	2.07
2002	1.10	1.54	0.82	1.88	2.08
2003	1.07	1.52	0.81	1.99	2.16
2004	1.01	1.23	1.06	2.02	1.90
2005	0.98	1.51	0.96	2.08	2.04
2006	1.01	1.23	1.06	2.02	1.90
Total	19.42	23.93	19.85	34.57	34.46
Average	1.022	1.260	1.045	1.818	1.814

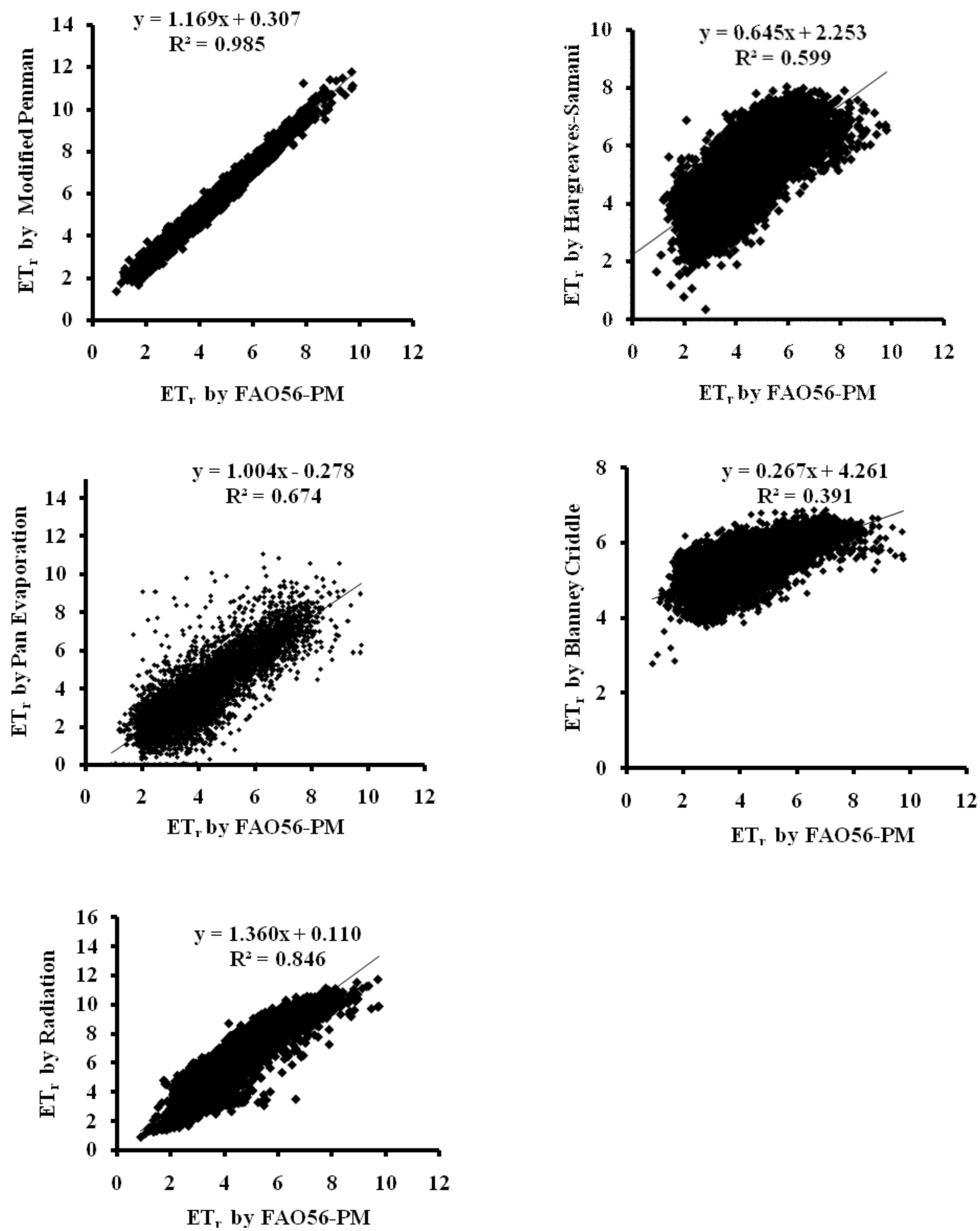

Fig.4.19 Regression analysis of ET_r (mm/day) estimates between Penman-Monteith method and Modified Penman, Hargreaves-Samani, Pan Evaporation, Blanney-Criddle and FAO Radiation methods for Pune district

The high correlation of ET_r by the Modified Penman method with Penman-Monteith method clearly reflects the importance of the incident solar radiation as they are calculated by using the temperature and solar radiation. This fact is also supported by many studies which reveal that the Modified Penman method is nearly as accurate as the Penman-Monteith method for estimating ET_r. Therefore, it is recommended to use the Modified Penman method in the case of other reliable data is not available or only temperature data is available.

4.3.4 Nasik District

The daily climatic data for the period of January, 1986 to December, 2007 (i.e.22 years) were used to determine daily and weekly reference crop evapotranspiration (ET_r). The average weekly ET_r values are presented in Appendix-D (Table D-4) and Fig. 4.20. Figure shows that the trend of variation of average ET_r over the year for all the methods is same.However none of the methods shows the same results. The difference in values of ET_r is due to different climatological variables used in each method. The mean yearly reference crop evapotranspiration (ET_r) obtained are 1603.0, 2003.0, 1755.4, 1349.1, 1936.9, and 2079.8 mm for Penman-Monteith, Modified Penman, Hargreaves-Samani, FAO Pan Evaporation, Blanney-Criddle, and FAO Radiation methods, respectively. It is observed from the average weekly values of ET_r that the estimates of ET_r by FAO radiation method are higher, followed by Modified penman method, Blanney-Criddle, Hargraeves-Samani, Penman-Monteith, and pan evaporation methods.

As one of the objectives of the study was to find out the method of estimation of ET_r that is close to Penman-Monteith method, the estimates of ET_r by different methods was compared with estimates of ET_r by Penman-Monteith method by regression analysis and computing root mean square error as discussed in section 3.5.8.

4.3.4.1 Regression analysis

The correlation between Penman-Monteith and other methods by regression analysis is shown in Fig. 4.21. The regression coefficient (r^2) between Penman-Monteith method and Modified Penman method, Hargreaves-Samani, Pan Evaporation, Blanney-Criddle, and FAO Radiation are 0.974, 0.674, 0.066, 0.283 and 0.575, respectively. Modified Penman method shows the highest correlation with Penman-Monteith method. This is evidance due to the fact that both the methods use the same set of data and is based on similar principle. These values of r^2 indicate the estimates of Modified Penman, Hargreaves-Samani and FAO Radiation are significantly correlated with ET_r estimates of Penman-Monteith method. Hence on the basis of regression analysis all the three methods can be used in lieu of Penman-Monteith method. However user needs to decide to select the appropriate method out of these three on the basis of data availability.

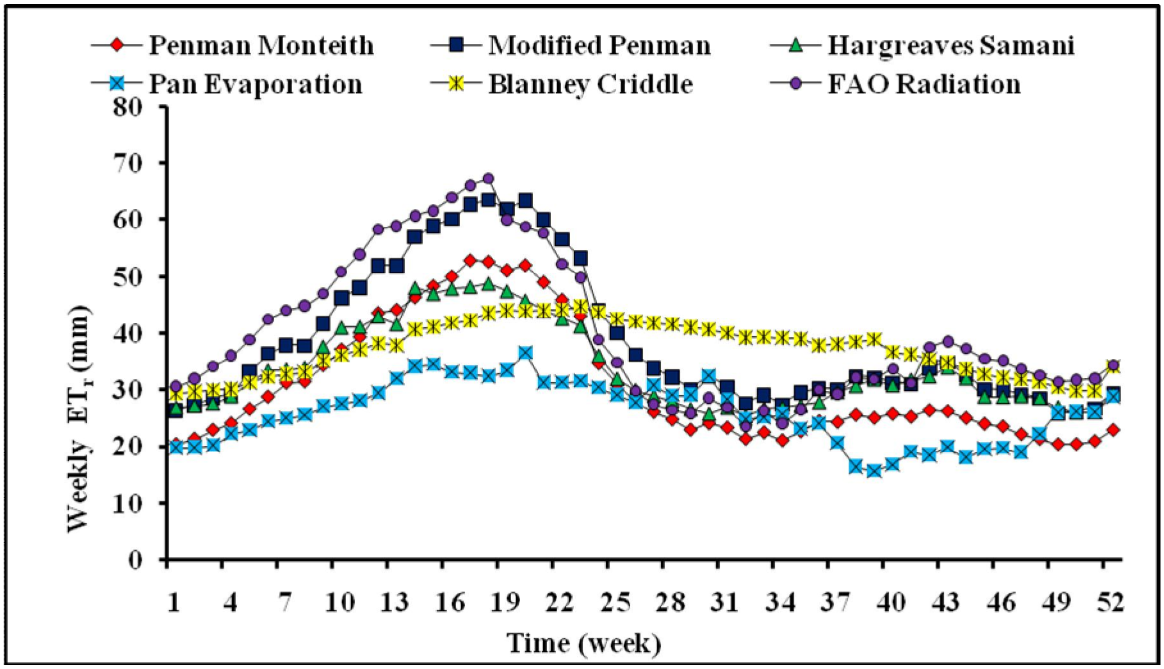

Fig. 4.20 Average weekly reference crop evepotranspiration for Nasik district. (1986-2007)

4.3.4.2 Root mean square error (RMSE)

The root mean square error between the daily ET_r estimates of Penman-Monteith method and other methods were compared for each year. The RMSE value for each year and average yearly values are presented in Table 4.5. The table shows that the lowest value of RMSE i.e. 1.05 mm/day is obtained for Hargraves-Samani, followed by 1.07 mm/day for Modified Penman, 1.52 mm/day for Radiation method, 1.64 mm/day for Blanney-Criddle, and 2.03 mm/day for Pan Evaporation methods. Thus on the basis of RMSE Hargraves Samani method is recommended for use in leiu of P-M method for Nasik district.

The high correlation of ET_r by the Hargraves-Samani method with Penman-Monteith method clearly reflects the importance of the incident solar radiation as they are calculated by using the temperature and solar radiation. This fact is also supported by many studies which reveal that the Hargreaves-Samani method is nearly as accurate as the Penman-Monteith method for estimating ET_r. Therefore, it is recommended to use the Hargraves-Samani method in the case of other reliable data is not available or only temperature data is available.

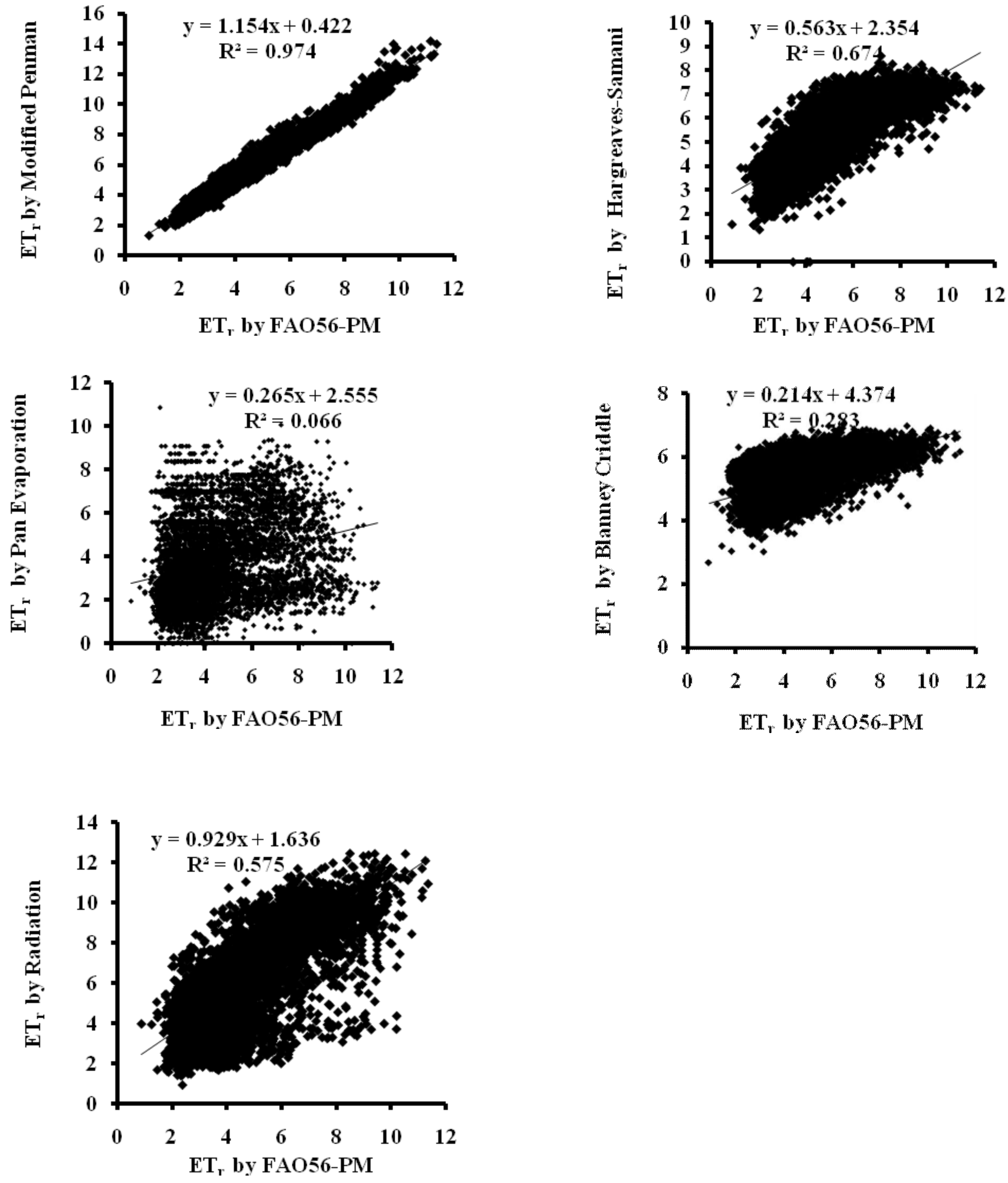

Fig. 4.21 Regression analysis of ET_r (mm/day) estimates between Penman-Monteith method and Modified Penman, Hargreaves-Samani, Pan Evaporation, Blanney-Criddle and FAO Radiation methods for Nasik district

On the basis of regression analysis, Modified Penman method is the best for all the dirticts. Hargraves Samani is the best for Solapur and Nasik districts and Modified Penman is best for Ahmednagar and Pune districts on the basis of root mean square error (RMSE).

Table 4.5 Root mean square error (RMSE) between ET_r estimates Penman-Monteith method and other methods for Nasik district (1986-2007)

Years	Root mean Square error (mm/day)				
	MP	HAR	EPan	BLC	RAD
1986	1.29	1.28	3.51	1.78	1.23
1987	1.29	1.18	3.25	1.69	1.35
1988	1.14	1.08	1.80	1.30	1.16
1989	1.23	1.08	3.11	1.68	1.48
1990	1.24	1.14	2.43	1.79	1.30
1991	1.16	1.03	2.96	1.72	1.15
1992	1.50	1.10	2.38	1.78	1.66
1993	1.72	1.34	3.74	2.03	2.00
1994	1.08	1.00	2.54	1.73	1.35
1995	1.18	1.10	2.22	1.68	1.53
1996	0.95	1.07	1.06	1.88	1.55
1997	1.17	0.94	3.29	1.63	1.53
1998	0.97	1.03	2.23	1.64	1.36
1999	0.91	1.36	0.85	2.01	1.78
2000	1.04	1.27	2.49	1.88	1.66
2001	1.09	1.24	1.75	1.91	1.72
2002	1.39	1.29	1.73	1.93	2.56
2003	1.35	1.13	2.57	2.02	2.48
2004	0.92	1.16	1.08	2.02	1.82
2005	1.18	1.00	1.84	1.69	2.19
2006	1.00	1.21	1.05	2.09	1.89
2007	0.94	1.22	0.71	1.47	1.61
Total	25.75	25.25	48.60	39.36	36.37
Average	1.07	1.05	2.03	1.64	1.52

4.3.5 Estimation of Actual Evapotranspiration of Pomegranate (ET_c)

In this study, ET_r values were estimated by six methods viz., Penman-Monteith, modified Penman, Hargreaves-Samani, Blanney-Criddle, Radiation and FAO Pan Evaporation methods. These values are presented and discussed in previous sections. This section deals with the estimation of pomegranate evapotranspiration (ET_c) for 1st, 2nd, 3rd, 4th and 5th year's pomegranate tree. The values of pomegranate crop evapotranspiration were estimated from reference crop evapotranspiration and crop coefficient values. Out of the six methods of estimation of ET_r that were considered for the reference crop evapotranspiration, the Penman-Monteith method which is considered as the most accurate and proposed by FAO, Irrigation and Drainage Paper -56 (Allen *et al.*, 1998) for use was considered for the pomegranate evapotranspiration. The crop coefficient values shown in Appendix-B (Table B-2) and reference evapotranspiration values estimated by Penman-Monteith method shown in Appendix-D (Table D-1 to D-4) were used for ET_c estimation. These values are in depth unit (mm). However the results are presented in litres/day/tree, since most of the growers use drip irrigation system which have drippers calibrated in litres/hour and operate at a level of 90 % irrigation efficiency. The tree to tree spacing and row to row spacing were considered as 3.0 and 4.5 m, respectively. The amount of water to be applied to the pomegranate tree of 1st, 2nd, 3rd, 4th and 5th year in litres/day/tree for Solapur, Ahmednagar, Pune and Nasik districts were calculated and discussed below in this section.

4.3.5.1 Solapur district

The daily values of evapotranspiration of pomegranate (ET_c) were estimated with the help of ET_r and k_c values developed through shaded area at solar noon hour for 1st, 2nd, 3rd, 4th and 5th year's pomegranate trees. The weekly estimated values of water to be applied to pomegranate were computed from ET_c, area occupied by tree (3.0 x 4.5 m^2), values of area factor and irrigation efficiency; and are presented in Table 4.6. The initial values of water use are 2.07, 4.29, 3.27, 4.55 and 5.62 litres/day/tree for 1st, 2nd, 3rd, 4th and 5th year's pomegranate tree. It gradually increases during different phenological development stages of pomegranate (i.e new leaf initiation, crop development, crop maturity, harvesting and rest period of the tree). The seasonal values of water to be applied to pomegranate tree are 175.61, 401.79, 1104.89, 1551.19 and 2008.19 litres/year for 1st, 2nd, 3rd, 4th and 5th year pomegranate tree. Pomegranate evapotranspiration values varies from 2.01 to 5.79, 4.29 to 10.85, 3.27 to 32.07, 4.55 to 45.61 and 5.62 to 62.14 litres/day/tree due to the variation of reference crop evapotranspiration, crop coefficient and area factor values for 1st, 2nd, 3rd, 4th and 5th year.

4.3.5.2 Ahmednagar district

The daily values of evapotranspiration of pomegranate (ET_c) were estimated with the help of ET_r and k_c values developed through shaded area at solar noon hour for 1st, 2nd, 3rd, 4th and 5th year's pomegranate trees. The weekly estimated values of water to be applied to pomegranate were computed from ET_c, area occupied by tree (3.0 x 4.5 m^2), values of area factor and irrigation efficiency; and are presented in Table 4.7. The initial values of water use are 2.02, 4.19, 3.20, 4.44 and 5.49 litres/day/tree for 1st, 2nd, 3rd, 4th and 5th year's pomegranate tree. It gradually increases during different phenological development stages of pomegranate (i.e new leaf initiation, crop development, crop maturity, harvesting and rest period of the tree). The seasonal values of water to be applied to pomegranate tree are 164.61, 374.02, 1024.89, 1439.78 and 1867.35 litres/year for 1st, 2nd, 3rd, 4th and 5th year pomegranate tree.

Table 4.6 Water use (litres/day/tree) of pomegranate tree of 1st to 5th year for Solapur district

MW	Av.ET_r (mm/week)	ET_c (litres /day/trees)				
		1	2	3	4	5
31	30.0	2.07	4.29	3.27	4.55	5.62
32	28.7	2.01	4.41	4.06	6.13	8.24
33	29.1	2.07	4.76	5.20	7.98	10.86
34	29.2	2.13	5.04	6.76	10.32	14.00
35	31.0	2.31	5.69	8.70	12.94	17.53
36	30.3	2.32	5.96	10.37	14.89	19.61
37	30.5	2.37	6.32	12.56	17.67	23.17
38	29.2	2.34	6.42	14.04	19.43	25.04
39	28.2	2.29	6.53	15.34	21.40	26.93
40	28.2	2.33	6.83	17.39	23.69	29.83
41	28.2	2.38	7.24	19.12	26.24	31.99
42	29.0	2.48	7.82	21.44	29.36	35.38
43	29.2	2.54	8.38	23.27	31.89	38.33
44	28.1	2.48	8.54	24.22	32.49	40.00
45	28.1	2.51	8.93	25.68	34.27	42.22
46	27.5	2.50	8.81	25.20	33.78	41.57
47	25.9	2.38	8.34	23.71	31.77	39.12
48	25.7	2.39	8.34	23.64	31.58	38.92
49	25.0	2.36	8.04	23.00	30.71	37.89
50	24.4	2.30	7.85	22.61	29.97	37.01
51	24.8	2.36	7.96	22.93	30.41	37.58
52	27.5	2.32	7.72	22.25	29.50	36.49
1	25.2	2.47	7.78	22.27	30.23	36.99
2	25.4	2.52	7.52	21.36	29.59	36.46
3	26.6	2.67	7.46	21.44	29.93	36.96
4	28.5	2.91	7.69	21.97	31.08	38.45
5	30.1	3.13	7.73	22.21	31.97	39.91
6	31.8	3.36	7.76	22.65	32.75	40.94
7	33.0	3.54	7.69	22.62	32.92	41.14
8	36.1	3.94	7.90	23.53	34.84	44.13
9	38.8	4.28	7.97	24.58	36.13	45.84
10	39.3	4.40	7.57	23.90	35.34	44.93
11	40.5	4.61	7.45	23.98	34.75	44.82
12	42.7	4.18	7.63	24.18	35.26	45.20
13	44.6	4.39	8.03	24.63	35.13	47.36
14	45.3	4.47	8.21	25.08	35.87	48.37
15	47.1	4.67	8.58	26.23	37.41	50.23
16	50.2	5.01	9.30	28.11	40.05	53.61
17	51.0	5.11	9.60	28.69	40.84	54.62
18	52.8	5.32	10.04	29.84	42.49	56.76
19	54.4	5.55	10.41	30.91	43.96	60.07
20	56.0	5.79	10.85	32.07	45.61	62.14
21	53.7	5.60	10.52	30.97	44.27	59.83
22	51.5	5.42	10.26	29.93	43.01	57.79
23	45.1	4.78	9.14	26.40	37.69	50.87
24	38.9	4.17	8.01	22.93	32.39	44.27
25	37.5	4.05	7.81	22.32	31.32	42.78
26	34.1	3.73	7.23	20.50	28.68	39.17
27	34.2	3.81	7.30	20.67	28.82	39.58
28	31.9	3.60	6.90	19.37	27.03	37.24
29	30.3	3.48	6.68	18.61	25.80	35.61
30	29.3	3.41	6.53	18.17	25.08	34.78

Table 4.7 Water use (litres/day/tree) of pomegranate tree of 1st to 5th year for Ahmednagar district

MW	Av. ET_r (mm/week)	ET_c (litres /day/trees)				
		1	2	3	4	5
31	29.3	2.02	4.19	3.20	4.44	5.49
32	28.5	2.00	4.38	4.03	6.09	8.18
33	29.7	2.12	4.86	5.31	8.15	11.09
34	29.8	2.17	5.15	6.90	10.54	14.29
35	28.5	2.13	5.24	8.01	11.91	16.13
36	30.2	2.30	5.92	10.31	14.81	19.50
37	29.3	2.28	6.07	12.07	16.97	22.26
38	28.6	2.28	6.27	13.71	18.98	24.46
39	27.2	2.21	6.30	14.81	20.66	26.00
40	27.8	2.29	6.73	17.13	23.34	29.39
41	28.7	2.42	7.37	19.48	26.72	32.58
42	28.0	2.40	7.56	20.72	28.37	34.20
43	27.0	2.35	7.75	21.54	29.51	35.47
44	25.9	2.29	7.87	22.33	29.96	36.89
45	24.7	2.21	7.86	22.62	30.19	37.19
46	23.6	2.14	7.54	21.58	28.92	35.58
47	22.4	2.06	7.21	20.50	27.47	33.83
48	22.0	2.04	7.12	20.18	26.96	33.23
49	21.5	2.03	6.91	19.77	26.39	32.56
50	21.0	1.98	6.75	19.45	25.79	31.85
51	20.6	1.97	6.62	19.07	25.28	31.25
52	23.3	1.96	6.56	18.88	25.03	30.96
1	21.1	2.06	6.51	18.63	25.28	30.93
2	21.9	2.17	6.48	18.41	25.50	31.41
3	23.3	2.34	6.53	18.77	26.20	32.35
4	24.7	2.52	6.66	19.03	26.93	33.31
5	26.1	2.71	6.68	19.20	27.63	34.50
6	27.9	2.94	6.79	19.82	28.65	35.81
7	29.6	3.17	6.89	20.28	29.51	36.88
8	31.4	3.42	6.86	20.45	30.28	38.35
9	34.9	3.86	7.18	22.13	32.53	41.28
10	35.2	3.94	6.78	21.40	31.66	40.25
11	36.7	4.18	6.75	21.73	31.50	40.63
12	39.3	3.85	7.02	22.25	32.45	41.60
13	41.4	4.07	7.45	22.86	32.61	43.96
14	42.2	4.17	7.64	23.35	33.40	45.04
15	44.5	4.42	8.12	24.82	35.40	47.53
16	47.8	4.77	8.86	26.78	38.15	51.07
17	50.0	5.01	9.42	28.14	40.06	53.57
18	52.9	5.32	10.05	29.86	42.53	56.81
19	50.8	5.18	9.72	28.88	41.07	56.12
20	53.6	5.54	10.38	30.68	43.63	59.45
21	52.9	5.51	10.36	30.50	43.60	58.92
22	49.8	5.25	9.94	28.97	41.64	55.95
23	44.2	4.69	8.97	25.89	36.96	49.89
24	37.6	4.02	7.73	22.12	31.24	42.69
25	36.1	3.90	7.53	21.52	30.19	41.24
26	34.8	3.80	7.38	20.92	29.27	39.98
27	33.0	3.68	7.05	19.96	27.82	38.20
28	31.3	3.53	6.77	18.99	26.50	36.51
29	30.5	3.50	6.71	18.69	25.92	35.78
30	29.4	3.43	6.56	18.24	25.19	34.93

Pomegranate evapotranspiration values varies from 1.96 to 5.54, 4.19 to 10.38, 3.20 to 30.68, 4.44 to 43.63 and 5.49 to 59.45 litres/day/tree for 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} year's due to the variation of reference crop evapotranspiration, crop coefficient and area factor values.

4.3.5.3 Pune district

The daily values of evapotranspiration of pomegranate (ET_c) were estimated with the help of ET_r and k_c values developed through shaded area at solar noon hour for 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} year's pomegranate trees. The weekly estimated values of water to be applied to pomegranate were computed from ET_c, area occupied by tree (3.0 x 4.5 m^2), values of area factor and irrigation efficiency; and are presented in Table 4.8. The initial values of water use are 1.50, 3.10, 2.37, 3.29 and 4.06 litres/day/tree for 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} year's pomegranate tree. It gradually increases during different phenological development stages of pomegranate (i.e new leaf initiation, crop development, crop maturity, harvesting and rest period of the tree). The seasonal values of water to be applied to pomegranate tree are 139.35, 316.78, 874.98, 1229.28 and 1592.57 litres/year for 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} year pomegranate tree. Pomegranate evapotranspiration values varies from 1.39 to 4.78, 3.04 to 8.96, 2.37 to 26.47, 3.29 to 37.65 and 4.06 to 51.30 litres/day/tree for 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} year due to the variation of reference crop evapotranspiration, crop coefficient and area factor values.

4.3.5.4 Nasik district

The daily values of evapotranspiration of pomegranate (ET_c) were estimated with the help of ET_r and k_c values developed through shaded area at solar noon hour for 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} year's pomegranate trees. The weekly estimated values of water to be applied to pomegranate were computed from ET_c, area occupied by tree (3.0 x 4.5 m^2), values of area factor and irrigation efficiency; and are presented in Table 4.9. The initial values of water use are 1.61, 3.34, 2.55, 3.54 and 4.38 litres/day/tree for 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} year's pomegranate tree. It gradually increases during different phenological development stages of pomegranate (i.e new leaf initiation, crop development, crop maturity, harvesting and rest period of the tree). The seasonal values of water to be applied to pomegranate tree are 156.67, 355.26, 985.46, 1384.85 and 1793.82 litres/year for 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} year pomegranate tree. Pomegranate evapotranspiration values varies from 1.49 to 5.37, 3.28 to 10.07, 2.55 to 29.75, 3.54 to 42.30 and 4.38 to 57.65 litres/day/tree for 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} year due to the variation of reference crop evapotranspiration, crop coefficient and area factor values.

Table 4.8 Water use (litres/day/tree) of pomegranate tree of 1st to 5th year for Pune district

MW	$Av.ET_r$ (mm/week)	ET_c (litres /day/trees)				
		1	2	3	4	5
31	21.7	1.50	3.10	2.37	3.29	4.06
32	19.8	1.39	3.04	2.80	4.23	5.68
33	21.4	1.52	3.50	3.82	5.87	7.98
34	21.0	1.53	3.62	4.85	7.42	10.06
35	21.7	1.62	4.00	6.11	9.09	12.31
36	24.3	1.85	4.77	8.30	11.92	15.69
37	24.2	1.88	5.01	9.95	13.99	18.36
38	24.3	1.94	5.33	11.66	16.14	20.80
39	23.0	1.87	5.32	12.51	17.45	21.96
40	22.6	1.87	5.49	13.97	19.03	23.97
41	22.7	1.92	5.84	15.42	21.15	25.79
42	23.2	1.99	6.25	17.14	23.48	28.30
43	23.2	2.02	6.67	18.53	25.39	30.52
44	22.4	1.98	6.82	19.35	25.96	31.97
45	21.8	1.95	6.92	19.92	26.59	32.75
46	20.5	1.86	6.55	18.75	25.13	30.92
47	19.7	1.81	6.35	18.07	24.22	29.82
48	18.8	1.75	6.10	17.30	23.12	28.49
49	18.6	1.75	5.99	17.12	22.86	28.20
50	18.5	1.74	5.93	17.09	22.66	27.98
51	18.8	1.80	6.06	17.44	23.13	28.58
52	20.8	1.75	5.84	16.83	22.31	27.60
1	18.1	1.77	5.59	15.98	21.69	26.54
2	19.1	1.89	5.65	16.06	22.24	27.40
3	20.5	2.05	5.74	16.49	23.02	28.42
4	21.7	2.22	5.87	16.77	23.73	29.35
5	22.3	2.32	5.72	16.45	23.67	29.55
6	24.7	2.61	6.03	17.60	25.45	31.81
7	27.1	2.90	6.31	18.57	27.03	33.78
8	28.5	3.10	6.22	18.54	27.45	34.77
9	29.8	3.29	6.13	18.91	27.78	35.26
10	31.7	3.55	6.12	19.30	28.55	36.29
11	34.0	3.87	6.25	20.13	29.17	37.63
12	36.5	3.57	6.51	20.64	30.10	38.58
13	38.0	3.73	6.83	20.96	29.89	40.30
14	40.0	3.95	7.24	22.12	31.64	42.67
15	41.1	4.08	7.50	22.90	32.67	43.86
16	42.0	4.19	7.78	23.53	33.51	44.86
17	44.5	4.46	8.39	25.05	35.66	47.69
18	46.0	4.63	8.75	26.00	37.02	49.46
19	46.1	4.71	8.83	26.24	37.31	50.99
20	46.2	4.78	8.96	26.47	37.65	51.30
21	44.4	4.63	8.70	25.61	36.62	49.49
22	40.3	4.25	8.04	23.44	33.68	45.26
23	38.6	4.09	7.82	22.57	32.22	43.49
24	29.4	3.15	6.06	17.34	24.48	33.46
25	27.7	2.99	5.77	16.49	23.13	31.60
26	24.1	2.63	5.11	14.49	20.27	27.69
27	24.6	2.74	5.26	14.88	20.74	28.48
28	24.6	2.78	5.32	14.94	20.84	28.72
29	22.2	2.55	4.89	13.64	18.92	26.11
30	21.9	2.55	4.88	13.57	18.74	25.98

Table 4.9 Water use (litres/day/tree) of pomegranate tree of 1st to 5th year for Nasik district

MW	Av.ET_r (mm/week)	ET_c (litres /day/tree)				
		1	2	3	4	5
31	23.3	1.61	3.34	2.55	3.54	4.38
32	21.3	1.49	3.28	3.01	4.56	6.12
33	22.5	1.61	3.69	4.02	6.18	8.41
34	21.1	1.54	3.64	4.88	7.46	10.11
35	22.7	1.69	4.17	6.37	9.47	12.84
36	24.5	1.87	4.81	8.37	12.03	15.84
37	24.3	1.89	5.04	10.01	14.08	18.46
38	25.6	2.05	5.62	12.29	17.01	21.93
39	25.1	2.04	5.81	13.66	19.05	23.98
40	25.8	2.13	6.25	15.92	21.68	27.31
41	25.3	2.13	6.50	17.16	23.54	28.71
42	26.4	2.26	7.13	19.54	26.77	32.26
43	26.3	2.29	7.54	20.95	28.70	34.49
44	25.1	2.22	7.62	21.61	28.99	35.70
45	24.0	2.15	7.64	21.99	29.35	36.16
46	23.6	2.14	7.54	21.57	28.91	35.57
47	22.2	2.04	7.14	20.31	27.20	33.50
48	21.3	1.98	6.91	19.59	26.17	32.26
49	20.4	1.92	6.55	18.74	25.02	30.87
50	20.4	1.93	6.56	18.90	25.06	30.94
51	20.9	2.00	6.73	19.39	25.71	31.77
52	22.9	1.93	6.45	18.57	24.63	30.46
1	20.4	2.00	6.30	18.02	24.47	29.93
2	21.4	2.12	6.32	17.96	24.87	30.65
3	22.9	2.30	6.44	18.49	25.81	31.86
4	24.1	2.46	6.51	18.61	26.32	32.56
5	26.6	2.77	6.83	19.64	28.27	35.29
6	28.8	3.04	7.02	20.50	29.64	37.05
7	31.0	3.32	7.22	21.24	30.91	38.63
8	31.5	3.43	6.88	20.51	30.36	38.46
9	34.3	3.80	7.07	21.79	32.02	40.63
10	37.1	4.15	7.16	22.59	33.41	42.48
11	39.3	4.47	7.23	23.27	33.73	43.51
12	43.6	4.26	7.77	24.65	35.94	46.08
13	44.1	4.34	7.93	24.35	34.73	46.82
14	46.3	4.57	8.39	25.63	36.66	49.44
15	48.3	4.79	8.81	26.93	38.42	51.58
16	50.0	4.99	9.27	28.02	39.91	53.43
17	52.8	5.30	9.95	29.72	42.31	56.58
18	52.6	5.30	9.99	29.71	42.30	56.51
19	51.1	5.21	9.77	29.03	41.27	56.40
20	52.0	5.37	10.07	29.75	42.31	57.65
21	49.0	5.11	9.61	28.27	40.42	54.63
22	45.9	4.84	9.15	26.68	38.34	51.52
23	43.1	4.57	8.73	25.21	35.98	48.58
24	34.7	3.72	7.14	20.43	28.85	39.43
25	30.9	3.34	6.44	18.42	25.84	35.29
26	27.9	3.04	5.90	16.75	23.43	32.00
27	26.1	2.91	5.58	15.80	22.02	30.24
28	24.8	2.80	5.36	15.05	21.00	28.94
29	23.0	2.63	5.05	14.09	19.54	26.96
30	24.1	2.81	5.38	14.96	20.65	28.64

4.4 PROBABILITY DISTRIBUTION FUNCTION FOR ET_r

One of the objectives of this study was to find out the evapotranspiration of pomegranate at the desired probability levels. These values are required for irrigation planning. However this needs first to investigate the appropriate probability distribution functions for ET_r values.

In present study as stated in section 3.6 commonly used probability distribution functions viz. Normal (Gaussian), Log Normal (Log Gaussian), Gamma, Gumbel and Weibull were evaluated for their suitability in fitting the weekly ET_r values. These probability distribution functions are described in chapter III. Chi-square test ($\chi_{cal}{}^2$) was used for testing the goodness of fit of the observed data to the theoretical distribution. The chi-square test was applied for goodness of fit at 5 per cent significance level to the weekly reference crop evapotranspiration (ET_r). The distribution that gives the lowest Chi-square value was selected as the best distribution.

The probability distribution functions were fitted to weekly ET_r values estimated by Penman-Monteith method only; as the method is considered to be the most accurate and all the climatological parameters required to estimates ET_r by this method were available for all the four districts.

4.4.1 Solapur District

The weekly ETr values were estimated by Penman-Monteith method for the years from 1984 to 2007 and above stated five probability distribution functions were fitted to the weekly ET_r data. The results of the fitting of these probability distribution functions to weekly ET_r values as estimated by Penman-Monteith method are given in Table 4.10. It is observed from the Table 4.10, that none of the probability distribution fit to all weeks. All the probability distributions under consideration fit to week no.1, 8, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 28, 30, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 45, 47, 48, 49, 50, 51 and 52. None of the probability distribution fit to week no.3. The number of weeks for which different probability distribution functions fit to weekly ETr data are given in Table 4.11. It is observed from the Table 4.11 that Gamma distribution function fits to maximum number of weeks (total weeks 50); followed by log normal distribution (total weeks 49), normal distribution (total week 48), Gumbel distribution (total week 46) and Weibulls distribution (total week 45)

As more than one distribution fits to many weeks, the best distribution for such week was considered as the distribution that gives the lowest values of chi-square at 5 per cent level of significance.

Table 4.10 Fitting of different probability distributions to weekly values of ET_r obtained by using Penman-Monteith method for Solapur district

MW	Probability Distributions					MW	Probability Distributions				
	Normal	**Log Normal**	**Gamma**	**Gumbel**	**Weibulls**		**Normal**	**Log Normal**	**Gamma**	**Gumbel**	**Weibulls**
1	Yes	Yes	Yes	Yes	Yes	27	Yes	Yes	Yes	Yes	No
2	Yes	Yes	Yes	No	Yes	28	Yes	Yes	Yes	Yes	Yes
3	No	No	No	No	No	29	No	No	Yes	Yes	Yes
4	Yes	Yes	Yes	Yes	No	30	Yes	Yes	Yes	Yes	Yes
5	Yes	Yes	Yes	Yes	No	31	No	Yes	Yes	Yes	No
6	Yes	Yes	Yes	Yes	No	32	Yes	Yes	Yes	Yes	Yes
7	Yes	No	Yes	No	Yes	33	Yes	Yes	Yes	Yes	Yes
8	Yes	Yes	Yes	Yes	Yes	34	Yes	Yes	Yes	Yes	Yes
9	Yes	Yes	Yes	No	Yes	35	Yes	Yes	Yes	Yes	Yes
10	Yes	Yes	Yes	Yes	Yes	36	Yes	Yes	Yes	Yes	Yes
11	Yes	Yes	Yes	Yes	Yes	37	Yes	Yes	Yes	Yes	Yes
12	Yes	Yes	Yes	Yes	Yes	38	Yes	Yes	Yes	Yes	Yes
13	Yes	Yes	Yes	Yes	Yes	39	Yes	Yes	Yes	Yes	Yes
14	Yes	Yes	Yes	Yes	Yes	40	Yes	Yes	Yes	Yes	Yes
15	Yes	Yes	Yes	Yes	Yes	41	Yes	Yes	Yes	Yes	Yes
16	Yes	Yes	Yes	Yes	Yes	42	Yes	Yes	Yes	Yes	Yes
17	Yes	Yes	Yes	Yes	Yes	43	Yes	Yes	Yes	Yes	Yes
18	Yes	Yes	Yes	Yes	Yes	44	Yes	Yes	Yes	Yes	No
19	Yes	Yes	Yes	Yes	Yes	45	Yes	Yes	Yes	Yes	Yes
20	Yes	Yes	Yes	Yes	Yes	46	No	Yes	No	No	Yes
21	Yes	Yes	Yes	Yes	Yes	47	Yes	Yes	Yes	Yes	Yes
22	Yes	Yes	Yes	Yes	Yes	48	Yes	Yes	Yes	Yes	Yes
23	Yes	Yes	Yes	Yes	Yes	49	Yes	Yes	Yes	Yes	Yes
24	Yes	Yes	Yes	Yes	Yes	50	Yes	Yes	Yes	Yes	Yes
25	Yes	Yes	Yes	Yes	Yes	51	Yes	Yes	Yes	Yes	Yes
26	Yes	Yes	Yes	Yes	Yes	52	Yes	Yes	Yes	Yes	Yes

Table 4.11 Number of weeks under various probability distribution functions fitting to weekly values of ET_r obtained by using Penmen-Monteith method for Solapur district

Types of distributions	Week numbers	Total numbers
Normal	1,2,4,5,6,7,8,9,10,11,12,13,14,15,16,17, 18,19,20,21,22,23,24,25,26,27,28,30, 32,33,34,35,36,37,38,39,40,41,42,43,44, 45,47,48,49,50,51,52	48
Log Normal	1,2,4,5,6,8,9,10,11,12,13,14,15,16,17, 18,19,20,21,22,23,24,25,26,27,28,30,31 32,33,34,35,36,37,38,39,40,41,42,43, 44,45,46,47,48,49,50,51,52	49
Gamma	1,2,4,5,6,7,8,9,10,11,12,13,14,15,16,17, 18,19,20,21,22,23,24,25,26,27,28,30,31 32,33,34,35,36,37,38,39,40,41,42,43, 44,45,47,48,49,50,51,52	50
Gumbel	1,4,6,8,10,11,12,13,14,15,16,17, 18,19,20,21,22,23,24,25,26,27,28,29,30, 31,32,33,34,35,36,37,38,39,40,41,42,43, 44,45,47,48,49,50,51,52	46
Weibull	1,2,7,8,9,10,11,12,13,14,15,16,17, 18,19,20,21,22,23,24,25,26,28,29,30, 32,33,34,35,36,37,38,39,40,41,42,43, 45,46,47,48,49,50,51,52	45

The values of the chi-square at 5 per cent for different distributions for the weeks to which these distributions fit are presented in Table 4.12. Table also gives the best fit distribution on the basis of the lowest value. In case more than one distribution yields the lowest value of Chi-square, all these distributions are considered as the best fit distributions. It is seen from the table that Normal distribution is the best fit for maximum weeks (25), followed by Log Normal (11), Gumbel (9), Gamma (4) and Weibull's (2).

Table 4.12 Chi square values for the different probability distributions which fitted to weekly ET_r obtained by using Penman-Monteith method for Solapur district

MW	Chi-square value for probability distributions						MW	Chi-square value for probability distributions					
	Normal	Log Normal	Gamma	Gumbel	Weibulls	Best fit		Normal	Log Nor	Gamma	Gumbel	Weibulls	Best fit
1	2.00	1.00	1.00	3.66	3.66	LN,Ga	27	0.33	1.0	0.33	1.0	----	N,Ga
2	6.33	2.33	4.00	----	6.33	LN	28	3.0	3.0	6.33	5.0	5.0	N,LN
3	----	-----	----	----	----	---	29	----	----	7.33	3.66	----	Gu
4	0.33	1.00	1.33	1.00	----	N	30	1.66	1.0	0.66	1.66	1.66	Ga
5	0.33	1.33	1.33	0.00	----	N	31	----	6.66	6.66	2.33	---	Gu
6	1.33	1.00	0.66	1.00	----	Ga	32	1.66	3.0	1.66	1.0	3.66	Gu
7	6.00	14.33	----	3.0	5.00	Gu	33	1.0	1.33	1.0	2.33	2.0	N,Ga
8	3.66	3.66	3.66	3.33	4.33	Gu	34	2.33	2.33	2.33	1.33	2.33	Gu
9	3.0	4.33	4.33	----	6.0	N	35	1.33	0.33	0.33	0.33	0.33	LN,Ga,Gu,W
10	1.0	1.0	1.0	0.66	0.33	N,LN,Ga	36	1.33	1.66	0.33	1.0	2.33	Ga
11	0.0	0.33	0.33	0.33	0.0	N	37	1.0	1.0	1.0	1.0	1.0	ALL
12	1.0	1.66	1.0	1.0	1.66	N,Ga,Gu	38	1.66	3.33	3.33	0.66	1.66	Gu
13	1.0	1.33	1.33	3.66	0.33	W	39	0.33	0.33	1.0	1.66	1.0	N,LN
14	1.0	2.0	1.0	1.66	1.66	N,Ga	40	1.0	1.0	1.66	1.0	0.66	N,LN,Gu
15	1.0	1.0	1.0	2.33	1.0	N,LN,Ga,W	41	2.33	1.0	1.0	5.0	1.0	LN,Ga,W
16	2.33	3.0	2.33	1.66	3.33	Gu	42	2.33	2.33	2.33	1.33	2.33	Gu
17	1.33	1.33	1.33	1.33	2.33	N,LN,Ga,W	43	2.0	2.0	2.0	5.66	0.66	N,LN,Ga
18	1.66	0.33	1.0	0.66	1.0	LN	44	1.0	0.33	1.33	6.66	---	LN
19	0.33	0.33	0.33	2.33	0.33	N,LN,Ga,W	45	2.0	1.0	1.0	2.33	2.0	LN,Ga
20	0.33	0.66	1.66	3.66	4.33	N	46	----	5.66	8.0	----	5.33	W
21	2.0	0.66	1.0	3.33	2.0	LN	47	0.33	0.33	0.33	1.33	0.33	N,LN,Ga,W
22	1.0	0.33	1.0	2.0	2.0	LN	48	0.33	0.33	0.33	1.66	0.33	N,LN,Ga,W
23	1.66	3.66	2.0	4.33	2.33	N	49	0.33	1.0	1.0	6.66	1.0	N
24	1.0	1.0	1.0	1.33	1.66	N,LN,Ga	50	2.33	1.33	1.33	3.0	2.33	LN,Ga
25	1.0	0.33	0.33	1.33	1.33	LN,Ga	51	4.33	4.33	7.66	6.33	4.33	N,LN,W
26	0.33	0.33	0.33	0.33	0.33	ALL	52	1.66	1.66	0.66	1.0	1.33	Gu
Tabulated value of Chi-square =7.815 at d.f. 3													

4.4.2 Ahmednagar District

The weekly ETr values were estimated by Penman-Monteith method for the years from 1976 to 2007 and above stated five probability distribution functions were fitted to the weekly ET_r data. The results of the fitting of these pdfs to weekly ET_r values as estimated by Penman-Monteith method are given in Table 4.13. It is observed from the Table 4.13, that none of the probability distribution fit to all weeks. All the probability distributions under consideration fit to week no. 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 19, 20, 21, 22, 23, 24, 26, 27, 30, 31, 32, 34, 35, 36, 37, 38, 39, 40, 41, 43, 45, 46, 47, 48, 49 and 52. The number of weeks for which different probability distribution functions fit to weekly ET_r data are given in Table 4.14. It is observed from the Table 4.14, that Gamma distribution functions fits to maximum number of weeks (total weeks 50); followed by normal distribution, Log Normal and Weibulls (total week 49) and Gumbel distribution (total week 45).

As more than one distribution fits too many weeks, the best distribution for such week was considered as the distribution that gives the lowest values of chi-square at 5 per cent level of significance.

The values of the chi-square at 5 per cent for different distributions for the weeks to which these distributions fit are presented in Table 4.15. Table also gives the best fit distribution on the basis of the lowest value. In case more than one distribution yields the lowest value of Chi-square, all these distributions are considered as the best fit distributions. It is seen from the table that Log normal distribution is the best fit for maximum weeks (11), followed by Normal (9), Gumbel (9), Weibull’s (8) and Gamma (6).

4.4.3 Pune District

The weekly ET_r values were estimated by Penman-Monteith method for the years from 1987 to 2006 and above stated five probability distribution functions were fitted to the weekly ET_r data. The results of the fitting of these probability distribution functions to weekly ET_r values as estimated by Penman-Monteith method are given in Table 4.16. It is observed from the Table 4.16, that none of the probability distribution fit to all weeks. All the probability distributions under consideration fit to week no. 1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 15, 16, 17, 18, 19, 21, 22, 23, 24, 26, 27, 29, 30, 31, 32, 33, 34, 35, 36, 37, 39, 40, 41, 42, 43, 44, 45, 46, 47, 50, 51 and 52. The number of weeks for which different probability distribution functions fit to weekly ET_r data are given in Table 4.17. It is observed from the Table 4.17, that Log Normal and Gamma distribution function fits to maximum number of weeks (total weeks 52); followed by normal distribution (Total week 51), Gumbel (Total week 50), and Weibulls (total week 44).

Table 4.13 Fitting of different probability distributions to weekly values of ET_r obtained by using Penman-Monteith method for Ahmednagar district

MW	Probability distributions					MW	Probability distributions				
	Normal	Log Normal	Gamma	Gumbel	Weibulls		Normal	Log Normal	Gamma	Gumbel	Weibulls
1	No	No	No	Yes	Yes	27	Yes	Yes	Yes	Yes	Yes
2	Yes	Yes	Yes	Yes	Yes	28	Yes	Yes	Yes	Yes	No
3	Yes	Yes	Yes	Yes	Yes	29	Yes	Yes	Yes	No	Yes
4	Yes	Yes	Yes	Yes	Yes	30	Yes	Yes	Yes	Yes	Yes
5	Yes	Yes	Yes	Yes	Yes	31	Yes	Yes	Yes	Yes	Yes
6	Yes	Yes	Yes	Yes	Yes	32	Yes	Yes	Yes	Yes	Yes
7	Yes	Yes	Yes	Yes	Yes	33	No	No	No	No	Yes
8	Yes	Yes	Yes	Yes	Yes	34	Yes	Yes	Yes	Yes	Yes
9	Yes	Yes	Yes	Yes	Yes	35	Yes	Yes	Yes	Yes	Yes
10	Yes	Yes	Yes	Yes	Yes	36	Yes	Yes	Yes	Yes	Yes
11	Yes	Yes	Yes	Yes	Yes	37	Yes	Yes	Yes	Yes	Yes
12	Yes	Yes	Yes	Yes	Yes	38	Yes	Yes	Yes	Yes	Yes
13	Yes	Yes	Yes	Yes	Yes	39	Yes	Yes	Yes	Yes	Yes
14	Yes	Yes	Yes	Yes	Yes	40	Yes	Yes	Yes	Yes	Yes
15	Yes	Yes	Yes	Yes	Yes	41	Yes	Yes	Yes	Yes	Yes
16	Yes	Yes	Yes	Yes	Yes	42	Yes	Yes	Yes	No	Yes
17	No	Yes	Yes	No	Yes	43	Yes	Yes	Yes	Yes	Yes
18	Yes	Yes	Yes	No	Yes	44	Yes	No	Yes	No	Yes
19	Yes	Yes	Yes	Yes	Yes	45	Yes	Yes	Yes	Yes	Yes
20	Yes	Yes	Yes	Yes	Yes	46	Yes	Yes	Yes	Yes	Yes
21	Yes	Yes	Yes	Yes	Yes	47	Yes	Yes	Yes	Yes	Yes
22	Yes	Yes	Yes	Yes	Yes	48	Yes	Yes	Yes	Yes	Yes
23	Yes	Yes	Yes	Yes	Yes	49	Yes	Yes	Yes	Yes	Yes
24	Yes	Yes	Yes	Yes	Yes	50	Yes	Yes	Yes	Yes	No
25	Yes	Yes	Yes	No	Yes	51	Yes	Yes	Yes	Yes	No
26	Yes	Yes	Yes	Yes	Yes	52	Yes	Yes	Yes	Yes	Yes

Table 4.14 Number of weeks under various different probability distribution functions fit to weekly values of ET_r obtained by using Penmen-Monteith method for Ahmednagar district

Types of distributions	Week numbers	Total numbers
Normal	2,3,4,5,6,7,8,9,10,11,12,13,14,15,16, 18,19,20,21,22,23,24,25,26,27,28,29, 30,31,32,34,35,36,37,38,39,40,41,42,43, 44,45,46, 47,48,49,50,51,52	49
Log Normal	2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17, 18,19,20,21,22,23,24,25,26,27,28,29, 30,31,32,34,35,36,37,38,39,40,41,42,43, 45,46, 47,48,49,50,51,52	49
Gamma	2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17, 18,19,20,21,22,23,24,25,26,27,28,29, 30,31,32,34,35,36,37,38,39,40,41,42,43, 44,45,46, 47,48,49,50,51,52	50
Gumbel	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,19,20, 21,22,23,24,26,27,28, 30,31,32, 34,35,36,37,38,39,40,41,43, 45,46, 47,48,49,50,51,52	45
Weibulls	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17, 18,19,20,21,22,23,24,25,26,27,29, 30,31, 32,33,34,35,36,37,38,39,40,41,42,43, 44,45,46, 47,48,49,52	49

As more than one distribution fits too many weeks, the best distribution for such week was considered as the distribution that gives the lowest values of chi-square at 5 per cent level of significance.

The values of the chi-square at 5 per cent for different distributions for the weeks to which these distributions fit are presented in Table 4.18. Table also gives the best fit distribution on the basis of the lowest value. In case more than one distribution yields the lowest value of Chi-square, all these distributions are considered as the best fit distributions. It is seen from the table that Normal distribution is the best fit for maximum weeks (25), followed by Log Normal (10), Gumbel (8), Weibull’s (5) and Gamma (4).

Table 4.15 Chi square values for the different probability distributions which fitted to weekly ET_r obtained by using Penman-Monteith Method for Ahmednagar district

MW	Chi-square value for probability distributions						MW	Chi-square value for probability distributions					
	Normal	Log Nor	Gamma	Gumbel	Weibull	Best fit		Normal	Log Nor	Gamma	Gumbel	Weibull	Best fit
1	----	----	----	5.87	5.12	W	27	1.75	1.00	1.00	7.37	1.75	LN,Ga
2	5.12	5.12	9.62	6.25	8.87	N,LN	28	3.62	2.5	2.5	1.37	----	Gu
3	3.25	8.5	6.62	2.12	3.12	Gu	29	4.00	2.5	2.87	----	4.00	LN
4	1.75	2.5	1.75	3.62	1.75	N,Ga,W	30	7.00	5.5	5.87	8.87	6.62	LN
5	1.75	1.37	1.37	1.37	1.37	LN,Ga,Gu,W	31	3.62	5.12	3.62	8.5	8.5	N,Ga
6	0.25	1.00	0.25	1.75	2.5	N,Ga	32	5.87	3.25	4.75	12.25	7.75	LN
7	5.5	4.75	4.75	7.37	5.5	LN,Ga	33	1.75	0.62	1.00	3.25	1.75	LN
8	2.12	1.75	1.75	3.25	1.00	W	34	----	11.5	----	13.7	7.00	W
9	1.75	3.25	3.25	1.00	1.00	Gu,W	35	1.00	0.25	0.62	9.99	0.62	LN
10	4.75	4.75	3.25	5.12	6.62	Gu	36	3.25	3.62	1.75	4.75	3.62	Ga
11	3.25	2.78	2.78	2.87	2.5	W	37	2.5	4.75	2.5	1.00	2.12	Gu
12	3.62	5.12	2.5	1.75	5.12	Gu	38	1.37	0.62	2.12	8.5	1.75	LN
13	6.25	5.5	5.87	4.37	1.37	W	39	3.62	3.62	2.5	2.87	3.62	Ga
14	6.62	6.62	6.62	5.87	3.25	W	40	0.62	2.12	2.12	4.75	1.75	N
15	1.37	2.5	1.37	9.62	2.12	N,Ga	41	2.5	3.25	2.12	4.00	1.00	Ga
16	8.12	7.32	8.87	7.00	8.12	Gu	42	3.62	3.25	6.62	----	5.5	LN
17	----	6.25	8.87	---	6.25	LN,W	43	2.87	2.87	2.87	7.75	2.12	W
18	8.87	2.12	4.37	32.8	6.62	LN	44	3.99	25.8	9.74	13.7	3.61	W
19	2.87	3.25	2.87	1.78	4.75	Gu	45	1.00	2.50	1.75	2.87	1.37	W
20	4.00	2.50	4.00	6.25	3.25	LN	46	2.12	2.5	3.25	4.37	4.37	LN
21	5.12	2.87	5.87	10.3	5.12	LN	47	7.37	7.75	10.0	1.75	7.75	Gu,W
22	1.00	2.12	2.12	4.00	4.00	N	48	2.5	2.12	2.12	7.00	----	N
23	3.25	2.5	2.5	10.7	5.12	LN,Ga	49	3.25	2.12	1.00	3.62	3.62	Ga
24	5.12	7.00	3.25	5.5	5.87	Ga	50	4.00	5.87	2.87	3.62	3.62	Ga
25	4.00	3.62	2.5	----	2.5	Ga,W	51	2.87	5.87	3.62	2.12	2.87	Gu
26	5.5	4.0	9.25	6.25	2.5	N,W	52	3.62	5.5	6.25	4.00	----	N
Tabulated value of Chi-square = 11.07 at d.f. 5													

Table 4.16 Fitting of different probability distributions to weekly values of ET_r obtained by using Penman-Monteith method for Pune district

MW	Probability distributions					MW	Probability distributions				
	Normal	Log Normal	Gamma	Gumbel	Weibulls		Normal	Log Normal	Gamma	Gumbel	Weibulls
1	Yes	Yes	Yes	Yes	Yes	27	Yes	Yes	Yes	Yes	Yes
2	Yes	Yes	Yes	Yes	Yes	28	Yes	Yes	Yes	Yes	No
3	Yes	Yes	Yes	Yes	Yes	29	Yes	Yes	Yes	Yes	Yes
4	Yes	Yes	Yes	Yes	Yes	30	Yes	Yes	Yes	Yes	Yes
5	Yes	Yes	Yes	Yes	No	31	Yes	Yes	Yes	Yes	Yes
6	Yes	Yes	Yes	Yes	Yes	32	Yes	Yes	Yes	Yes	Yes
7	Yes	Yes	Yes	Yes	Yes	33	Yes	Yes	Yes	Yes	Yes
8	Yes	Yes	Yes	Yes	Yes	34	Yes	Yes	Yes	Yes	Yes
9	Yes	Yes	Yes	Yes	Yes	35	Yes	Yes	Yes	Yes	Yes
10	Yes	Yes	Yes	Yes	Yes	36	Yes	Yes	Yes	Yes	Yes
11	Yes	Yes	Yes	Yes	Yes	37	Yes	Yes	Yes	Yes	Yes
12	Yes	Yes	Yes	Yes	Yes	38	Yes	Yes	Yes	Yes	No
13	No	Yes	Yes	No	Yes	39	Yes	Yes	Yes	Yes	Yes
14	Yes	Yes	Yes	Yes	No	40	Yes	Yes	Yes	Yes	Yes
15	Yes	Yes	Yes	Yes	Yes	41	Yes	Yes	Yes	Yes	Yes
16	Yes	Yes	Yes	Yes	Yes	42	Yes	Yes	Yes	Yes	Yes
17	Yes	Yes	Yes	Yes	Yes	43	Yes	Yes	Yes	Yes	Yes
18	Yes	Yes	Yes	Yes	Yes	44	Yes	Yes	Yes	Yes	Yes
19	Yes	Yes	Yes	Yes	Yes	45	Yes	Yes	Yes	Yes	Yes
20	Yes	Yes	Yes	Yes	No	46	Yes	Yes	Yes	Yes	Yes
21	Yes	Yes	Yes	Yes	Yes	47	Yes	Yes	Yes	Yes	Yes
22	Yes	Yes	Yes	Yes	Yes	48	Yes	Yes	Yes	Yes	No
23	Yes	Yes	Yes	Yes	Yes	49	Yes	Yes	Yes	Yes	No
24	Yes	Yes	Yes	Yes	Yes	50	Yes	Yes	Yes	Yes	Yes
25	Yes	Yes	Yes	No	No	51	Yes	Yes	Yes	Yes	Yes
26	Yes	Yes	Yes	Yes	Yes	52	Yes	Yes	Yes	Yes	Yes

Table 4.17 Number of weeks under various probability distribution functions fitting to weekly values of ET_r obtained by using Penmen-Monteith method for Pune district

Types of distributions	Week numbers	Total numbers
Normal	1,2,3,4,5,6,7,8,9,10,11,12,14,15,16,17, 18,19,20,21,22,23,24,25,26,27,28,29, 30,31,32,33,34,35,36,37,38,39,40,41,42, 43,44,45,46, 47,48,49,50,51,52	51
Log Normal	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17 ,18,19,20,21,22,23,24,25,26,27,28,29, 30,31,32,33,34,35,36,37,38,39,40,41,42, 43,44,45,46, 47,48,49,50,51,52	52
Gamma	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17 ,18,19,20,21,22,23,24,25,26,27,28,29, 30,31,32,33,34,35,36,37,38,39,40,41,42, 43,44,45,46, 47,48,49,50,51,52	52
Gumbel	1,2,3,4,5,6,7,8,9,10,11,12,14,15,16,17, 18,19,20,21,22,23,24,26,27,28,29, 30, 31,32,33,34,35,36,37,38,39,40,41,42,43, 44,45,46, 47,48,49,50,51,52	50
Weibulls	1,2,3,4,6,7,8,9,10,11,12,13,15,16,17, 18,19,21,22,23,24,26,27,29, 30,31,32, 33,34,35,36,37,39,40,41,42,43,44,45, 46, 47,50,51,52	44

4.4.4 Nasik District

The weekly ET_r values were estimated by Penman-Monteith method for the years from 1985 to 2007 and above stated five probability distribution functions were fitted to the weekly ET_r data. The results of the fitting of these probability distribution functions to weekly ET_r values as estimated by Penman-Monteith method are given in Table 4.19. It is observed from the Table 4.19, that none of the probability distribution fit to all weeks. All the probability distributions under consideration fit to week no. 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 19, 20, 21, 22, 23, 24, 26, 27, 30, 31, 32, 34, 35, 36, 37, 38, 39, 40, 41, 43, 45, 46, 47, 48, 49 and 52. The number of weeks for which different probability distribution functions fit to weekly ET_r data is given in Table 4.20. It is

Table 4.18 Chi square values for the different probability distributions which fitted to weekly ET_r obtained by using Penman-Monteith Method for Pune district

MW	Chi-square value for probability distributions						MW	Chi-square value for probability distributions					
	Normal	Log Nor	Gamma	Gumbel	Weibull	Best fit		Normal	Log Nor	Gamma	Gumbel	Weibull	Best fit
1	0.73	0.73	0.73	1.36	0.73	N,LN,Ga,W	27	0.78	0.10	0.16	0.78	0.10	LN
2	1.36	1.36	0.42	0.73	1.36	Ga	28	0.75	1.36	1.58	1.36	2.0	N
3	0.73	0.73	0.10	0.73	0.73	Ga	29	0.10	0.10	0.10	0.42	0.10	N,LN,Ga,W
4	0.73	0.73	0.73	2.63	0.42	W	30	1.36	0.73	2.0	2.0	1.36	LN
5	1.36	1.36	1.36	0.73	---	Gu	31	0.10	0.73	2.0	5.15	0.73	N
6	2.0	3.89	3.89	0.73	1.68	Gu	32	0.10	2.0	2.0	1.68	1.36	N
7	0.73	0.42	0.73	2.63	0.10	LN	33	0.73	0.10	0.73	0.73	0.73	LN
8	0.42	0.42	0.42	2.63	0.42	N,LN,Ga,W	34	0.10	0.10	0.10	0.42	0.10	LN
9	2.0	2.0	2.0	1.68	2.0	Gu	35	0.10	0.10	0.73	0.10	0.10	N,LN,Ga
10	0.10	0.10	0.10	0.10	0.73	N,LN,Ga,Gu	36	0.73	0.73	0.73	1.36	3.26	N,LN,Ga
11	1.36	0.42	0.42	0.73	1.36	LN,Ga	37	0.42	0.10	0.10	0.10	1.36	LN,Ga,Gu
12	0.10	0.10	0.10	0.73	0.10	N,LN,Ga,W	38	2.0	3.89	2.0	5.15	1.36	W
13	6.42	2.0	3.89	26.9	0.10	W	39	0.73	0.73	0.73	0.42	0.42	Gu,W
14	1.36	1.36	1.36	3.89	18.1	N,LN,Ga	40	1.36	1.36	1.36	0.73	0.73	Gu,W
15	0.73	0.75	0.73	0.73	0.10	W	41	0.73	0.73	0.73	0.78	0.79	N,LN,Ga
16	0.10	0.10	0.10	0.42	0.12	N,LN,Ga	42	0.42	0.10	0.78	0.10	0.71	LN,Gu
17	0.42	0.73	1.68	2.94	0.42	N,W	43	0.42	0.42	0.42	0.42	2.94	N,LN,Ga,Gu
18	1.36	1.36	1.36	3.26	2.0	N,LN,Ga,Gu	44	0.42	2.94	0.42	1.36	2.0	N,LN
19	2.63	2.63	2.63	0.73	2.63	Gu	45	0.10	0.10	0.10	0.10	0.10	All
20	0.42	1.36	1.36	0.42	---	N,Gu	46	0.42	0.42	0.42	1.36	0.42	N,LN,Ga,W
21	0.73	0.73	0.73	0.73	0.73	All	47	0.73	0.71	0.88	0.85	0.10	W
22	0.73	1.36	1.36	1.36	1.36	N	48	0.42	0.45	0.42	0.15	2.0	Gu
23	0.73	1.36	1.36	1.68	0.73	N,W	49	0.42	0.48	44	0.10	---	Gu
24	0.42	0.10	0.10	0.42	1.36	LN,Ga	50	1.36	1.39	1.32	2.63	2.63	Ga
25	0.73	0.73	0.73	10.8	11.7	N,LN,Ga	51	0.42	0.48	0.41	5.15	0.73	Ga
26	0.73	2.63	0.73	2.0	0.75	N,LN	52	0.42	0.41	0.732	1.68	2.0	LN
Tabulated value of Chi-square = 5.991 at d.f.2													

Table 4.19 Fitting of different probability distributions to weekly values of ET_r obtained by using Penman-Monteith Method for Nasik district

MW	Probability distributions					MW	Probability distributions				
	Normal	Log Normal	Gamma	Gumbel	Weibulls		Normal	Log Normal	Gamma	Gumbel	Weibulls
1	Yes	Yes	Yes	Yes	No	27	Yes	Yes	Yes	Yes	Yes
2	Yes	Yes	Yes	Yes	Yes	28	Yes	Yes	Yes	Yes	Yes
3	Yes	Yes	Yes	Yes	Yes	29	Yes	Yes	Yes	Yes	Yes
4	Yes	Yes	Yes	Yes	Yes	30	Yes	Yes	Yes	Yes	Yes
5	Yes	Yes	Yes	No	No	31	Yes	Yes	Yes	Yes	Yes
6	Yes	Yes	Yes	Yes	No	32	Yes	Yes	Yes	Yes	Yes
7	Yes	Yes	Yes	Yes	No	33	Yes	Yes	Yes	Yes	Yes
8	Yes	Yes	Yes	Yes	Yes	34	Yes	Yes	Yes	No	Yes
9	Yes	Yes	Yes	Yes	No	35	Yes	Yes	Yes	Yes	Yes
10	Yes	Yes	Yes	Yes	Yes	36	Yes	Yes	Yes	Yes	Yes
11	Yes	Yes	Yes	Yes	No	37	Yes	Yes	Yes	Yes	Yes
12	Yes	Yes	Yes	No	Yes	38	Yes	Yes	Yes	Yes	Yes
13	Yes	Yes	Yes	Yes	Yes	39	Yes	Yes	Yes	Yes	Yes
14	No	Yes	Yes	Yes	No	40	Yes	Yes	Yes	Yes	Yes
15	Yes	Yes	Yes	Yes	Yes	41	Yes	Yes	Yes	No	Yes
16	Yes	Yes	Yes	Yes	Yes	42	Yes	Yes	Yes	No	Yes
17	Yes	Yes	Yes	Yes	No	43	Yes	Yes	Yes	Yes	Yes
18	Yes	Yes	No	Yes	Yes	44	Yes	Yes	Yes	Yes	Yes
19	Yes	Yes	Yes	Yes	Yes	45	Yes	Yes	Yes	Yes	Yes
20	Yes	Yes	Yes	No	Yes	46	Yes	Yes	Yes	No	Yes
21	Yes	Yes	Yes	Yes	No	47	Yes	Yes	Yes	Yes	Yes
22	Yes	Yes	Yes	Yes	Yes	48	Yes	Yes	Yes	Yes	Yes
23	Yes	Yes	Yes	Yes	Yes	49	Yes	Yes	Yes	Yes	Yes
24	Yes	Yes	Yes	Yes	Yes	50	Yes	Yes	Yes	Yes	Yes
25	Yes	Yes	No	No	Yes	51	Yes	Yes	Yes	Yes	Yes
26	Yes	Yes	Yes	Yes	No	52	Yes	Yes	Yes	Yes	Yes

Table 4.20 Number of weeks under various probability distribution functions fitting to weekly values of ET_r obtained by using Penmen-Monteith method for Nasik district

Types of distributions	Week numbers	Total numbers
Normal	1,2,3,4,5,6,7,8,9,10,11,12,13,15,16,17,18, 19,20,21,22,23,24,25,26,27,28,29, 30,31, 32,33,34,35,36,37,38,39,40,41,42,43, 44, 45,46, 47,48,49,50,51,52	51
Log Normal	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17, 18,19,20,21,22,23,24,25,26,27,28,29, 30, 31,32,33,34,35,36,37,38,39,40,41,42,43, 44,45,46, 47,48,49,50,51,52	52
Gamma	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17, 19,20,21,22,23,24,26,27,28,29, 30,31,32, 33,34,35,36,37,38,39,40,41,42,43,44,45, 46, 47,48,49,50,51,52	50
Gumbel	1,2,3,4,6,7,8,9,10,11,13,14,15,16,17, 18,19,21,22,23,24,26,27,28,29, 30,31, 32,33,35,36,37,38,39,40,43,44,45, 47, 48,49,50,51,52	44
Weibulls	2,3,4,8,10,12,13,15,16,18,19,20,22,23,24, 25,27,28,29, 30,31,32,33,34,35,36,37,38, 39,40,41,42,43,44,45,46, 47,48,49, 50,51,52	42

Table 4.21 Chi square values for the different probability distributions which fitted to weekly ET_r obtained by using Penman-Monteith Method for Nasik district

MW	Chi-square value for probability distributions						MW	Chi-square value for probability distributions					
	Normal	Log Nor	Gamma	Gumbel	Weibull	Best fit		Normal	Log Nor	Gamma	Gumbel	Weibulls	Best fit
1	3.45	1.63	0.90	2.36	---	Ga	27	0.18	0.18	0.18	0.54	0.54	N,LN,Ga
2	3.18	3.81	3.81	3.81	3.81	All	28	2.0	0.90	0.90	0.90	4.90	LN,Ga,Gu
3	3.81	2.0	2.0	2.0	2.0	LN,Ga,Gu,W	29	0.54	0.54	0.54	1.63	0.54	N,LN,Ga,W
4	6.72	6.72	6.72	3.12	5.27	Gu	30	1.63	1.63	1.63	0.90	1.63	Gu
5	6.0	6.0	6.0	9.27	--	N,LN,Ga	31	1.63	5.27	3.81	1.63	5.27	N,Gu
6	4.54	6.22	3.09	6.36	--	Ga	32	0.18	1.63	0.90	1.63	0.18	N,W
7	3.45	3.81	3.45	2.36	--	Gu	33	0.54	0.54	0.90	3.81	0.90	N,LN
8	1.63	1.63	1.63	0.90	2.36	Gu	34	3.09	1.63	1.63	14.0	0.90	W
9	6.36	6.36	3.81	5.27	--	Ga	35	2.0	3.09	0.90	0.90	3.09	Ga,Gu,W
10	5.27	5.27	5.27	2.0	3.81	Gu	36	4.54	2.36	6.0	7.45	2.36	LN,W
11	4.90	6.72	4.90	3.81	---	Gu	37	0.90	0.90	0.90	0.90	0.90	All
12	6.72	6.72	6.72	9.81	6.72	N,LN,Ga,W	38	0.90	0.90	0.90	0.90	2.0	N,LN,Ga,Gu
13	0.54	1.63	0.54	1.63	0.54	N,Ga,W	39	0.90	0.18	0.18	5.27	0.90	LN,Ga
14	11.8	7.45	6.36	7.45	11.8	Ga	40	1.63	0.90	0.90	6.0	1.63	LN,Ga
15	3.45	3.45	3.45	3.09	4.90	Gu	41	3.81	0.90	2.0	23.45	0.90	W
16	5.27	6.36	3.81	3.81	3.81	Ga,Gu,W	42	3.45	4.54	6.45	18.0	6.0	N
17	3.09	0.90	0.90	3.09	8.18	LN,Ga	43	0.90	2.0	2.0	3.81	0.90	N,W
18	6.36	3.81	8.09	7.45	6.36	LN	44	0.90	0.90	0.90	0.90	1.63	N,LN,Ga,Gu
19	0.90	0.90	0.18	1.63	1.63	Ga	45	0.90	0.54	0.90	6.72	0.54	LN,W
20	5.27	3.45	5.27	7.81	5.27	LN	46	1.63	0.54	0.54	8.90	1.63	LN,Ga
21	3.81	3.81	3.81	3.45	---	N,LN,Ga	47	0.54	3.54	3.45	3.81	0.90	N
22	0.90	2.36	2.36	2.0	2.0	N	48	0.90	0.90	0.18	0.90	0.90	Ga
23	0.90	0.90	0.45	0.54	0.54	Ga	49	4.90	6.90	3.09	4.90	3.90	Ga
24	0.90	3.09	3.09	2.0	3.09	N	50	0.90	1.63	0.90	6.0	1.63	N,Ga
25	3.09	6.0	8.81	10.7	6.0	N	51	5.27	3.45	3.85	1.63	6.36	Gu
26	4.54	3.09	2.0	6.0	--	Ga	52	1.63	1.63	1.63	0.90	0.90	Gu,W
Tabulated value of Chi-square =7.815 at d.f. 3													

observed from the Table 4.20, that Log Normal distribution function fits to maximum number of weeks (total weeks 52); followed by normal distribution (Total week 51), Gamma (Total week 50), Gumbel distribution (total week 44) and Weibull's (total week 42).

As more than one distribution fits too many weeks, the best distribution for such week was considered as the distribution that gives the lowest values of chi-square at 5 per cent level of significance.

The values of the chi-square at 5 per cent for different distributions for the weeks to which these distributions fit are presented in Table 4.21. Table also gives the best fit distribution on the basis of the lowest value. In case more than one distribution yields the lowest value of Chi-square, all these distributions are considered as the best fit distributions. It is seen from the table that Normal distribution is the best fit for maximum weeks (20) followed by Gamma (11), Log Normal (10), Gumbel (9) and Weibull's (2).

4.4.5 Estimation of ET_r Values at Different Probability Levels

In previous section the best fit probability distribution functions for ET_r of each week were presented. ET_r values at different probability levels viz. 10, 20, 30, 40, 50, 60, 70, 80 and 90% were estimated by using these best probability distribution functions for all the weeks. In case of more than one distribution is the best fit, the distribution selected for estimating ET_r values was in order of Normal, Log Normal, Gamma, Gumbel and Weibull's. This order of preference was decided on the basis of reviews that showed fitting of distributions to hydrological variable in above order. The values of ET_r by Penman-Monteith method at different probability levels for all the weeks are shown in Fig. 4.22, 4.23, 4.24 and 4.25 for Solapur, Ahmednagar, Pune and Nasik districts, respectively.

The expected ET_r values at desired probability levels may readily be obtained from these graphs on the weekly basis for Solapur, Ahmednagar, Pune and Nasik districts. These values are often useful for the design, management and operation of irrigation system and development of water resources projects. In most of the irrigation and water resources projects, the values of hydrological parameters at 70% reference probability level are used to minimize the risk in operation. The weekly ET_r values at 70% probability levels for different districts are presented in Table 4.22 for ready reference.

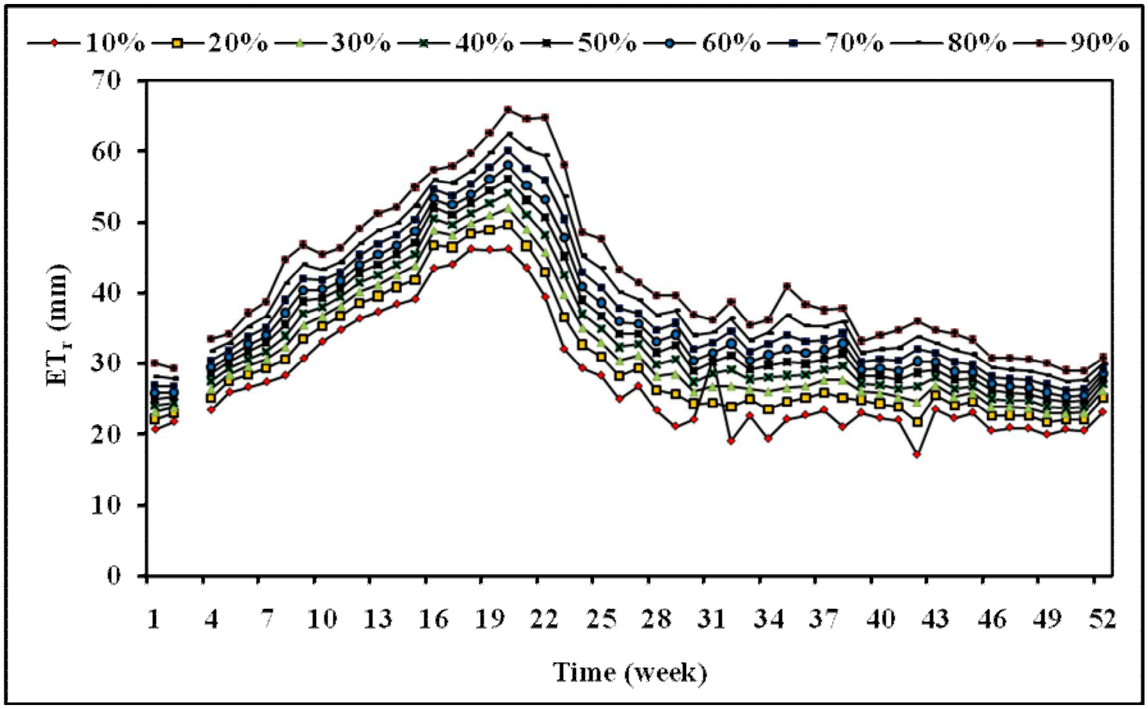

Fig.4.22 Weekly ET_r values at different probability levels by using best fit probability distribution functions for Penman-Monteith method for Solapur district.

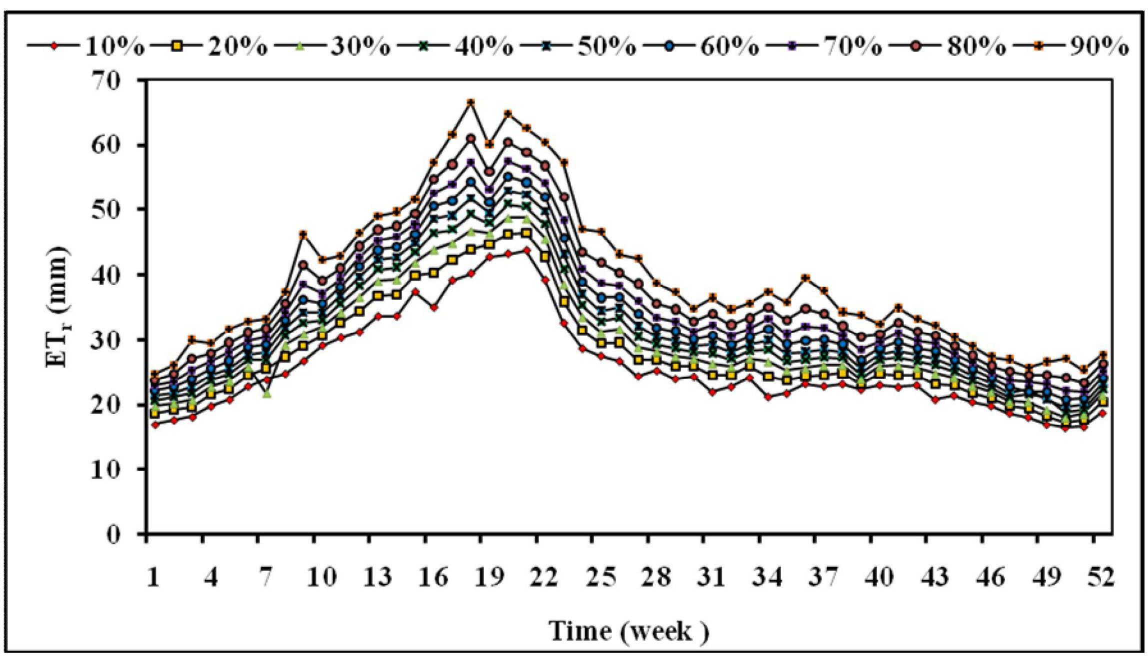

Fig.4.23 Weekly ET_r values at different probability levels by using best fit probability distribution function for Penman-Monteith method for Ahmednagar district

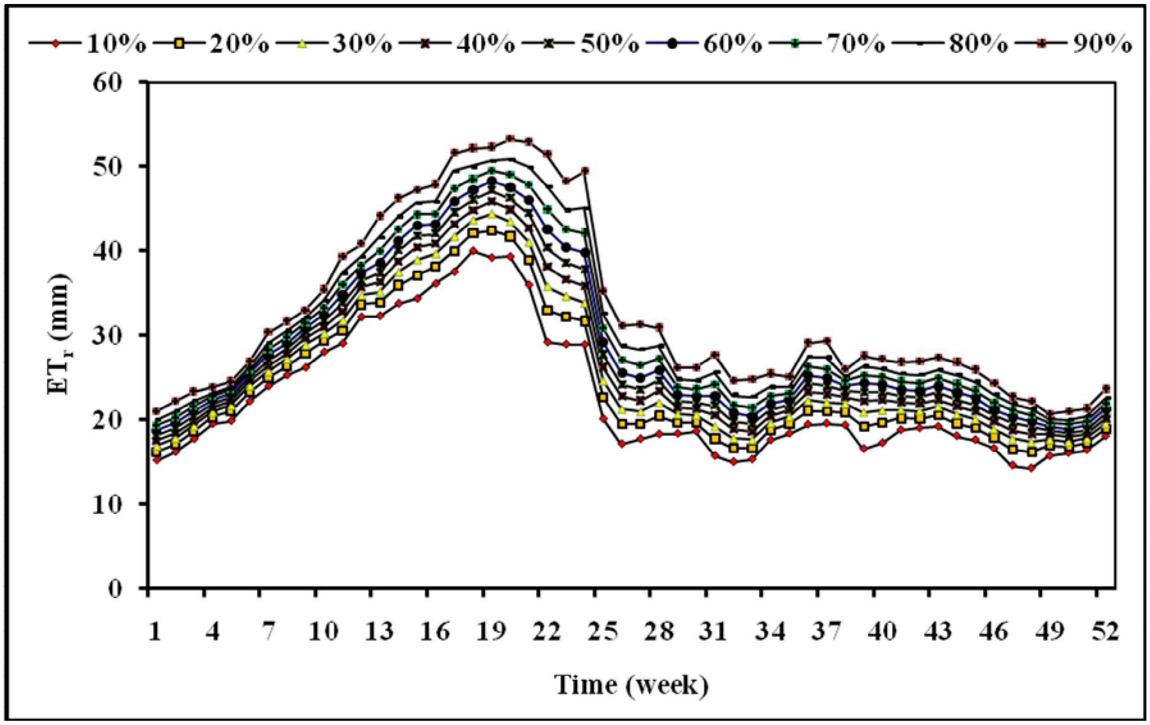

Fig.4.24 Weekly ET_r values at different probability levels by using best fit probability distribution function for Penman-Monteith method for Pune district

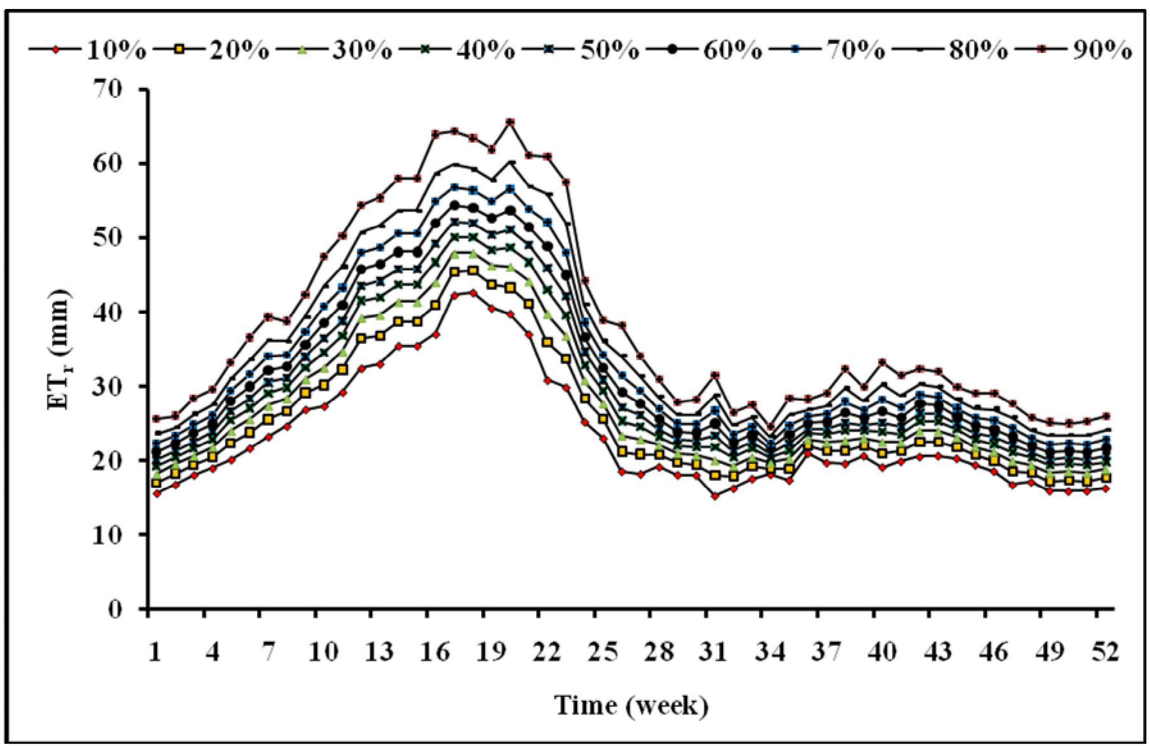

Fig.4.25 Weekly ET_r values at different probability levels by using best fit probability distribution function for Penman-Monteith method for Nasik district

Table 4.22 The weekly values of ET_r (mm) estimated by Penman-Monteith method at 70 % probability level for different districts

MW	Districts				MW	Districts			
	Solapur	Ahmd.	Pune	Nasik		Solapur	Ahmd.	Pune	Nasik
1	26.9	22.9	19.3	22.3	27	37.2	36.1	26.4	29.4
2	26.9	23.7	20.3	23.3	28	34.8	33.5	27.2	26.9
3	28.7	25.3	21.6	24.8	29	35.8	32.9	23.8	25.0
4	30.5	26.7	22.7	26.1	30	32.0	31.3	23.6	24.9
5	31.8	28.0	23.5	29.3	31	32.9	32.2	24.1	26.7
6	33.9	29.9	25.9	31.6	32	34.6	30.7	21.7	23.4
7	35.2	30.4	28.3	33.9	33	31.7	31.8	21.5	24.5
8	39.0	34.3	29.8	34.1	34	32.7	33.2	22.8	22.3
9	42.1	38.5	31.5	37.3	35	34.1	31.0	23.1	24.7
10	41.8	37.1	33.2	40.7	36	33.2	32.0	26.2	25.9
11	42.9	39.5	35.9	43.2	37	33.4	31.8	26.0	26.2
12	45.3	42.8	38.2	48.0	38	34.3	30.6	24.5	27.9
13	46.9	45.3	39.9	48.7	39	30.2	28.4	25.2	26.8
14	48.2	45.8	42.5	50.5	40	30.6	29.7	25.1	28.2
15	50.3	47.8	44.3	50.5	41	30.4	31.0	24.5	27.1
16	54.6	52.6	44.4	54.9	42	32.0	29.9	24.3	28.8
17	53.8	53.9	47.4	56.8	43	31.5	29.5	24.9	28.6
18	55.4	57.4	48.5	56.4	44	30.2	28.0	24.2	27.0
19	57.8	53.2	49.5	54.9	45	29.9	26.5	23.5	25.8
20	60.1	57.5	49.1	56.5	46	28.2	25.0	22.0	25.4
21	57.5	56.3	47.8	53.9	47	27.9	23.8	21.1	24.4
22	56.0	54.2	44.9	52.0	48	27.7	23.5	20.5	23.0
24	50.4	48.5	42.5	48.0	49	27.1	23.1	19.6	22.1
24	42.9	41.0	42.1	38.6	50	26.3	22.2	19.4	22.3
25	40.8	38.8	30.8	34.1	51	26.5	22.0	19.8	22.2
26	37.9	38.3	27.0	31.4	52	29.2	25.2	21.8	22.8

4.4.6 Pomegranate Crop Evapotranspiration at Different Probability Levels

In the previous section ET_r at different probability levels were estimated for different weeks for Solapur, Ahmednagar, Pune and Nasik districts. Section 4.1 provides the weekly values of k_c for the pomegranate trees of different ages. The pomegranate evapotranspiration values at different probability levels were then computed by multiplying weekly ET_r values at different probability levels with corresponding weekly k_c values.

The pomegranate crop evapotranspiration values for different districts are presented and discussed in this section.

4.4.6.1 Solapur district

Weekly values of pomegranate ET at different probability levels are presented in Table 4.23 to 4.27 for 1st to 5th year's tree for 52 crop weeks of phenological development stages for Solapur district.

4.4.6.1.1 1st Year

Weekly values of pomegranate ET at different probability levels are presented in Table 4.23 for 1st year tree. It is seen from the table that the weekly values of pomegranate ET are low during initial stage and tends to increase during crop development stages. It is observed from the table that at 70 % probability level weekly pomegranate ET ranges from 2.26 to 6.21 litres/day/tree. Maximum values of pomegranate ET are observed in 20th and 22nd weeks. These values are 6.46, 6.21, 5.79 and 5.12 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. Minimum values of the pomegranate ET are observed in 31st week. These are 2.38, 2.26, 2.07 and 1.67 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. The total pomegranate ET at 70% probability level over a period of 52 weeks of phenological stages is 187.2 litres/year/tree.

4.4.6.1.2 2nd Year

Weekly values of pomegranate ET at different probability levels are presented in Table 4.24 for 2nd year tree. It is seen from the table that the weekly values of pomegranate ET are low during initial stage and tends to increase during crop development stages. It is observed from the table that at 70 % probability level weekly pomegranate ET ranges from 4.72 to 9.6 litres/day/tree. Maximum values of pomegranate ET are observed in 45th week. These values are 10.0, 9.6, 9.1 and 8.2 litres/day/tree at probability levels 80%, 70%, 50% and 20% respectively. Minimum values of the pomegranate ET are observed in 31st week. These are 4.93, 4.72, 4.32 and

Table 4.23 The values of pomegranate ET (litres/day/tree) for 1st year Pomegranate tree at different probability levels for Solapur district

MW	Pdf's	Probability levels								
		10%	20%	30%	40%	50%	60%	70%	80%	90%
31	Gumbel	1.40	1.68	1.85	1.97	2.08	2.18	2.27	2.38	2.50
32	Gumbel	1.33	1.67	1.88	2.04	2.17	2.30	2.42	2.55	2.71
33	Normal	1.61	1.77	1.89	1.98	2.07	2.16	2.26	2.38	2.53
34	Gumbel	1.41	1.71	1.90	2.05	2.17	2.28	2.39	2.50	2.65
35	Log Normal	1.65	1.84	1.98	2.11	2.25	2.39	2.55	2.75	3.05
36	Gamma	1.74	1.91	2.05	2.17	2.28	2.40	2.54	2.70	2.93
37	Normal	1.82	2.01	2.15	2.27	2.37	2.48	2.60	2.73	2.92
38	Gumbel	1.68	2.01	2.21	2.37	2.50	2.62	2.74	2.87	3.02
39	Normal	1.87	2.02	2.12	2.21	2.29	2.37	2.46	2.56	2.70
40	Normal	1.84	2.01	2.13	2.23	2.33	2.42	2.52	2.64	2.81
41	Log Normal	1.86	2.01	2.13	2.23	2.34	2.45	2.57	2.72	2.94
42	Gumbel	1.46	1.86	2.10	2.29	2.45	2.60	2.74	2.90	3.08
43	Normal	2.05	2.22	2.34	2.44	2.54	2.64	2.74	2.86	3.03
44	Log Normal	1.97	2.12	2.24	2.34	2.45	2.55	2.67	2.82	3.04
45	Log Normal	2.07	2.20	2.31	2.40	2.49	2.58	2.68	2.80	2.99
46	Weibulls	1.87	2.05	2.17	2.28	2.37	2.47	2.56	2.67	2.80
47	Normal	1.93	2.08	2.19	2.29	2.38	2.47	2.56	2.67	2.83
48	Normal	1.94	2.10	2.21	2.30	2.39	2.48	2.58	2.69	2.85
49	Normal	1.88	2.04	2.17	2.26	2.35	2.45	2.55	2.67	2.83
50	Log Normal	1.96	2.08	2.16	2.24	2.32	2.40	2.48	2.59	2.74
51	Normal	1.96	2.10	2.20	2.28	2.36	2.44	2.53	2.63	2.77
52	Gumbel	2.23	2.42	2.52	2.61	2.68	2.75	2.82	2.89	2.97
1	Log Normal	2.02	2.17	2.27	2.36	2.44	2.53	2.63	2.76	2.94
2	Log Normal	2.16	2.27	2.35	2.43	2.50	2.57	2.66	2.76	2.90
3	Not Fitted	--	--	--	--	--	--	--	--	--
4	Normal	2.39	2.57	2.70	2.80	2.91	3.01	3.12	3.24	3.42
5	Normal	2.70	2.85	2.95	3.04	3.13	3.21	3.31	3.41	3.56
6	Gamma	2.82	2.99	3.12	3.24	3.34	3.45	3.58	3.72	3.93
7	Gumbel	2.94	3.13	3.28	3.40	3.52	3.64	3.77	3.93	4.16
8	Gumbel	3.09	3.33	3.52	3.70	3.87	4.05	4.25	4.51	4.88
9	Normal	3.39	3.70	3.92	4.11	4.28	4.46	4.65	4.87	5.17
10	Normal	3.70	3.94	4.11	4.26	4.40	4.53	4.68	4.85	5.09
11	Normal	3.95	4.18	4.34	4.48	4.61	4.74	4.88	5.04	5.27
12	Normal	3.56	3.77	3.93	4.06	4.18	4.30	4.44	4.59	4.80
13	Weibulls	3.67	3.88	4.04	4.18	4.32	4.46	4.61	4.79	5.04
14	Normal	3.79	4.03	4.20	4.34	4.47	4.61	4.75	4.92	5.15
15	Normal	3.88	4.15	4.35	4.51	4.67	4.82	4.99	5.19	5.46
16	Gumbel	4.34	4.66	4.87	5.04	5.19	5.32	5.45	5.59	5.74
17	Normal	4.41	4.65	4.82	4.97	5.11	5.25	5.40	5.57	5.81
18	Log Normal	4.65	4.86	5.02	5.16	5.29	5.43	5.58	5.76	6.02
19	Normal	4.70	4.99	5.20	5.38	5.55	5.72	5.90	6.11	6.40
20	Normal	4.77	5.12	5.37	5.59	5.79	5.99	6.21	6.46	6.81
21	Log Normal	4.54	4.86	5.10	5.32	5.53	5.75	6.00	6.30	6.74
22	Log Normal	4.15	4.52	4.82	5.07	5.33	5.60	5.90	6.27	6.84
23	Normal	3.40	3.87	4.22	4.51	4.78	5.06	5.35	5.69	6.17
24	Normal	3.14	3.50	3.75	3.97	4.17	4.38	4.59	4.85	5.20
25	Log Normal	3.06	3.34	3.57	3.77	3.97	4.17	4.41	4.70	5.14
26	Normal	2.73	3.07	3.32	3.53	3.73	3.92	4.14	4.38	4.72
27	Normal	2.99	3.27	3.48	3.65	3.81	3.98	4.15	4.35	4.63
28	Normal	2.64	2.96	3.19	3.38	3.56	3.74	3.94	4.16	4.48
29	Gumbel	2.43	2.94	3.27	3.51	3.72	3.91	4.10	4.30	4.55
30	Gamma	2.57	2.83	3.02	3.20	3.36	3.54	3.73	3.96	4.30
Total (l/y/tree)		138	150	159	166	173	180	187	196	208

Table 4.24 The values of pomegranate ET (litres/day/tree) for 2nd year pomegranate tree at different probability levels for Solapur district

MW	Pdf's	Probability levels								
		10%	20%	30%	40%	50%	60%	70%	80%	90%
31	Gumbel	2.90	3.49	3.83	4.09	4.32	4.52	4.72	4.93	5.19
32	Gumbel	2.92	3.66	4.11	4.47	4.76	5.04	5.30	5.59	5.94
33	Normal	3.70	4.07	4.33	4.55	4.76	4.97	5.19	5.45	5.82
34	Gumbel	3.35	4.06	4.50	4.84	5.13	5.40	5.65	5.93	6.27
35	Log Normal	4.07	4.52	4.88	5.21	5.53	5.88	6.27	6.76	7.52
36	Gamma	4.47	4.92	5.27	5.57	5.87	6.18	6.52	6.94	7.55
37	Normal	4.86	5.36	5.72	6.03	6.32	6.61	6.92	7.28	7.79
38	Gumbel	4.62	5.52	6.08	6.51	6.87	7.21	7.54	7.88	8.30
39	Normal	5.35	5.75	6.04	6.29	6.53	6.76	7.01	7.30	7.71
40	Normal	5.41	5.89	6.25	6.55	6.83	7.11	7.41	7.76	8.25
41	Log Normal	5.69	6.15	6.51	6.83	7.15	7.48	7.85	8.31	8.99
42	Gumbel	4.54	5.76	6.53	7.11	7.61	8.06	8.51	8.98	9.56
43	Normal	6.76	7.32	7.71	8.06	8.37	8.70	9.03	9.44	9.99
44	Log Normal	6.78	7.30	7.70	8.06	8.41	8.78	9.19	9.69	10.44
45	Log Normal	7.35	7.83	8.21	8.52	8.84	9.16	9.51	9.96	10.62
46	Weibull's	6.57	7.21	7.65	8.02	8.36	8.69	9.03	9.39	9.85
47	Normal	6.75	7.30	7.69	8.02	8.34	8.65	8.98	9.38	9.92
48	Normal	6.76	7.30	7.69	8.02	8.34	8.65	8.98	9.37	9.91
49	Normal	6.50	7.05	7.48	7.80	8.13	8.45	8.81	9.20	9.75
50	Log Normal	6.77	7.17	7.47	7.74	8.01	8.28	8.58	8.94	9.48
51	Normal	6.71	7.19	7.53	7.82	8.09	8.37	8.66	9.00	9.48
52	Gumbel	7.59	8.23	8.60	8.89	9.14	9.37	9.59	9.83	10.13
1	Log Normal	6.27	6.71	7.02	7.30	7.57	7.85	8.16	8.54	9.10
2	Log Normal	6.35	6.67	6.92	7.14	7.36	7.57	7.82	8.11	8.53
3	Not Fitted	--	--	--	--	--	--	--	--	--
4	Normal	6.35	6.82	7.16	7.44	7.72	7.98	8.27	8.61	9.08
5	Normal	6.66	7.03	7.29	7.52	7.73	7.94	8.16	8.43	8.80
6	Gamma	6.51	6.91	7.21	7.47	7.72	7.97	8.25	8.59	9.07
7	Gumbel	6.39	6.81	7.12	7.39	7.65	7.92	8.20	8.55	9.04
8	Gumbel	6.31	6.81	7.20	7.56	7.91	8.28	8.69	9.21	9.97
9	Normal	6.54	7.13	7.56	7.92	8.26	8.60	8.96	9.38	9.97
10	Normal	6.63	7.06	7.36	7.63	7.87	8.12	8.38	8.68	9.11
11	Normal	6.39	6.75	7.01	7.24	7.45	7.66	7.88	8.15	8.51
12	Normal	6.49	6.88	7.16	7.40	7.63	7.85	8.09	8.37	8.76
13	Weibull's	6.71	7.10	7.39	7.65	7.90	8.15	8.43	8.76	9.22
14	Normal	6.96	7.39	7.70	7.96	8.21	8.46	8.72	9.03	9.46
15	Normal	7.13	7.63	7.99	8.30	8.58	8.87	9.18	9.54	10.03
16	Gumbel	6.50	6.98	7.31	7.56	7.78	7.99	8.18	8.38	8.60
17	Normal	6.62	6.98	7.24	7.46	7.67	7.87	8.10	8.36	8.72
18	Log Normal	6.97	7.29	7.53	7.74	7.94	8.14	8.37	8.64	9.04
19	Normal	7.05	7.49	7.80	8.07	8.32	8.57	8.84	9.16	9.59
20	Normal	7.16	7.68	8.06	8.39	8.69	8.99	9.32	9.70	10.22
21	Log Normal	6.81	7.28	7.65	7.98	8.30	8.63	9.00	9.45	10.11
22	Log Normal	6.23	6.78	7.22	7.60	8.00	8.39	8.85	9.41	10.26
23	Normal	5.10	5.81	6.32	6.76	7.17	7.58	8.02	8.54	9.25
24	Normal	4.71	5.24	5.63	5.95	6.26	6.56	6.89	7.27	7.80
25	Log Normal	4.59	5.01	5.35	5.66	5.95	6.26	6.61	7.05	7.72
26	Normal	4.09	4.61	4.98	5.29	5.59	5.89	6.20	6.57	7.08
27	Normal	4.49	4.91	5.22	5.48	5.72	5.96	6.22	6.53	6.95
28	Normal	3.96	4.44	4.78	5.07	5.34	5.61	5.90	6.24	6.72
29	Gumbel	3.64	4.41	4.90	5.27	5.58	5.87	6.16	6.46	6.83
30	Gamma	3.86	4.24	4.54	4.80	5.05	5.31	5.59	5.95	6.46
Total (l/y/tree)		293.9	319.9	338.4	354.0	368.6	383.2	398.7	417.0	442.4

3.49 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. The total pomegranate ET at 70% probability level over a period of 52 weeks of phonological stages is 398.7 litres/year/tree.

4.4.6.1.3 3rd Year

Weekly values of pomegranate ET at different probability levels are presented in Table 4.25 for 3rd year tree. It is seen from the table that the weekly values of pomegranate ET are low during initial stage and tends to increase during crop development stages. It is observed from the table that at 70% probability level weekly pomegranate ET ranges from 3.60 to 34.4 litres/day/tree. Maximum values of pomegranate ET are observed in 20nd week. These values are 35.8, 34.4, 32.1 and 28.4 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. Minimum values of the pomegranate ET are observed in 31st week. These are 3.76, 3.60, 3.12 and 2.66 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. The total pomegranate ET at 70% probability level over a period of 52 weeks of phonological stages is 1184.1 litres/year/tree.

4.4.6.1.4 4th Year

Weekly values of pomegranate ET at different probability levels are presented in Table 4.26 for 4th year tree. It is seen from the table that the weekly values of pomegranate ET are low during initial stage and tends to increase during crop development stages. It is observed from the Table that at 70% probability level weekly pomegranate ET ranges from 5.0 to 48.9 litres/day/tree. Maximum values of pomegranate ET are observed in 20th week. These values are 50.9, 48.9, 45.6 and 40.3litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. Minimum values of the pomegranate ET are observed in 31st week. These are 5.22, 5.00, 4.57 and 3.70 litres/day/tree at probability levels 80%, 70%, 50% and 20% respectively. The total pomegranate ET at 70% probability level over a period of 52 weeks of phonological stages is 1648.5 litres/year/tree.

4.4.6.1.5 5th Year

Weekly values of pomegranate ET at different probability levels are presented in Table 4.27 for 5th year tree. It is seen from the table that the weekly values of pomegranate ET are low during initial stage and tends to increase during crop development stages. It is observed from the Table that at 70% probability level weekly pomegranate ET ranges from 6.18 to 66.6 litres/day/tree. Maximum values of pomegranate ET are observed in 20th week. These values are 69.4, 66.6, 62.2 and 55.0 litres/day/tree at probability levels 80%, 70%, 50% and 20%,

Table 4.25 The values of pomegranate ET (litres/day/tree) for 3rd year pomegranate tree at different probability levels for Solapur district

MW	Pdf's	Probability levels								
		10%	20%	30%	40%	50%	60%	70%	80%	90%
31	Gumbel	2.2	2.7	2.9	3.1	3.3	3.4	3.6	3.8	4.0
32	Gumbel	2.7	3.4	3.8	4.1	4.4	4.6	4.9	5.1	5.5
33	Normal	4.0	4.4	4.7	5.0	5.2	5.4	5.7	6.0	6.4
34	Gumbel	4.4	5.3	5.9	6.3	6.7	7.0	7.4	7.7	8.1
35	Log Normal	6.2	6.9	7.5	8.0	8.5	9.0	9.6	10.3	11.5
36	Gamma	7.8	8.6	9.2	9.7	10.2	10.8	11.4	12.1	13.1
37	Normal	9.2	10.1	10.8	11.4	11.9	12.5	13.1	13.8	14.7
38	Gumbel	9.5	11.3	12.5	13.4	14.1	14.8	15.5	16.2	17.1
39	Normal	12.6	13.5	14.2	14.8	15.3	15.9	16.5	17.2	18.1
40	Normal	13.6	14.8	15.7	16.5	17.2	17.9	18.7	19.6	20.8
41	Log Normal	15.0	16.2	17.1	18.0	18.8	19.7	20.7	21.9	23.7
42	Gumbel	12.6	16.1	18.2	19.8	21.2	22.5	23.7	25.0	26.6
43	Normal	18.8	20.3	21.4	22.4	23.3	24.2	25.1	26.2	27.8
44	Log Normal	19.2	20.7	21.8	22.9	23.9	24.9	26.1	27.5	29.6
45	Log Normal	21.1	22.5	23.6	24.5	25.4	26.4	27.4	28.6	30.6
46	Weibull's	18.8	20.6	21.9	23.0	23.9	24.9	25.8	26.9	28.2
47	Normal	19.2	20.8	21.9	22.8	23.7	24.6	25.6	26.7	28.2
48	Normal	19.2	20.7	21.8	22.7	23.6	24.5	25.5	26.6	28.1
49	Normal	18.4	19.9	21.1	22.1	23.0	23.9	24.9	26.0	27.6
50	Log Normal	19.1	20.3	21.2	21.9	22.7	23.4	24.3	25.3	26.8
51	Normal	19.0	20.4	21.3	22.2	22.9	23.7	24.5	25.5	26.8
52	Gumbel	21.5	23.3	24.4	25.2	25.9	26.6	27.2	27.9	28.7
1	Log Normal	17.7	19.0	19.8	20.6	21.4	22.2	23.1	24.1	25.7
2	Log Normal	17.9	18.9	19.6	20.2	20.8	21.4	22.1	22.9	24.1
3	Not Fitted	--	--	--	--	--	--	--	--	--
4	Normal	18.1	19.4	20.3	21.2	21.9	22.7	23.5	24.5	25.8
5	Normal	19.5	20.6	21.3	22.0	22.6	23.2	23.9	24.7	25.7
6	Gamma	19.7	20.9	21.8	22.6	23.4	24.2	25.0	26.0	27.5
7	Gumbel	20.1	21.5	22.5	23.3	24.1	25.0	25.9	26.9	28.5
8	Gumbel	20.0	21.6	22.9	24.0	25.1	26.3	27.6	29.3	31.7
9	Normal	21.1	23.0	24.4	25.5	26.6	27.7	28.9	30.3	32.2
10	Normal	22.0	23.4	24.4	25.3	26.1	26.9	27.8	28.8	30.2
11	Normal	22.5	23.8	24.7	25.5	26.3	27.0	27.8	28.7	30.0
12	Normal	23.0	24.4	25.4	26.2	27.0	27.8	28.7	29.7	31.0
13	Weibull's	20.6	21.8	22.7	23.5	24.2	25.0	25.9	26.9	28.3
14	Normal	21.3	22.6	23.5	24.3	25.1	25.8	26.6	27.6	28.9
15	Normal	21.8	23.3	24.4	25.4	26.2	27.1	28.0	29.1	30.7
16	Gumbel	24.34	26.14	27.34	28.30	29.13	29.89	30.62	31.37	32.20
17	Normal	24.76	26.10	27.08	27.91	28.69	29.46	30.29	31.26	32.61
18	Log Normal	26.08	27.26	28.15	28.93	29.69	30.45	31.30	32.32	33.79
19	Normal	26.18	27.80	28.97	29.97	30.91	31.85	32.84	34.01	35.63
20	Normal	26.42	28.37	29.76	30.96	32.08	33.20	34.39	35.79	37.74
21	Log Normal	25.11	26.87	28.22	29.43	30.60	31.83	33.19	34.86	37.31
22	Log Normal	22.91	24.94	26.57	27.97	29.42	30.88	32.56	34.60	37.74
23	Normal	18.75	21.38	23.27	24.89	26.40	27.91	29.52	31.42	34.04
24	Normal	17.27	19.21	20.62	21.81	22.93	24.05	25.25	26.65	28.59
25	Log Normal	16.87	18.42	19.67	20.80	21.88	23.01	24.32	25.93	28.38
26	Normal	15.01	16.90	18.26	19.42	20.50	21.58	22.75	24.10	25.98
27	Normal	16.22	17.75	18.85	19.79	20.67	21.55	22.49	23.60	25.12
28	Normal	14.21	15.90	17.12	18.17	19.14	20.12	21.16	22.38	24.07
29	Gumbel	12.97	15.74	17.46	18.78	19.91	20.93	21.94	23.01	24.33
30	Gamma	13.70	15.07	16.10	17.03	17.92	18.85	19.86	21.12	22.93
Total (l/y/tree)		880.4	954.8	1008	1053	1096	1138	1184	1237	1312

Table 4.26 The values of pomegranate ET (litres/day/tree) for 4th year Pomegranate tree at different probability levels for Solapur district

MW	Pdf's	Probability levels								
		10%	20%	30%	40%	50%	60%	70%	80%	90%
31	Gumbel	3.1	3.7	4.1	4.3	4.6	4.8	5.0	5.2	5.5
32	Gumbel	4.1	5.1	5.7	6.2	6.6	7.0	7.4	7.8	8.3
33	Normal	6.2	6.8	7.3	7.6	8.0	8.3	8.7	9.1	9.8
34	Gumbel	6.5	7.9	8.8	9.5	10.0	10.5	11.0	11.6	12.3
35	Log Normal	9.0	10.0	10.8	11.6	12.3	13.1	13.9	15.0	16.7
36	Gamma	11.2	12.3	13.2	13.9	14.7	15.5	16.3	17.4	18.9
37	Normal	13.2	14.5	15.5	16.4	17.1	17.9	18.8	19.7	21.1
38	Gumbel	14.1	16.9	18.6	19.9	21.1	22.1	23.1	24.2	25.4
39	Normal	17.5	18.9	19.8	20.6	21.4	22.2	23.0	23.9	25.3
40	Normal	18.7	20.4	21.7	22.7	23.7	24.7	25.7	26.9	28.6
41	Log Normal	20.5	22.2	23.5	24.7	25.8	27.0	28.3	30.0	32.5
42	Gumbel	17.3	22.0	24.9	27.1	29.0	30.7	32.5	34.2	36.5
43	Normal	25.7	27.8	29.3	30.6	31.8	33.1	34.4	35.9	38.0
44	Log Normal	26.2	28.2	29.7	31.1	32.5	33.9	35.5	37.4	40.3
45	Log Normal	28.4	30.2	31.7	32.9	34.1	35.3	36.7	38.4	41.0
46	Weibull's	25.2	27.6	29.3	30.7	32.0	33.3	34.6	36.0	37.7
47	Normal	25.8	27.9	29.4	30.7	31.9	33.1	34.3	35.9	37.9
48	Normal	25.8	27.8	29.3	30.6	31.8	33.0	34.2	35.7	37.8
49	Normal	24.8	26.9	28.5	29.8	31.0	32.2	33.6	35.1	37.2
50	Log Normal	25.8	27.4	28.5	29.5	30.6	31.6	32.7	34.1	36.1
51	Normal	25.6	27.4	28.8	29.9	30.9	32.0	33.1	34.4	36.2
52	Gumbel	29.0	31.4	32.8	33.9	34.9	35.8	36.6	37.5	38.7
1	Log Normal	24.8	26.5	27.8	28.9	29.9	31.1	32.3	33.8	36.0
2	Log Normal	25.4	26.7	27.7	28.6	29.4	30.3	31.3	32.4	34.1
3	Not Fitted	--	--	--	--	--	--	--	--	--
4	Normal	25.6	27.5	28.8	30.0	31.1	32.1	33.3	34.6	36.5
5	Normal	28.1	29.6	30.7	31.7	32.6	33.4	34.4	35.5	37.0
6	Gamma	27.6	29.3	30.6	31.7	32.7	33.8	35.0	36.4	38.5
7	Gumbel	27.4	29.2	30.5	31.7	32.8	33.9	35.1	36.6	38.7
8	Gumbel	27.7	29.9	31.6	33.2	34.7	36.4	38.2	40.5	43.8
9	Normal	28.9	31.5	33.4	35.0	36.5	38.0	39.6	41.5	44.1
10	Normal	30.6	32.5	33.9	35.1	36.3	37.4	38.6	40.0	42.0
11	Normal	31.0	32.8	34.1	35.2	36.2	37.2	38.3	39.6	41.3
12	Normal	28.5	30.2	31.4	32.5	33.4	34.4	35.5	36.7	38.4
13	Weibull's	29.4	31.1	32.4	33.5	34.6	35.7	36.9	38.3	40.3
14	Normal	30.4	32.3	33.6	34.8	35.9	36.9	38.1	39.4	41.3
15	Normal	31.1	33.3	34.8	36.2	37.4	38.7	40.0	41.6	43.7
16	Gumbel	34.67	37.24	38.95	40.32	41.50	42.58	43.62	44.68	45.87
17	Normal	35.25	37.16	38.55	39.73	40.84	41.95	43.12	44.51	46.43
18	Log Normal	37.13	38.82	40.09	41.20	42.27	43.37	44.58	46.02	48.12
19	Normal	37.23	39.54	41.20	42.62	43.95	45.28	46.70	48.36	50.67
20	Normal	37.53	40.30	42.29	43.99	45.57	47.17	48.87	50.85	53.62
21	Log Normal	35.64	38.14	40.06	41.78	43.44	45.18	47.11	49.48	52.96
22	Log Normal	32.42	35.30	37.61	39.58	41.64	43.70	46.08	48.96	53.41
23	Normal	26.50	30.21	32.89	35.17	37.31	39.44	41.72	44.40	48.11
24	Normal	24.39	27.13	29.11	30.80	32.38	33.96	35.65	37.63	40.38
25	Log Normal	23.67	25.84	27.60	29.19	30.69	32.28	34.12	36.38	39.81
26	Normal	21.00	23.64	25.55	27.16	28.67	30.20	31.83	33.72	36.35
27	Normal	22.61	24.75	26.28	27.59	28.82	30.05	31.36	32.90	35.02
28	Normal	19.83	22.19	23.90	25.35	26.71	28.07	29.52	31.23	33.59
29	Gumbel	17.98	21.82	24.21	26.05	27.61	29.03	30.43	31.91	33.74
30	Gamma	18.92	20.80	22.23	23.51	24.75	26.02	27.43	29.16	31.66
Total (l/y/tree)		1225	1329	1403	1466	1525	1585	1648	1723	1827

Table 4.27 The values of pomegranate ET (litres/day/tree) for 5th year Pomegranate tree at different probability levels for Solapur district

MW	Pdf's	Probability levels								
		10%	20%	30%	40%	50%	60%	70%	80%	90%
31	Gumbel	3.8	4.6	5.0	5.4	5.7	5.9	6.2	6.5	6.8
32	Gumbel	5.5	6.8	7.7	8.3	8.9	9.4	9.9	10.4	11.1
33	Normal	8.4	9.3	9.9	10.4	10.8	11.3	11.8	12.4	13.3
34	Gumbel	9.3	11.3	12.5	13.4	14.2	15.0	15.7	16.5	17.4
35	Log Normal	12.5	13.9	15.0	16.0	17.0	18.1	19.3	20.8	23.2
36	Gamma	14.7	16.2	17.3	18.4	19.3	20.4	21.5	22.9	24.9
37	Normal	17.8	19.6	21.0	22.1	23.2	24.2	25.4	26.7	28.5
38	Gumbel	18.0	21.5	23.7	25.4	26.8	28.1	29.4	30.8	32.4
39	Normal	22.1	23.7	24.9	26.0	26.9	27.9	28.9	30.1	31.8
40	Normal	23.6	25.7	27.3	28.6	29.8	31.1	32.4	33.9	36.0
41	Log Normal	25.0	27.1	28.7	30.1	31.5	32.9	34.6	36.6	39.6
42	Gumbel	20.9	26.5	30.0	32.7	35.0	37.1	39.1	41.3	44.0
43	Normal	30.9	33.5	35.3	36.9	38.3	39.8	41.3	43.2	45.7
44	Log Normal	31.8	34.2	36.1	37.8	39.4	41.1	43.1	45.4	48.9
45	Log Normal	34.8	37.0	38.8	40.3	41.8	43.3	45.0	47.1	50.3
46	Weibull's	31.0	34.0	36.1	37.9	39.5	41.0	42.6	44.3	46.5
47	Normal	31.7	34.2	36.1	37.7	39.1	40.6	42.2	44.0	46.5
48	Normal	31.5	34.1	35.9	37.4	38.9	40.4	41.9	43.7	46.3
49	Normal	30.3	32.9	34.8	36.3	37.9	39.4	41.0	42.9	45.4
50	Log Normal	31.4	33.3	34.7	36.0	37.2	38.5	39.9	41.6	44.0
51	Normal	31.2	33.4	34.9	36.3	37.6	38.8	40.2	41.8	44.0
52	Gumbel	35.1	38.1	39.8	41.1	42.3	43.4	44.4	45.5	46.9
1	Log Normal	30.4	32.5	34.0	35.3	36.6	38.0	39.5	41.3	44.0
2	Log Normal	31.3	32.9	34.1	35.2	36.2	37.3	38.5	40.0	42.0
3	Not Fitted	--	--	--	--	--	--	--	--	--
4	Normal	31.9	34.2	35.9	37.4	38.7	40.1	41.5	43.2	45.6
5	Normal	34.9	36.9	38.3	39.4	40.6	41.7	42.8	44.2	46.2
6	Gamma	35.2	37.4	39.0	40.4	41.7	43.1	44.6	46.4	49.0
7	Gumbel	35.8	38.1	39.9	41.4	42.8	44.3	45.9	47.8	50.6
8	Gumbel	36.2	39.0	41.3	43.4	45.4	47.5	49.9	52.8	57.2
9	Normal	38.7	42.2	44.7	46.8	48.8	50.8	53.0	55.5	59.0
10	Normal	40.9	43.5	45.4	47.0	48.5	50.0	51.6	53.5	56.1
11	Normal	41.0	43.4	45.0	46.5	47.8	49.2	50.6	52.3	54.7
12	Normal	38.5	40.8	42.4	43.9	45.2	46.5	47.9	49.6	51.9
13	Weibull's	39.6	41.9	43.6	45.2	46.6	48.1	49.7	51.7	54.4
14	Normal	40.9	43.4	45.2	46.8	48.2	49.7	51.2	53.0	55.6
15	Normal	41.7	44.7	46.8	48.6	50.2	51.9	53.7	55.8	58.7
16	Gumbel	46.41	49.85	52.14	53.97	55.55	56.99	58.39	59.81	61.41
17	Normal	47.14	49.70	51.55	53.14	54.62	56.09	57.67	59.52	62.08
18	Log Normal	49.60	51.86	53.55	55.04	56.47	57.93	59.55	61.48	64.28
19	Normal	50.88	54.03	56.30	58.24	60.06	61.88	63.82	66.09	69.24
20	Normal	51.19	54.97	57.67	59.99	62.16	64.33	66.65	69.36	73.13
21	Log Normal	48.51	51.92	54.53	56.87	59.13	61.50	64.13	67.35	72.09
22	Log Normal	44.24	48.17	51.31	54.01	56.82	59.62	62.88	66.81	72.87
23	Normal	36.14	41.19	44.85	47.96	50.87	53.78	56.89	60.54	65.60
24	Normal	33.33	37.08	39.79	42.10	44.26	46.42	48.73	51.43	55.18
25	Log Normal	32.32	35.29	37.69	39.86	41.92	44.09	46.60	49.69	54.37
26	Normal	28.69	32.29	34.90	37.10	39.16	41.24	43.47	46.05	49.64
27	Normal	31.05	33.98	36.09	37.88	39.58	41.25	43.06	45.17	48.09
28	Normal	27.32	30.58	32.92	34.93	36.80	38.68	40.68	43.02	46.28
29	Gumbel	24.82	30.12	33.42	35.95	38.10	40.06	42.00	44.04	46.57
30	Gamma	26.24	28.85	30.83	32.60	34.31	36.09	38.03	40.43	43.90
Total (l/y/tree)		1596	1731	1829	1911	1988	2066	2149	2246	2383

respectively. Minimum values of the pomegranate ET are observed in 31st week. These are 6.45, 6.18, 5.65 and 4.57 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. The total pomegranate ET at 70% probability level over a period of 52 weeks of phenological stages is 2148.9litres/year/tree.

4.4.6.2 Ahmednagar district

Weekly values of pomegranate ET at different probability levels are presented in Table 4.28 to 4.32 for 1st to 5th year's tree for 52 crop weeks of phenological development stages for Ahmednagar district.

4.4.6.2.1 1st Year

Weekly values of pomegranate ET at different probability levels are presented in Table 4.28 for 1st year tree. It is seen from the table that the weekly values of pomegranate ET are low during initial stage and tends to increase during crop development stages. It is observed from the table that at 70% probability level weekly pomegranate ET ranges from 1.65 to 5.7 litres/day/tree. Maximum values of pomegranate ET are observed in 20th week. These values are 6.3, 5.9, 5.5 and 4.8 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. Minimum values of the pomegranate ET are observed in 31st week. These are 2.24, 1.65, 1.97 and 1.70 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. The total pomegranate ET at 70% probability level over a period of 52 weeks of phenological stages is 171.8 litres/year/tree.

4.4.6.2.2 2nd Year

Weekly values of pomegranate ET at different probability levels are presented in Table 4.29 for 2nd year tree. It is seen from the table that the weekly values of pomegranate ET are low during initial stage and tends to increase during crop development stages. It is observed from the table that at 70% probability level weekly pomegranate ET ranges from 3.90 to 8.7 litres/day/tree. Maximum values of pomegranate ET are observed in 20th week. These values are 9.4, 8.9, 8.2 and 7.3 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. Minimum values of the pomegranate ET are observed in 31st week. These are 4.64, 3.90, 4.08 and 3.52 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. The total pomegranate ET at 70 % probability level over a period of 52 weeks of phenological stages is 376.8 litres/year/tree.

Table 4.28 The values of pomegranate ET (litres/day/tree) for 1st year pomegranate tree at different probability levels for Ahmednagar district

MW	Pdf's	Probability levels								
		10%	20%	30%	40%	50%	60%	70%	80%	90%
31	Normal	1.56	1.70	1.80	1.88	1.97	2.05	2.14	2.24	2.38
32	Log Normal	1.60	1.72	1.81	1.89	1.97	2.05	2.15	2.26	2.43
33	Log Normal	1.73	1.85	1.93	2.02	2.10	2.18	2.27	2.38	2.54
34	Weibull's	1.74	1.91	2.03	2.14	2.24	2.34	1.65	2.57	2.74
35	Log Normal	1.63	1.77	1.88	1.99	2.09	2.19	2.31	2.46	2.68
36	Gamma	1.61	1.79	1.92	2.04	2.15	2.26	2.39	2.54	2.76
37	Gumbel	1.63	1.88	2.04	2.16	2.27	2.36	2.46	2.55	2.67
38	Log Normal	1.86	1.98	2.08	2.17	2.26	2.35	2.44	2.57	2.75
39	Gamma	1.86	2.01	2.11	2.21	2.30	2.40	2.50	2.63	2.81
40	Normal	1.88	2.03	2.13	2.23	2.31	2.40	2.49	2.60	2.75
41	Gamma	1.93	2.06	2.16	2.25	2.33	2.41	2.50	2.61	2.77
42	Log Normal	1.97	2.10	2.20	2.29	2.37	2.46	2.56	2.68	2.86
43	Weibull's	1.91	2.06	2.17	2.27	2.36	2.45	2.55	2.66	2.81
44	Weibull's	1.90	2.04	2.14	2.22	2.04	2.39	2.47	2.57	2.70
45	Weibull's	1.83	1.95	2.05	2.13	2.20	2.28	2.37	2.47	2.61
46	Log Normal	1.81	1.91	1.99	2.06	2.12	2.19	2.27	2.36	2.50
47	Gumbel	1.55	1.75	1.88	1.98	2.06	2.14	2.21	2.29	2.38
48	Weibull's	1.57	1.76	1.88	1.97	2.05	2.12	2.19	2.26	2.35
49	Gamma	1.63	1.75	1.85	1.93	2.01	2.09	2.18	2.29	2.44
50	Gamma	1.59	1.71	1.80	1.89	1.97	2.05	2.14	2.25	2.40
51	Gumbel	1.70	1.93	2.07	2.18	2.28	2.36	2.45	2.54	2.65
52	Weibull's	1.59	1.73	1.83	1.91	1.99	2.07	2.15	2.25	2.37
1	Weibull's	1.64	1.81	1.93	2.02	2.10	2.18	2.26	2.34	2.43
2	Normal	1.75	1.89	2.00	2.08	2.17	2.25	2.34	2.44	2.59
3	Gumbel	1.69	1.97	2.14	2.28	2.39	2.50	2.60	2.71	2.84
4	Normal	2.02	2.19	2.32	2.42	2.52	2.62	2.72	2.85	3.02
5	Log Normal	2.16	2.33	2.45	2.56	2.67	2.78	2.91	3.07	3.30
6	Normal	2.42	2.60	2.72	2.84	2.94	3.04	3.16	3.28	3.46
7	Log Normal	2.56	2.74	2.88	3.01	3.13	3.26	3.40	3.58	3.83
8	Weibulls	2.66	2.96	3.16	3.33	3.48	3.62	3.76	3.91	4.08
9	Gumbel	2.97	3.36	3.61	3.79	3.95	4.09	4.23	4.39	4.57
10	Gumbel	2.95	3.38	3.64	3.84	4.02	4.17	4.33	4.49	4.69
11	Weibull's	3.45	3.70	3.89	4.04	4.19	4.33	4.49	4.66	4.89
12	Gumbel	2.93	3.33	3.58	3.76	3.93	4.07	4.22	4.37	4.56
13	Weibull's	3.31	3.61	3.82	3.99	4.15	4.30	4.44	4.60	4.80
14	Weibull's	3.45	3.72	3.91	4.08	4.23	4.37	4.52	4.69	4.90
15	Normal	3.71	3.95	4.13	4.28	4.42	4.56	4.71	4.88	5.13
16	Gumbel	3.50	4.04	4.37	4.63	4.85	5.05	5.25	5.46	5.72
17	LogNormal	3.93	4.24	4.49	4.71	4.92	5.15	5.41	5.72	6.18
18	LogNormal	4.05	4.42	4.70	4.96	5.21	5.48	5.78	6.15	6.70
19	Gumbel	4.08	4.54	4.83	5.06	5.24	5.42	5.58	5.76	5.98
20	LogNormal	4.46	4.79	5.04	5.26	5.47	5.70	5.95	6.25	6.71
21	LogNormal	4.56	4.85	5.07	5.27	5.46	5.66	5.88	6.14	6.54
22	Normal	3.43	3.85	4.15	4.42	4.66	4.91	5.16	5.47	5.89
23	LogNormal	3.46	3.81	4.09	4.34	4.59	4.85	5.15	5.52	6.08
24	Gamma	3.44	3.83	4.13	4.40	4.66	4.93	5.24	5.61	6.15
25	Gamma	3.10	3.39	3.62	3.82	4.01	4.21	4.43	4.69	5.08
26	Normal	2.57	2.93	3.18	3.40	3.60	3.81	4.03	4.28	4.64
27	LogNormal	2.73	3.00	3.21	3.40	3.60	3.80	4.03	4.31	4.74
28	Gumbel	2.09	2.66	3.01	3.28	3.51	3.72	3.92	4.14	4.41
29	LogNormal	2.88	3.11	3.27	3.42	3.56	3.70	3.86	4.05	4.33
30	LogNormal	2.74	2.99	3.18	3.35	3.51	3.68	3.86	4.09	4.41
Total (l/y/tree)		129	141	150	158	165	172	178	188	200

Table 4.29 The values of pomegranate ET (litres/day/tree) for 2nd year Pomegranate tree at different probability levels for Ahmednagar district

MW	Pdf's	Probability levels								
		10%	20%	30%	40%	50%	60%	70%	80%	90%
31	Normal	3.24	3.52	3.74	3.91	4.08	4.25	4.44	4.64	4.94
32	Log Normal	3.50	3.76	3.96	4.14	4.32	4.50	4.71	4.96	5.33
33	Log Normal	3.96	4.24	4.44	4.63	4.81	4.99	5.21	5.45	5.83
34	Weibull's	4.12	4.52	4.81	5.06	5.30	5.54	3.90	6.10	6.49
35	Log Normal	4.00	4.36	4.64	4.89	5.14	5.40	5.69	6.06	6.60
36	Gamma	4.13	4.61	4.94	5.23	5.52	5.81	6.14	6.53	7.11
37	Gumbel	4.34	5.02	5.44	5.76	6.04	6.29	6.54	6.80	7.12
38	Log Normal	5.10	5.45	5.72	5.96	6.20	6.44	6.71	7.05	7.54
39	Gamma	5.31	5.72	6.03	6.30	6.57	6.83	7.13	7.49	8.01
40	Normal	5.51	5.95	6.26	6.54	6.79	7.04	7.31	7.63	8.07
41	Gamma	5.91	6.31	6.61	6.87	7.12	7.37	7.66	7.99	8.48
42	Log Normal	6.12	6.52	6.83	7.10	7.36	7.64	7.94	8.32	8.86
43	Weibull's	6.30	6.80	7.17	7.49	7.79	8.09	8.41	8.77	9.26
44	Weibull's	6.53	7.00	7.35	7.65	7.02	8.21	8.50	8.84	9.28
45	Weibull's	6.51	6.94	7.27	7.55	7.83	8.11	8.41	8.78	9.28
46	Log Normal	6.36	6.73	7.00	7.25	7.48	7.73	8.00	8.33	8.81
47	Gumbel	5.44	6.15	6.59	6.93	7.22	7.49	7.75	8.02	8.36
48	Weibull's	5.45	6.12	6.54	6.86	7.13	7.38	7.62	7.88	8.20
49	Gamma	5.62	6.05	6.38	6.66	6.93	7.21	7.52	7.90	8.43
50	Gamma	5.48	5.91	6.23	6.52	6.79	7.07	7.39	7.76	8.30
51	Gumbel	5.81	6.60	7.10	7.48	7.80	8.10	8.39	8.70	9.08
52	Weibull's	5.42	5.89	6.23	6.51	6.78	7.05	7.33	7.65	8.06
1	Weibull's	5.09	5.61	5.97	6.26	6.51	6.75	6.99	7.25	7.54
2	Normal	5.15	5.57	5.88	6.13	6.38	6.62	6.88	7.19	7.61
3	Gumbel	4.71	5.50	5.99	6.37	6.69	6.98	7.27	7.57	7.95
4	Normal	5.37	5.82	6.15	6.43	6.69	6.95	7.23	7.56	8.01
5	Log Normal	5.34	5.74	6.05	6.33	6.59	6.87	7.19	7.57	8.14
6	Normal	5.58	6.00	6.29	6.56	6.78	7.02	7.29	7.58	8.00
7	Log Normal	5.57	5.97	6.27	6.54	6.81	7.09	7.40	7.78	8.34
8	Weibull's	5.43	6.04	6.46	6.81	7.11	7.40	7.69	7.99	8.34
9	Gumbel	5.74	6.49	6.95	7.31	7.62	7.90	8.17	8.46	8.81
10	Gumbel	5.29	6.05	6.52	6.88	7.19	7.47	7.75	8.04	8.40
11	Weibull's	5.58	5.99	6.28	6.53	6.77	7.00	7.25	7.53	7.90
12	Gumbel	5.34	6.07	6.52	6.87	7.16	7.43	7.69	7.97	8.31
13	Weibull's	6.05	6.60	6.98	7.30	7.58	7.86	8.13	8.42	8.78
14	Weibull's	6.32	6.82	7.18	7.48	7.76	8.02	8.30	8.61	9.00
15	Normal	6.81	7.26	7.59	7.86	8.12	8.38	8.66	8.98	9.43
16	Gumbel	5.24	6.05	6.56	6.95	7.28	7.58	7.87	8.19	8.57
17	LogNormal	5.90	6.36	6.74	7.07	7.39	7.73	8.11	8.57	9.27
18	LogNormal	6.08	6.63	7.05	7.44	7.82	8.22	8.67	9.22	10.05
19	Gumbel	6.12	6.82	7.25	7.58	7.86	8.12	8.38	8.65	8.98
20	LogNormal	6.70	7.18	7.55	7.89	8.21	8.54	8.92	9.38	10.06
21	LogNormal	6.83	7.27	7.60	7.90	8.19	8.48	8.81	9.22	9.80
22	Normal	5.14	5.77	6.23	6.62	6.99	7.37	7.75	8.21	8.84
23	LogNormal	5.19	5.71	6.13	6.50	6.88	7.27	7.72	8.28	9.12
24	Gamma	5.16	5.75	6.20	6.60	6.99	7.40	7.85	8.41	9.22
25	Gamma	4.65	5.09	5.43	5.72	6.01	6.31	6.64	7.04	7.62
26	Normal	3.85	4.39	4.77	5.09	5.40	5.72	6.04	6.42	6.96
27	LogNormal	4.09	4.50	4.82	5.11	5.39	5.70	6.04	6.47	7.11
28	Gumbel	3.14	3.99	4.52	4.92	5.26	5.58	5.89	6.21	6.62
29	LogNormal	4.33	4.66	4.91	5.13	5.34	5.56	5.79	6.08	6.50
30	LogNormal	4.11	4.48	4.77	5.02	5.26	5.52	5.79	6.13	6.61
Total (l/y/tree)		274	300	319	334	348	363	377	397	421

4.4.6.2.3 3rd Year

Weekly values of pomegranate ET at different probability levels are presented in Table 4.30 for 3rd year tree. It is seen from the table that the weekly values of pomegranate ET are low during initial stage and tends to increase during crop development stages. It is observed from the Table that at 70% probability level weekly pomegranate ET ranges from 3.39 to 32.9 litres/day/tree. Maximum values of pomegranate ET are observed in 20th week. These values are 34.6, 32.9, 30.3 and 26.8 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. Minimum values of the pomegranate ET are observed in 31st week. These are 3.54, 3.39, 3.11 and 2.69 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. The total pomegranate ET at 70% probability level over a period of 52 weeks of phonological stages is 1124.3 litres/year/tree.

4.4.6.2.4 4th Year

Weekly values of pomegranate ET at different probability levels are presented in Table 4.31 for 4th year tree. It is seen from the table that the weekly values of pomegranate ET are low during initial stage and tends to increase during crop development stages. It is observed from the Table that at 70% probability level weekly pomegranate ET ranges from 4.70 to 46.8 litres/day/tree. Maximum values of pomegranate ET are observed in 20th. These values are 49.2, 46.8, 43.1 and 38.1 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. Minimum values of the pomegranate ET are observed in 31st week. These are 4.92, 4.70, 4.32 and 3.73 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. The total pomegranate ET at 70% probability level over a period of 52 weeks of phonological stages is 1566.2 litres/year/tree.

4.4.6.2.5 5th Year

Weekly values of pomegranate ET at different probability levels are presented in Table 4.32 for 5th year tree. It is seen from the table that the weekly values of pomegranate ET are low during initial stage and tends to increase during crop development stages. It is observed from the Table that at 70% probability level weekly pomegranate ET ranges from 5.81 to 50.7 litres/day/tree. Maximum values of pomegranate ET are observed in 15th week. These values are 52.6, 50.7, 47.5 and 42.5 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. Minimum values of the pomegranate ET are observed in 31st week. These are 6.08,

Table 4.30 The values of pomegranate ET (litres/day/tree) for 3rd year Pomegranate tree at different probability levels for Ahmednagar district

MW	Pdf's	Probability levels								
		10%	20%	30%	40%	50%	60%	70%	80%	90%
31	Normal	2.5	2.7	2.9	3.0	3.1	3.2	3.4	3.5	3.8
32	Log Normal	3.2	3.5	3.6	3.8	4.0	4.1	4.3	4.6	4.9
33	Log Normal	4.3	4.6	4.8	5.1	5.3	5.5	5.7	6.0	6.4
34	Weibull's	5.4	5.9	6.3	6.6	6.9	7.2	5.1	7.9	8.4
35	Log Normal	6.1	6.7	7.1	7.5	7.9	8.3	8.7	9.3	10.1
36	Gamma	7.2	8.0	8.6	9.1	9.6	10.1	10.7	11.4	12.4
37	Gumbel	8.2	9.5	10.3	10.9	11.4	11.9	12.3	12.8	13.5
38	Log Normal	10.5	11.2	11.8	12.2	12.7	13.2	13.8	14.5	15.5
39	Gamma	12.5	13.4	14.2	14.8	15.4	16.1	16.8	17.6	18.8
40	Normal	13.9	15.0	15.8	16.5	17.1	17.7	18.4	19.2	20.3
41	Gamma	15.6	16.6	17.4	18.1	18.7	19.4	20.1	21.0	22.3
42	Log Normal	17.0	18.2	19.0	19.8	20.5	21.3	22.1	23.2	24.7
43	Weibull's	17.5	18.9	19.9	20.8	21.6	22.5	23.4	24.4	25.7
44	Weibull's	18.5	19.9	20.8	21.7	19.9	23.3	24.1	25.1	26.3
45	Weibull's	18.7	20.0	20.9	21.7	22.5	23.3	24.2	25.3	26.7
46	Log Normal	18.2	19.2	20.0	20.7	21.4	22.1	22.9	23.8	25.2
47	Gumbel	15.5	17.5	18.8	19.7	20.5	21.3	22.0	22.8	23.8
48	Weibull's	15.5	17.4	18.5	19.4	20.2	20.9	21.6	22.3	23.2
49	Gamma	15.9	17.1	18.0	18.8	19.6	20.4	21.3	22.3	23.8
50	Gamma	15.5	16.7	17.6	18.4	19.2	20.0	20.9	22.0	23.5
51	Gumbel	16.5	18.7	20.1	21.2	22.1	23.0	23.8	24.6	25.7
52	Weibull's	15.4	16.7	17.6	18.5	19.2	20.0	20.8	21.7	22.8
1	Weibull's	14.4	15.9	16.9	17.7	18.4	19.1	19.8	20.5	21.3
2	Normal	14.6	15.8	16.6	17.3	18.0	18.7	19.5	20.3	21.5
3	Gumbel	13.3	15.5	16.9	17.9	18.8	19.6	20.5	21.3	22.4
4	Normal	15.3	16.6	17.5	18.3	19.0	19.8	20.6	21.5	22.8
5	Log Normal	15.6	16.8	17.7	18.5	19.3	20.1	21.0	22.2	23.8
6	Normal	16.9	18.2	19.1	19.9	20.5	21.3	22.1	23.0	24.2
7	Log Normal	17.5	18.8	19.8	20.6	21.5	22.3	23.3	24.5	26.3
8	Weibulls	17.3	19.2	20.5	21.6	22.6	23.5	24.4	25.4	26.5
9	Gumbel	18.5	20.9	22.4	23.6	24.6	25.5	26.3	27.3	28.4
10	Gumbel	17.6	20.1	21.6	22.9	23.9	24.8	25.7	26.7	27.9
11	Weibull's	19.7	21.1	22.1	23.0	23.9	24.7	25.6	26.6	27.9
12	Gumbel	18.9	21.5	23.1	24.3	25.4	26.3	27.2	28.2	29.5
13	Weibull's	18.6	20.3	21.4	22.4	23.3	24.1	24.9	25.8	26.9
14	Weibull's	19.3	20.8	21.9	22.9	23.7	24.5	25.4	26.3	27.5
15	Normal	20.8	22.2	23.2	24.0	24.8	25.6	26.5	27.4	28.8
16	Gumbel	19.62	22.66	24.55	26.00	27.24	28.37	29.47	30.64	32.09
17	LogNormal	22.06	23.81	25.21	26.45	27.63	28.93	30.33	32.08	34.67
18	LogNormal	22.73	24.78	26.37	27.82	29.23	30.73	32.40	34.48	37.59
19	Gumbel	22.73	25.31	26.92	28.16	29.21	30.17	31.11	32.11	33.34
20	LogNormal	24.72	26.52	27.88	29.11	30.30	31.54	32.93	34.63	37.13
21	LogNormal	25.21	26.82	28.05	29.14	30.20	31.29	32.51	34.00	36.17
22	Normal	18.90	21.22	22.91	24.36	25.70	27.10	28.49	30.18	32.50
23	LogNormal	19.09	21.03	22.55	23.93	25.31	26.76	28.40	30.46	33.55
24	Gamma	18.90	21.05	22.70	24.18	25.62	27.11	28.78	30.81	33.78
25	Gamma	17.09	18.71	19.96	21.05	22.11	23.21	24.42	25.89	28.02
26	Normal	14.11	16.10	17.48	18.68	19.82	20.96	22.16	23.54	25.52
27	LogNormal	14.78	16.25	17.41	18.45	19.49	20.59	21.83	23.38	25.71
28	Gumbel	11.26	14.29	16.18	17.63	18.87	20.00	21.10	22.27	23.71
29	LogNormal	15.42	16.61	17.49	18.27	19.03	19.80	20.66	21.68	23.16
30	LogNormal	14.58	15.92	16.93	17.82	18.69	19.59	20.57	21.77	23.48
Total (l/y/tree)		813	892	947	994	1035	1081	1124	1180	1254

Table 4.31 The values of pomegranate ET (litres/day/tree) for 4th year Pomegranate tree at different probability levels for Ahmednagar district

MW	Pdf's	Probability levels								
		10%	20%	30%	40%	50%	60%	70%	80%	90%
31	Normal	3.4	3.7	4.0	4.1	4.3	4.5	4.7	4.9	5.2
32	Log Normal	4.9	5.2	5.5	5.8	6.0	6.3	6.5	6.9	7.4
33	Log Normal	6.6	7.1	7.4	7.8	8.1	8.4	8.7	9.1	9.8
34	Weibull's	8.1	8.8	9.4	9.9	10.4	10.8	7.6	11.9	12.7
35	Log Normal	8.9	9.7	10.3	10.9	11.4	12.0	12.6	13.4	14.7
36	Gamma	10.3	11.5	12.4	13.1	13.8	14.5	15.4	16.3	17.8
37	Gumbel	11.8	13.6	14.7	15.6	16.4	17.1	17.7	18.4	19.3
38	Log Normal	15.6	16.7	17.5	18.3	19.0	19.7	20.6	21.6	23.1
39	Gamma	17.4	18.8	19.8	20.7	21.5	22.4	23.4	24.6	26.2
40	Normal	19.1	20.6	21.7	22.7	23.5	24.4	25.4	26.5	28.0
41	Gamma	21.3	22.8	23.9	24.8	25.7	26.6	27.6	28.8	30.6
42	Log Normal	23.3	24.9	26.0	27.1	28.1	29.1	30.3	31.7	33.8
43	Weibull's	23.9	25.9	27.3	28.5	29.6	30.8	32.0	33.4	35.2
44	Weibull's	25.2	27.1	28.4	29.5	27.1	31.7	32.8	34.1	35.8
45	Weibull's	25.1	26.8	28.0	29.1	30.2	31.3	32.5	33.9	35.8
46	Log Normal	24.4	25.8	26.8	27.8	28.7	29.6	30.6	31.9	33.7
47	Gumbel	20.8	23.5	25.2	26.5	27.6	28.6	29.6	30.7	32.0
48	Weibull's	20.8	23.3	24.9	26.2	27.2	28.1	29.1	30.0	31.3
49	Gamma	21.4	23.1	24.3	25.4	26.4	27.5	28.7	30.1	32.2
50	Gamma	20.9	22.5	23.8	24.9	25.9	27.0	28.2	29.6	31.7
51	Gumbel	22.2	25.2	27.1	28.6	29.8	30.9	32.1	33.2	34.7
52	Weibull's	20.7	22.5	23.8	24.9	25.9	26.9	28.0	29.2	30.8
1	Weibull's	20.1	22.2	23.6	24.7	25.8	26.7	27.6	28.7	29.8
2	Normal	20.6	22.3	23.5	24.5	25.5	26.5	27.5	28.7	30.4
3	Gumbel	18.9	22.0	24.0	25.5	26.8	28.0	29.1	30.4	31.9
4	Normal	21.6	23.4	24.8	25.9	26.9	28.0	29.1	30.4	32.2
5	Log Normal	22.5	24.2	25.5	26.6	27.8	29.0	30.3	31.9	34.3
6	Normal	23.7	25.4	26.7	27.8	28.7	29.8	30.9	32.2	33.9
7	Log Normal	23.8	25.5	26.9	28.0	29.2	30.3	31.7	33.3	35.7
8	Weibull's	23.9	26.5	28.4	29.9	31.2	32.5	33.8	35.1	36.7
9	Gumbel	25.3	28.7	30.7	32.3	33.6	34.9	36.1	37.3	38.9
10	Gumbel	24.4	27.9	30.0	31.7	33.1	34.4	35.7	37.1	38.7
11	Weibull's	27.1	29.1	30.5	31.7	32.9	34.0	35.2	36.6	38.4
12	Gumbel	23.4	26.6	28.6	30.1	31.4	32.6	33.7	34.9	36.5
13	Weibull's	26.5	28.9	30.6	32.0	33.2	34.4	35.6	36.9	38.4
14	Weibull's	27.6	29.8	31.4	32.7	33.9	35.1	36.3	37.6	39.3
15	Normal	29.7	31.7	33.1	34.3	35.4	36.5	37.7	39.1	41.1
16	Gumbel	27.96	32.28	34.97	37.04	38.81	40.41	41.98	43.65	45.71
17	LogNormal	31.41	33.89	35.90	37.66	39.34	41.19	43.19	45.67	49.36
18	LogNormal	32.37	35.29	37.56	39.61	41.63	43.75	46.14	49.10	53.53
19	Gumbel	32.32	35.99	38.28	40.04	41.53	42.90	44.23	45.66	47.40
20	LogNormal	35.13	37.67	39.62	41.36	43.05	44.82	46.78	49.20	52.75
21	LogNormal	35.78	38.07	39.81	41.36	42.86	44.42	46.15	48.26	51.34
22	Normal	26.75	30.04	32.42	34.48	36.37	38.35	40.32	42.71	46.00
23	LogNormal	26.98	29.72	31.87	33.82	35.77	37.81	40.14	43.04	47.41
24	Gamma	26.68	29.73	32.06	34.15	36.18	38.29	40.64	43.50	47.71
25	Gamma	23.98	26.25	28.00	29.53	31.02	32.56	34.25	36.32	39.31
26	Normal	19.74	22.52	24.45	26.13	27.73	29.32	31.00	32.93	35.71
27	LogNormal	20.61	22.66	24.27	25.73	27.18	28.70	30.43	32.59	35.84
28	Gumbel	15.71	19.94	22.58	24.61	26.33	27.90	29.44	31.07	33.09
29	LogNormal	21.39	23.03	24.25	25.34	26.39	27.46	28.64	30.06	32.11
30	LogNormal	20.14	21.98	23.37	24.61	25.81	27.04	28.40	30.06	32.42
Total (l/y/tree)		1132	1242	1320	1385	1442	1506	1566	1644	1748

Table 4.32 The values of pomegranate ET (litres/day/tree) for 5th year Pomegranate tree at different probability levels for Ahmednagar district

MW	Pdf's	Probability levels								
		10%	20%	30%	40%	50%	60%	70%	80%	90%
31	Normal	4.2	4.6	4.9	5.1	5.3	5.6	5.8	6.1	6.5
32	Log Normal	6.5	7.0	7.4	7.7	8.1	8.4	8.8	9.3	10.0
33	Log Normal	9.0	9.7	10.1	10.6	11.0	11.4	11.9	12.4	13.3
34	Weibull's	11.4	12.5	13.3	14.1	14.7	15.4	10.8	16.9	18.0
35	Log Normal	12.3	13.4	14.3	15.1	15.8	16.6	17.5	18.7	20.3
36	Gamma	13.6	15.2	16.3	17.2	18.2	19.1	20.2	21.5	23.4
37	Gumbel	15.9	18.4	19.9	21.1	22.1	23.1	24.0	24.9	26.1
38	Log Normal	19.9	21.3	22.3	23.3	24.2	25.1	26.2	27.5	29.4
39	Gamma	21.9	23.6	24.9	26.0	27.1	28.2	29.4	30.9	33.0
40	Normal	24.0	26.0	27.4	28.5	29.6	30.8	31.9	33.3	35.2
41	Gamma	26.0	27.8	29.1	30.2	31.3	32.5	33.7	35.2	37.3
42	Log Normal	28.1	30.0	31.4	32.6	33.8	35.1	36.5	38.2	40.7
43	Weibull's	28.8	31.1	32.8	34.3	35.6	37.0	38.5	40.1	42.4
44	Weibull's	30.6	32.8	34.4	35.8	32.9	38.5	39.8	41.4	43.5
45	Weibull's	30.8	32.8	34.4	35.7	37.0	38.3	39.8	41.5	43.9
46	Log Normal	30.0	31.7	33.0	34.2	35.3	36.5	37.7	39.3	41.5
47	Gumbel	25.5	28.9	30.9	32.5	33.9	35.1	36.4	37.6	39.2
48	Weibull's	25.5	28.6	30.5	32.0	33.3	34.4	35.6	36.8	38.3
49	Gamma	26.2	28.2	29.7	31.0	32.3	33.6	35.0	36.8	39.3
50	Gamma	25.5	27.5	29.0	30.3	31.6	32.9	34.3	36.1	38.6
51	Gumbel	27.0	30.7	33.0	34.7	36.2	37.6	39.0	40.4	42.1
52	Weibull's	25.1	27.3	28.8	30.1	31.4	32.6	33.9	35.4	37.3
1	Weibull's	24.6	27.1	28.9	30.3	31.5	32.7	33.8	35.1	36.5
2	Normal	25.4	27.4	28.9	30.2	31.4	32.6	33.9	35.4	37.5
3	Gumbel	23.4	27.3	29.8	31.7	33.3	34.7	36.1	37.7	39.5
4	Normal	27.0	29.2	30.9	32.3	33.6	34.9	36.3	37.9	40.2
5	Log Normal	28.0	30.1	31.7	33.2	34.6	36.1	37.7	39.7	42.7
6	Normal	30.2	32.4	34.0	35.5	36.6	38.0	39.4	41.0	43.2
7	Log Normal	31.2	33.4	35.1	36.6	38.1	39.7	41.4	43.5	46.7
8	Weibull's	31.1	34.7	37.1	39.0	40.8	42.4	44.1	45.8	47.9
9	Gumbel	33.9	38.3	41.1	43.2	45.0	46.7	48.3	50.0	52.1
10	Gumbel	32.6	37.3	40.2	42.4	44.3	46.0	47.7	49.6	51.8
11	Weibull's	35.8	38.4	40.3	42.0	43.5	45.0	46.6	48.4	50.7
12	Gumbel	31.7	36.0	38.6	40.7	42.4	44.0	45.6	47.2	49.3
13	Weibull's	35.7	39.0	41.2	43.1	44.8	46.4	48.0	49.7	51.8
14	Weibull's	37.2	40.1	42.2	44.0	45.6	47.2	48.8	50.6	52.9
15	Normal	39.9	42.5	44.4	46.0	47.5	49.0	50.7	52.6	55.2
16	Gumbel	37.42	43.20	46.82	49.58	51.95	54.09	56.20	58.43	61.19
17	LogNormal	42.00	45.33	48.00	50.36	52.61	55.08	57.76	61.08	66.01
18	LogNormal	43.24	47.14	50.17	52.92	55.61	58.45	61.64	65.60	71.51
19	Gumbel	44.17	49.19	52.31	54.72	56.76	58.62	60.45	62.39	64.78
20	LogNormal	47.91	51.38	54.03	56.41	58.72	61.12	63.81	67.10	71.95
21	LogNormal	48.71	51.82	54.19	56.30	58.34	60.46	62.81	65.69	69.88
22	Normal	36.49	40.98	44.24	47.05	49.63	52.33	55.02	58.28	62.77
23	LogNormal	36.79	40.52	43.46	46.12	48.77	51.56	54.73	58.69	64.65
24	Gamma	36.47	40.63	43.81	46.67	49.44	52.33	55.55	59.46	65.20
25	Gamma	32.75	35.85	38.24	40.33	42.36	44.47	46.78	49.61	53.69
26	Normal	26.97	30.75	33.39	35.69	37.87	40.05	42.34	44.98	48.77
27	LogNormal	28.29	31.11	33.32	35.32	37.32	39.41	41.79	44.75	49.21
28	Gumbel	21.65	27.47	31.11	33.90	36.27	38.45	40.56	42.81	45.59
29	LogNormal	29.52	31.79	33.48	34.98	36.42	37.90	39.53	41.50	44.33
30	LogNormal	27.92	30.48	32.41	34.12	35.79	37.50	39.39	41.68	44.96
Total (l/y/tree)		1476	1620	1721	1807	1882	1965	2044	2146	2282

5.81, 5.34 and 4.61litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. The total pomegranate ET at 70% probability level over a period of 52 weeks of phonological stages is 1265.20 litres/year/tree.

4.4.6.3 Pune district

Weekly values of pomegranate ET at different probability levels are presented in Table 4.33 to 4.37 for 1st to 5th year's tree for 52 crop weeks of phenological development stages for Pune district.

4.4.6.3.1 1st Year

Weekly values of pomegranate ET at different probability levels are presented in Table 4.33 for 1st year tree. It is seen from the table that the weekly values of pomegranate ET are low during initial stage and tends to increase during crop development stages. It is observed from the Table that at 70% probability level weekly pomegranate ET ranges from 1.52 to 5.1 litres/day/tree. Maximum values of pomegranate ET are observed in 20th week. These values are 5.25, 5.07, 4.81 and 4.32 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. Minimum values of the pomegranate ET are observed in 31st week. These are 1.61, 1.52, 1.39 and 1.16 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. The total pomegranate ET at 70% probability level over a period of 52 weeks of phonological stages is 150litres/year/tree.

4.4.6.3.2 2nd Year

Weekly values of pomegranate ET at different probability levels are presented in Table 4.34 for 2nd year tree. It is seen from the table that the weekly values of pomegranate ET are low during initial stage and tends to increase during crop development stages. It is observed from the table that at 70% probability level weekly pomegranate ET ranges from 3.33 to 8.1 litres/day/tree. Maximum values of pomegranate ET are observed in 38th week. These values are 8.3, 8.1, 7.6 and 6.8 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. Minimum values of the pomegranate ET are observed in 31st week. These are 3.52, 3.33, 3.04 and 2.25 l/d/t at probability levels 80%, 70%, 50% and 20% respectively. The total pomegranate ET at 70% probability level over a period of 52 weeks of phonological stages is 318.2 litres/year/tree.

Table 4.33 The values of pomegranate ET (litres/day/tree) for 1st year pomegranate tree at different probability levels for Pune district

MW	Pdf's	Probability levels								
		10%	20%	30%	40%	50%	60%	70%	80%	90%
31	Normal	1.08	1.22	1.33	1.41	1.49	1.58	1.66	1.76	1.91
32	Normal	1.05	1.16	1.25	1.32	1.39	1.45	1.52	1.61	1.72
33	LogNormal	1.09	1.19	1.26	1.32	1.39	1.46	1.53	1.62	1.76
34	LogNormal	1.28	1.37	1.43	1.49	1.54	1.60	1.66	1.74	1.85
35	Normal	1.37	1.46	1.52	1.57	1.62	1.67	1.73	1.79	1.87
36	Normal	1.48	1.61	1.70	1.78	1.85	1.93	2.00	2.09	2.22
37	LogNormal	1.52	1.63	1.72	1.79	1.86	1.94	2.02	2.13	2.28
38	Weibull's	1.55	1.67	1.75	1.81	1.87	1.91	1.96	2.01	2.07
39	Gumbel	1.35	1.56	1.70	1.80	1.89	1.97	2.05	2.13	2.24
40	Gumbel	1.43	1.62	1.75	1.84	1.92	2.00	2.07	2.14	2.24
41	Normal	1.59	1.70	1.79	1.86	1.92	1.99	2.07	2.15	2.26
42	LogNormal	1.63	1.73	1.80	1.87	1.94	2.00	2.08	2.17	2.30
43	Normal	1.67	1.79	1.88	1.95	2.02	2.09	2.17	2.25	2.38
44	Normal	1.60	1.73	1.83	1.91	1.98	2.06	2.14	2.24	2.37
45	Normal	1.58	1.71	1.80	1.88	1.95	2.02	2.10	2.19	2.32
46	Normal	1.51	1.63	1.72	1.79	1.86	1.93	2.00	2.09	2.21
47	Weibull's	1.34	1.52	1.63	1.72	1.80	1.87	1.94	2.01	2.09
48	Gumbel	1.33	1.51	1.62	1.70	1.78	1.85	1.91	1.98	2.07
49	Gumbel	1.48	1.59	1.66	1.72	1.76	1.81	1.85	1.89	1.95
50	Gamma	1.52	1.59	1.64	1.69	1.74	1.78	1.83	1.89	1.97
51	Gamma	1.57	1.64	1.70	1.74	1.79	1.84	1.89	1.95	2.04
52	LogNormal	1.74	1.82	1.88	1.94	1.99	2.04	2.10	2.17	2.28
1	Normal	1.49	1.58	1.65	1.71	1.77	1.83	1.89	1.96	2.05
2	Gamma	1.60	1.70	1.76	1.82	1.88	1.94	2.00	2.08	2.19
3	Gamma	1.78	1.87	1.93	1.99	2.05	2.10	2.16	2.24	2.34
4	Weibull's	1.99	2.08	2.14	2.19	2.23	2.28	2.32	2.37	2.43
5	Gumbel	2.06	2.18	2.25	2.31	2.36	2.40	2.44	2.49	2.54
6	Gumbel	2.35	2.46	2.54	2.60	2.65	2.69	2.73	2.78	2.84
7	LogNormal	2.57	2.68	2.76	2.82	2.89	2.96	3.03	3.12	3.25
8	Normal	2.76	2.88	2.96	3.03	3.10	3.17	3.24	3.33	3.45
9	Gumbel	2.89	3.07	3.19	3.27	3.35	3.41	3.48	3.55	3.64
10	Normal	3.14	3.28	3.38	3.47	3.55	3.63	3.72	3.82	3.96
11	LogNormal	3.30	3.48	3.61	3.73	3.84	3.96	4.09	4.24	4.47
12	Normal	3.15	3.29	3.40	3.49	3.57	3.65	3.74	3.85	3.99
13	Weibull's	3.18	3.33	3.45	3.56	3.67	3.79	3.92	4.08	4.33
14	Normal	3.33	3.54	3.69	3.82	3.95	4.07	4.20	4.35	4.56
15	Weibull's	3.41	3.67	3.86	4.01	4.14	4.27	4.39	4.52	4.68
16	Normal	3.61	3.81	3.95	4.07	4.19	4.31	4.43	4.57	4.77
17	Normal	3.76	4.00	4.17	4.32	4.46	4.60	4.75	4.95	5.16
18	Normal	4.03	4.23	4.39	4.51	4.63	4.75	4.88	5.03	5.24
19	Gumbel	4.00	4.32	4.52	4.68	4.81	4.93	5.05	5.17	5.33
20	Normal	4.06	4.31	4.49	4.64	4.78	4.92	5.07	5.25	5.50
21	Normal	3.75	4.05	4.27	4.46	4.63	4.80	4.99	5.21	5.51
22	Normal	3.08	3.48	3.77	4.02	4.25	4.48	4.73	5.02	5.42
23	Normal	3.07	3.42	3.67	3.89	4.09	4.29	4.50	4.75	5.11
24	LogNormal	3.10	3.40	3.62	3.84	4.05	4.27	4.51	4.82	5.29
25	Normal	2.17	2.45	2.66	2.83	2.99	3.16	3.33	3.52	3.80
26	Normal	1.87	2.13	2.32	2.48	2.63	2.79	2.95	3.14	3.40
27	LogNormal	1.98	2.18	2.34	2.48	2.63	2.78	2.95	3.16	3.49
28	Normal	2.07	2.31	2.49	2.64	2.78	2.92	3.07	3.24	3.49
29	Normal	2.11	2.26	2.37	2.46	2.55	2.64	2.73	2.84	2.99
30	LogNormal	2.17	2.30	2.40	2.48	2.57	2.65	2.75	2.87	3.04
Total (l/y/tree)		116	124	130	136	140	145	150	156	165

Table 4.34 The values of pomegranate ET (litres/day/tree) for 2nd year pomegranate tree at different probability levels for Pune district

MW	Pdf's	Probability levels								
		10%	20%	30%	40%	50%	60%	70%	80%	90%
31	Normal	2.3	2.5	2.8	2.9	3.1	3.3	3.5	3.7	4.0
32	Normal	2.3	2.6	2.7	2.9	3.0	3.2	3.3	3.5	3.8
33	LogNormal	2.5	2.7	2.9	3.0	3.2	3.3	3.5	3.7	4.0
34	LogNormal	3.0	3.2	3.4	3.5	3.7	3.8	3.9	4.1	4.4
35	Normal	3.4	3.6	3.7	3.9	4.0	4.1	4.2	4.4	4.6
36	Normal	3.8	4.1	4.4	4.6	4.8	5.0	5.2	5.4	5.7
37	LogNormal	4.1	4.3	4.6	4.8	5.0	5.2	5.4	5.7	6.1
38	Weibull's	4.2	4.6	4.8	5.0	5.1	5.3	5.4	5.5	5.7
39	Gumbel	3.8	4.5	4.8	5.1	5.4	5.6	5.8	6.1	6.4
40	Gumbel	4.2	4.8	5.1	5.4	5.6	5.9	6.1	6.3	6.6
41	Normal	4.9	5.2	5.5	5.7	5.9	6.1	6.3	6.6	6.9
42	LogNormal	5.1	5.4	5.6	5.8	6.0	6.2	6.4	6.7	7.1
43	Normal	5.5	5.9	6.2	6.4	6.7	6.9	7.1	7.4	7.8
44	Normal	5.5	6.0	6.3	6.6	6.8	7.1	7.4	7.7	8.1
45	Normal	5.6	6.1	6.4	6.7	6.9	7.2	7.5	7.8	8.2
46	Normal	5.3	5.7	6.0	6.3	6.6	6.8	7.0	7.4	7.8
47	Weibull's	4.7	5.3	5.7	6.0	6.3	6.6	6.8	7.1	7.3
48	Gumbel	4.6	5.2	5.6	5.9	6.2	6.4	6.7	6.9	7.2
49	Gumbel	5.1	5.5	5.7	5.9	6.1	6.2	6.4	6.5	6.7
50	Gamma	5.2	5.5	5.7	5.8	6.0	6.2	6.3	6.5	6.8
51	Gamma	5.4	5.6	5.8	6.0	6.1	6.3	6.5	6.7	7.0
52	LogNormal	5.9	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.8
1	Normal	4.6	4.9	5.1	5.3	5.5	5.7	5.8	6.1	6.4
2	Gamma	4.7	5.0	5.2	5.4	5.5	5.7	5.9	6.1	6.4
3	Gamma	5.0	5.2	5.4	5.6	5.7	5.9	6.0	6.2	6.5
4	Weibull's	5.3	5.5	5.7	5.8	5.9	6.0	6.2	6.3	6.5
5	Gumbel	5.1	5.4	5.6	5.7	5.8	5.9	6.0	6.1	6.3
6	Gumbel	5.4	5.7	5.9	6.0	6.1	6.2	6.3	6.4	6.5
7	LogNormal	5.6	5.8	6.0	6.1	6.3	6.4	6.6	6.8	7.1
8	Normal	5.6	5.9	6.1	6.2	6.3	6.5	6.6	6.8	7.0
9	Gumbel	5.6	5.9	6.1	6.3	6.5	6.6	6.7	6.8	7.0
10	Normal	5.6	5.9	6.1	6.2	6.4	6.5	6.7	6.8	7.1
11	LogNormal	5.3	5.6	5.8	6.0	6.2	6.4	6.6	6.9	7.2
12	Normal	5.7	6.0	6.2	6.4	6.5	6.7	6.8	7.0	7.3
13	Weibulls	5.8	6.1	6.3	6.5	6.7	6.9	7.2	7.5	7.9
14	Normal	6.1	6.5	6.8	7.0	7.2	7.5	7.7	8.0	8.4
15	Weibull's	6.3	6.8	7.1	7.4	7.6	7.8	8.1	8.3	8.6
16	Normal	5.41	5.71	5.93	6.11	6.29	6.46	6.64	6.86	7.16
17	Normal	5.64	6.00	6.26	6.48	6.69	6.90	7.13	7.43	7.75
18	Normal	6.04	6.35	6.58	6.77	6.95	7.13	7.33	7.55	7.86
19	Gumbel	6.00	6.48	6.79	7.02	7.21	7.39	7.57	7.76	7.99
20	Normal	6.09	6.46	6.73	6.96	7.17	7.38	7.61	7.88	8.25
21	Normal	5.62	6.08	6.40	6.68	6.94	7.20	7.48	7.81	8.26
22	Normal	4.61	5.22	5.65	6.02	6.37	6.72	7.09	7.53	8.13
23	Normal	4.60	5.13	5.51	5.83	6.13	6.43	6.76	7.13	7.66
24	LogNormal	4.65	5.10	5.43	5.76	6.08	6.40	6.77	7.23	7.94
25	Normal	3.26	3.68	3.99	4.25	4.49	4.73	4.99	5.28	5.71
26	Normal	2.81	3.20	3.48	3.72	3.95	4.18	4.42	4.70	5.10
27	LogNormal	2.97	3.27	3.51	3.73	3.94	4.17	4.43	4.75	5.23
28	Normal	3.10	3.47	3.73	3.96	4.17	4.38	4.60	4.87	5.23
29	Normal	3.16	3.39	3.55	3.69	3.83	3.96	4.10	4.26	4.49
30	LogNormal	3.26	3.45	3.59	3.73	3.85	3.98	4.13	4.30	4.56
Total (l/y/tree)		245	264	277	288	298	308	318	331	348

4.4.6.3.3 3rd Year

Weekly values of pomegranate ET at different probability levels are presented in Table 4.35 for 3rd year tree. It is seen from the table that the weekly values of pomegranate ET are low during initial stage and tends to increase during crop development stages. It is observed from the table that at 70% probability level weekly pomegranate ET ranges from 2.63 to 28.1 litres/day/tree. Maximum values of pomegranate ET are observed in 20th week. These values are 29.1, 28.1, 26.8 and 24.1 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. Minimum values of the pomegranate ET are observed in 31st week. These are 2.79, 2.63, 2.37 and 1.94 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. The total pomegranate ET at 70% probability level over a period of 52 weeks of phenological stages is 953.3 litres/year/tree.

4.4.6.3.4 4th Year

Weekly values of pomegranate ET at different probability levels are presented in Table 4.36 for 4th year tree. It is seen from the table that the weekly values of pomegranate ET are low during initial stage and tends to increase during crop development stages. It is observed from the Table that at 70% probability level weekly pomegranate ET ranges from 3.66 to 40.0 litres/day/tree. Maximum values of pomegranate ET are observed in 20th week. These values are 41.3, 40.3, 38.1 and 34.2 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. Minimum values of the pomegranate ET are observed in 31st week. These are 3.88, 3.66, 3.29 and 2.69 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. The total pomegranate ET at 70% probability level over a period of 52 weeks of phenological stages is 1327.2 litres/year/tree.

4.4.6.3.4 5th Year

Weekly values of pomegranate ET at different probability levels are presented in Table 4.37 for 5th year tree. It is seen from the table that the weekly values of pomegranate ET are low during initial stage and tends to increase during crop development stages. It is observed from the Table that at 70% probability level weekly pomegranate ET ranges from 4.52 to 54.4.2 litres/day/tree. Maximum values of pomegranate ET are observed in 20th week. These values are 56.4, 54.6, 52.1 and 46.6 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. Minimum values of the pomegranate ET are observed in 31st week. These are 4.79, 4.52, 4.06 and 3.33 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively.

Table 4.35 The values of pomegranate ET (litres/day/tree) for 3rd year pomegranate tree at different probability levels for Pune district

MW	Pdf's	Probability levels								
		10%	20%	30%	40%	50%	60%	70%	80%	90%
31	Normal	1.7	1.9	2.1	2.2	2.4	2.5	2.6	2.8	3.0
32	Normal	2.1	2.3	2.5	2.7	2.8	2.9	3.1	3.2	3.5
33	LogNormal	2.7	3.0	3.2	3.3	3.5	3.6	3.8	4.1	4.4
34	LogNormal	4.0	4.2	4.4	4.6	4.7	4.9	5.1	5.4	5.7
35	Normal	5.2	5.5	5.7	5.9	6.1	6.3	6.5	6.7	7.1
36	Normal	6.6	7.2	7.6	8.0	8.3	8.6	9.0	9.4	9.9
37	LogNormal	7.7	8.2	8.6	9.0	9.4	9.8	10.2	10.7	11.5
38	Weibull's	8.7	9.4	9.9	10.2	10.5	10.8	11.1	11.3	11.7
39	Gumbel	9.0	10.5	11.4	12.1	12.7	13.2	13.7	14.3	15.0
40	Gumbel	10.5	12.0	12.9	13.6	14.2	14.8	15.3	15.9	16.6
41	Normal	12.8	13.7	14.4	14.9	15.5	16.0	16.6	17.3	18.2
42	LogNormal	14.1	14.9	15.6	16.2	16.7	17.3	17.9	18.7	19.9
43	Normal	15.3	16.4	17.2	17.9	18.5	19.1	19.9	20.7	21.8
44	Normal	15.6	16.9	17.8	18.6	19.3	20.1	20.9	21.8	23.1
45	Normal	16.1	17.4	18.4	19.2	19.9	20.7	21.5	22.4	23.7
46	Normal	15.2	16.4	17.3	18.0	18.8	19.4	20.1	21.1	22.3
47	Weibull's	13.4	15.1	16.3	17.2	18.0	18.7	19.4	20.1	20.8
48	Gumbel	13.1	14.9	16.0	16.8	17.6	18.2	18.9	19.6	20.4
49	Gumbel	14.4	15.5	16.2	16.8	17.2	17.6	18.0	18.5	19.0
50	Gamma	14.8	15.6	16.1	16.5	17.0	17.4	17.9	18.5	19.3
51	Gamma	15.2	15.9	16.5	16.9	17.4	17.8	18.3	18.9	19.8
52	LogNormal	16.8	17.6	18.2	18.7	19.2	19.7	20.3	21.0	22.0
1	Normal	13.0	13.9	14.5	15.0	15.5	16.0	16.5	17.1	18.0
2	Gamma	13.3	14.1	14.7	15.2	15.7	16.1	16.7	17.3	18.2
3	Gamma	14.0	14.7	15.2	15.7	16.1	16.5	17.0	17.6	18.4
4	Weibull's	15.1	15.7	16.1	16.5	16.8	17.2	17.5	17.9	18.3
5	Gumbel	14.9	15.8	16.3	16.7	17.0	17.3	17.7	18.0	18.4
6	Gumbel	16.4	17.2	17.8	18.2	18.5	18.8	19.1	19.5	19.9
7	LogNormal	17.6	18.3	18.9	19.4	19.8	20.3	20.8	21.4	22.3
8	Normal	17.9	18.7	19.2	19.7	20.2	20.6	21.1	21.6	22.4
9	Gumbel	18.0	19.1	19.8	20.4	20.8	21.2	21.6	22.1	22.6
10	Normal	18.6	19.5	20.1	20.6	21.1	21.6	22.1	22.7	23.6
11	LogNormal	18.8	19.8	20.6	21.3	21.9	22.6	23.3	24.2	25.5
12	Normal	20.3	21.3	21.9	22.5	23.1	23.6	24.2	24.8	25.8
13	Weibull's	17.8	18.7	19.4	20.0	20.6	21.3	22.0	22.9	24.3
14	Normal	18.7	19.9	20.7	21.4	22.1	22.8	23.5	24.4	25.5
15	Weibull's	19.2	20.6	21.7	22.5	23.3	24.0	24.7	25.4	26.3
16	Normal	20.25	21.37	22.19	22.88	23.53	24.17	24.86	25.68	26.80
17	Normal	21.10	22.46	23.41	24.26	25.04	25.83	26.68	27.80	28.98
18	Normal	22.58	23.75	24.60	25.32	26.00	26.67	27.39	28.23	29.40
19	Gumbel	22.27	24.07	25.20	26.06	26.79	27.46	28.12	28.81	29.67
20	Normal	22.50	23.86	24.84	25.69	26.47	27.25	28.10	29.08	30.44
21	Normal	20.74	22.42	23.62	24.65	25.61	26.57	27.60	28.80	30.48
22	Normal	16.97	19.19	20.79	22.15	23.43	24.71	26.08	27.68	29.90
23	Normal	16.94	18.88	20.27	21.46	22.57	23.68	24.86	26.24	28.19
24	LogNormal	17.02	18.67	19.91	21.09	22.26	23.44	24.80	26.51	29.10
25	Normal	11.98	13.53	14.66	15.62	16.51	17.41	18.36	19.43	20.98
26	Normal	10.29	11.73	12.77	13.66	14.49	15.32	16.21	17.25	18.69
27	LogNormal	10.73	11.82	12.68	13.46	14.24	15.06	15.99	17.15	18.90
28	Normal	11.12	12.43	13.37	14.18	14.93	15.69	16.50	17.44	18.75
29	Normal	11.27	12.08	12.67	13.17	13.64	14.10	14.61	15.20	16.01
30	LogNormal	11.56	12.24	12.77	13.23	13.68	14.14	14.65	15.27	16.18
Total (l/y/tree)		736	791	829	861	891	921	953	990	1040

Table 4.36 The values of pomegranate ET (litres/day/tree) for 4th year pomegranate tree at different probability levels for Pune district

MW	Pdf's	Probability levels								
		10%	20%	30%	40%	50%	60%	70%	80%	90%
31	Normal	2.4	2.7	2.9	3.1	3.3	3.5	3.7	3.9	4.2
32	Normal	3.2	3.5	3.8	4.0	4.2	4.4	4.6	4.9	5.2
33	LogNormal	4.2	4.6	4.8	5.1	5.3	5.6	5.9	6.3	6.8
34	LogNormal	5.9	6.3	6.6	6.9	7.1	7.4	7.7	8.1	8.6
35	Normal	7.5	8.0	8.3	8.6	8.9	9.1	9.4	9.8	10.2
36	Normal	9.6	10.4	11.0	11.5	11.9	12.4	12.9	13.5	14.3
37	LogNormal	11.0	11.8	12.4	12.9	13.5	14.0	14.6	15.4	16.5
38	Weibull's	13.0	14.1	14.8	15.3	15.7	16.1	16.5	16.9	17.4
39	Gumbel	12.6	14.6	15.9	16.9	17.7	18.4	19.2	20.0	20.9
40	Gumbel	14.5	16.5	17.8	18.8	19.6	20.3	21.1	21.8	22.8
41	Normal	17.5	18.8	19.8	20.5	21.2	22.0	22.8	23.8	25.0
42	LogNormal	19.3	20.5	21.3	22.1	22.9	23.7	24.6	25.7	27.2
43	Normal	21.0	22.5	23.6	24.5	25.3	26.2	27.2	28.3	29.8
44	Normal	21.2	23.0	24.3	25.3	26.3	27.4	28.4	29.7	31.5
45	Normal	21.6	23.4	24.6	25.7	26.7	27.7	28.8	30.0	31.8
46	Normal	20.4	21.9	23.2	24.2	25.1	26.0	27.0	28.2	29.8
47	Weibull's	18.0	20.3	21.9	23.1	24.1	25.1	26.0	27.0	28.0
48	Gumbel	17.6	20.0	21.5	22.6	23.6	24.5	25.4	26.3	27.5
49	Gumbel	19.5	21.0	21.9	22.6	23.2	23.8	24.3	24.9	25.6
50	Gamma	20.0	21.0	21.7	22.3	22.9	23.5	24.1	24.9	26.0
51	Gamma	20.5	21.5	22.2	22.8	23.4	24.0	24.7	25.5	26.6
52	LogNormal	22.6	23.7	24.5	25.2	25.9	26.6	27.3	28.3	29.6
1	Normal	18.2	19.4	20.3	21.0	21.7	22.4	23.1	24.0	25.2
2	Gamma	18.8	19.9	20.7	21.5	22.1	22.8	23.6	24.5	25.8
3	Gamma	19.9	20.9	21.7	22.3	22.9	23.5	24.2	25.1	26.2
4	Weibull's	21.3	22.2	22.8	23.4	23.9	24.3	24.8	25.3	26.0
5	Gumbel	21.5	22.7	23.5	24.0	24.5	25.0	25.4	25.9	26.5
6	Gumbel	23.0	24.1	24.9	25.4	25.9	26.3	26.8	27.2	27.8
7	LogNormal	23.9	24.9	25.7	26.3	26.9	27.5	28.2	29.1	30.3
8	Normal	24.7	25.8	26.6	27.2	27.9	28.5	29.1	29.9	31.0
9	Gumbel	24.6	26.2	27.1	27.9	28.5	29.1	29.6	30.2	31.0
10	Normal	25.9	27.0	27.9	28.6	29.3	30.0	30.7	31.5	32.7
11	LogNormal	25.9	27.3	28.3	29.3	30.2	31.1	32.1	33.3	35.1
12	Normal	25.2	26.3	27.2	27.9	28.5	29.2	29.9	30.7	31.9
13	Weibull's	25.4	26.7	27.6	28.5	29.4	30.3	31.4	32.7	34.7
14	Normal	26.7	28.4	29.6	30.7	31.6	32.6	33.6	34.9	36.5
15	Weibull's	27.3	29.4	30.9	32.1	33.2	34.2	35.2	36.3	37.5
16	Normal	28.84	30.45	31.60	32.59	33.51	34.43	35.42	36.58	38.18
17	Normal	30.05	31.97	33.33	34.53	35.66	36.78	37.98	39.58	41.27
18	Normal	32.16	33.83	35.03	36.05	37.02	37.98	39.01	40.21	41.87
19	Gumbel	31.67	34.23	35.83	37.05	38.10	39.05	39.98	40.97	42.20
20	Normal	31.96	33.90	35.30	36.49	37.61	38.72	39.92	41.32	43.25
21	Normal	29.44	31.82	33.53	34.99	36.36	37.72	39.18	40.89	43.26
22	Normal	24.01	27.16	29.42	31.35	33.16	34.97	36.91	39.17	42.32
23	Normal	23.94	26.67	28.64	30.32	31.90	33.46	35.14	37.09	39.84
24	LogNormal	24.04	26.37	28.12	29.78	31.44	33.11	35.02	37.43	41.09
25	Normal	16.81	18.98	20.57	21.91	23.16	24.42	25.76	27.26	29.44
26	Normal	14.39	16.41	17.86	19.11	20.26	21.43	22.68	24.13	26.15
27	LogNormal	14.96	16.48	17.68	18.77	19.85	20.99	22.29	23.91	26.35
28	Normal	15.52	17.35	18.66	19.79	20.84	21.90	23.02	24.34	26.17
29	Normal	15.63	16.75	17.57	18.26	18.91	19.56	20.26	21.07	22.20
30	LogNormal	15.96	16.91	17.62	18.27	18.88	19.52	20.23	21.09	22.34
Total(l/y/tree)		1025	1101	1154	1199	1241	1283	1327	1378	1449

Table 4.37 The values of pomegranate ET (litres/day/tree) for 5th year pomegranate tree at different probability levels for Pune district

MW	Pdf's	Probability levels								
		10%	20%	30%	40%	50%	60%	70%	80%	90%
31	Normal	2.9	3.3	3.6	3.8	4.1	4.3	4.5	4.8	5.2
32	Normal	4.3	4.8	5.1	5.4	5.7	5.9	6.2	6.6	7.0
33	LogNormal	5.7	6.2	6.6	6.9	7.3	7.6	8.0	8.5	9.2
34	LogNormal	8.4	9.0	9.4	9.8	10.1	10.5	10.9	11.4	12.2
35	Normal	10.4	11.1	11.5	11.9	12.3	12.7	13.1	13.6	14.2
36	Normal	12.6	13.6	14.4	15.1	15.7	16.3	17.0	17.7	18.8
37	LogNormal	14.9	15.9	16.7	17.5	18.2	18.9	19.7	20.8	22.2
38	Weibull's	16.6	17.9	18.8	19.4	20.0	20.5	21.0	21.5	22.2
39	Gumbel	15.8	18.4	20.0	21.2	22.3	23.2	24.1	25.1	26.3
40	Gumbel	18.3	20.8	22.4	23.6	24.7	25.6	26.5	27.5	28.7
41	Normal	21.4	23.0	24.1	25.0	25.9	26.8	27.8	29.0	30.4
42	LogNormal	23.2	24.7	25.7	26.7	27.6	28.6	29.6	30.9	32.8
43	Normal	25.2	27.1	28.4	29.4	30.5	31.5	32.7	34.0	35.9
44	Normal	25.8	27.9	29.4	30.7	32.0	33.2	34.5	36.0	38.2
45	Normal	26.5	28.7	30.2	31.5	32.7	34.0	35.3	36.8	39.0
46	Normal	25.1	27.0	28.5	29.8	31.0	32.0	33.2	34.7	36.7
47	Weibull's	22.1	24.9	26.8	28.3	29.6	30.8	31.9	33.1	34.3
48	Gumbel	21.6	24.5	26.3	27.7	28.9	30.0	31.1	32.2	33.6
49	Gumbel	23.8	25.6	26.8	27.6	28.4	29.1	29.7	30.4	31.3
50	Gamma	24.4	25.5	26.4	27.2	27.9	28.6	29.4	30.4	31.7
51	Gamma	24.9	26.1	27.0	27.7	28.5	29.2	30.0	31.0	32.4
52	LogNormal	27.4	28.7	29.7	30.5	31.4	32.2	33.1	34.3	35.9
1	Normal	22.3	23.8	24.8	25.7	26.5	27.4	28.3	29.3	30.8
2	Gamma	23.2	24.6	25.6	26.4	27.3	28.1	29.0	30.2	31.8
3	Gamma	24.7	26.0	26.9	27.7	28.4	29.2	30.1	31.1	32.5
4	Weibull's	26.6	27.7	28.5	29.1	29.7	30.3	30.9	31.6	32.4
5	Gumbel	26.7	28.3	29.2	29.9	30.5	31.1	31.7	32.2	33.0
6	Gumbel	29.3	30.8	31.7	32.4	33.0	33.6	34.1	34.7	35.4
7	LogNormal	31.3	32.6	33.5	34.4	35.2	36.0	36.9	38.0	39.6
8	Normal	32.3	33.7	34.7	35.6	36.4	37.2	38.0	39.0	40.4
9	Gumbel	33.0	35.0	36.3	37.3	38.2	38.9	39.7	40.5	41.5
10	Normal	34.6	36.2	37.3	38.3	39.2	40.1	41.0	42.1	43.7
11	LogNormal	34.3	36.1	37.5	38.7	39.9	41.1	42.4	44.0	46.4
12	Normal	34.0	35.6	36.7	37.7	38.6	39.5	40.4	41.6	43.1
13	Weibull's	34.3	36.0	37.3	38.5	39.6	40.9	42.3	44.1	46.7
14	Normal	35.9	38.2	39.8	41.2	42.5	43.8	45.2	46.9	49.1
15	Weibull's	36.7	39.5	41.5	43.1	44.5	45.9	47.2	48.7	50.4
16	Normal	38.61	40.76	42.31	43.62	44.86	46.09	47.41	48.96	51.10
17	Normal	40.18	42.75	44.58	46.18	47.68	49.18	50.79	52.93	55.18
18	Normal	42.96	45.19	46.80	48.16	49.45	50.73	52.11	53.71	55.94
19	Gumbel	43.28	46.78	48.97	50.64	52.06	53.36	54.64	55.98	57.66
20	Normal	43.59	46.23	48.14	49.77	51.29	52.81	54.44	56.35	58.99
21	Normal	40.08	43.31	45.64	47.63	49.49	51.34	53.33	55.65	58.89
22	Normal	32.76	37.05	40.14	42.78	45.25	47.72	50.36	53.45	57.74
23	Normal	32.65	36.37	39.06	41.35	43.49	45.62	47.91	50.57	54.32
24	LogNormal	32.86	36.04	38.43	40.70	42.97	45.25	47.86	51.16	56.16
25	Normal	22.96	25.93	28.10	29.93	31.64	33.35	35.18	37.24	40.21
26	Normal	19.66	22.41	24.40	26.09	27.68	29.27	30.97	32.96	35.71
27	LogNormal	20.53	22.63	24.28	25.77	27.25	28.83	30.61	32.83	36.18
28	Normal	21.38	23.90	25.71	27.26	28.71	30.17	31.72	33.53	36.05
29	Normal	21.57	23.12	24.25	25.21	26.10	26.99	27.96	29.08	30.63
30	LogNormal	22.14	23.44	24.44	25.33	26.19	27.07	28.05	29.24	30.98
Total (l/y/tree)		1336	1435	1504	1563	1618	1672	1730	1798	1891

The total pomegranate ET at 70% probability level over a period of 37 weeks of phonological stages is 1730.3 litres/year/tree.

4.4.6.4 Nasik district

Weekly values of pomegranate ET at different probability levels are presented in Table 4.38 to 4.42 for 1st to 5th year's tree for 52 crop weeks of phenological development stages for Nasik district.

4.4.6.4.1 1st Year

Weekly values of pomegranate ET at different probability levels are presented in Table 4.38 for 1st year tree. It is seen from the table that the weekly values of pomegranate ET are low during initial stage and tends to increase during crop development stages. It is observed from the Table that at 70% probability level weekly pomegranate ET ranges from 1.80 to 7.1 litres/day/tree. Maximum values of pomegranate ET are observed in 20th week. These values are 7.4, 7.1, 6.8 and 6.2 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. Minimum values of the pomegranate ET are observed in 31st week. These are 1.93, 1.80, 1.62 and 1.31 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. The total pomegranate ET at 70% probability level over a period of 52 weeks of phenological stages is 220.1 litres/year/tree.

4.4.6.4.2 2nd Year

Weekly values of pomegranate ET at different probability levels are presented in Table 4.39 for 2nd year tree. It is seen from the table that the weekly values of pomegranate ET are low during initial stage and tends to increase during crop development stages. It is observed from the table that at 70% probability level weekly pomegranate ET ranges from 3.95 to 12.3litres/day/tree. Maximum values of pomegranate ET are observed in 20th week. These values are 13.2, 12.3, 11.3 and 10.5 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. Minimum values of the pomegranate ET are observed in 31st week. These are 4.22, 3.95, 3.55 and 2.71 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. The total pomegranate ET at 70% probability level over a period of 52 weeks of phonological stages is 477.3 litres/year/tree.

4.4.6.1.3 3rd Year

Weekly values of pomegranate ET at different probability levels are presented in Table 4.40 for 3rd year tree. It is seen from the table that the weekly values of pomegranate ET are low

Table 4.38 The values of pomegranate ET (litres/day/tree) for 1st year pomegranate tree at different probability levels for Nasik district

MW	Pdf's	Probability levels								
		10%	20%	30%	40%	50%	60%	70%	80%	90%
31	Normal	1.10	1.31	1.47	1.63	1.78	1.94	2.13	2.36	2.71
32	Normal	1.24	1.36	1.45	1.54	1.62	1.71	1.80	1.93	2.11
33	Normal	1.41	1.57	1.69	1.79	1.88	1.97	2.07	2.19	2.35
34	Weibull's	1.32	1.46	1.56	1.65	1.74	1.83	1.93	2.06	2.24
35	Gamma	1.34	1.53	1.68	1.81	1.94	2.08	2.23	2.42	2.69
36	LogNormal	1.85	2.01	2.12	2.21	2.30	2.39	2.49	2.60	2.76
37	Normal	1.69	1.89	2.04	2.16	2.28	2.40	2.52	2.67	2.87
38	Normal	1.83	2.03	2.19	2.34	2.49	2.66	2.86	3.12	3.53
39	LogNormal	2.07	2.30	2.44	2.56	2.65	2.74	2.82	2.91	3.02
40	LogNormal	1.92	2.22	2.43	2.61	2.78	2.96	3.14	3.35	3.65
41	Weibull's	1.95	2.19	2.36	2.50	2.64	2.77	2.92	3.09	3.32
42	Normal	2.72	2.88	2.99	3.10	3.20	3.30	3.42	3.56	3.76
43	Normal	2.75	2.94	3.08	3.21	3.33	3.45	3.60	3.77	4.02
44	Normal	2.75	2.93	3.06	3.18	3.29	3.40	3.53	3.68	3.89
45	LogNormal	2.70	2.85	2.96	3.07	3.16	3.26	3.37	3.51	3.70
46	LogNormal	2.76	2.91	3.02	3.11	3.20	3.29	3.38	3.49	3.64
47	Normal	2.54	2.79	2.95	3.07	3.17	3.27	3.36	3.46	3.58
48	Gamma	2.62	2.75	2.84	2.93	3.01	3.10	3.19	3.30	3.45
49	Gamma	2.35	2.53	2.67	2.81	2.95	3.10	3.28	3.51	3.89
50	Normal	2.65	2.77	2.85	2.92	2.99	3.06	3.14	3.23	3.36
51	Gumbel	2.62	2.81	2.94	3.03	3.11	3.18	3.25	3.33	3.42
52	Gumbel	2.64	2.83	2.98	3.12	3.27	3.43	3.62	3.86	4.26
1	Gamma	2.51	2.72	2.85	2.95	3.04	3.11	3.19	3.27	3.37
2	Normal	2.70	2.86	2.98	3.07	3.17	3.26	3.36	3.47	3.63
3	LogNormal	3.03	3.21	3.32	3.41	3.48	3.55	3.61	3.68	3.77
4	Gumbel	3.39	3.48	3.56	3.62	3.68	3.74	3.81	3.89	4.00
5	Normal	3.59	3.74	3.85	3.94	4.03	4.12	4.22	4.34	4.50
6	Gamma	3.83	4.04	4.20	4.34	4.47	4.60	4.75	4.93	5.18
7	Gumbel	4.19	4.37	4.51	4.62	4.73	4.83	4.95	5.08	5.26
8	Gumbel	4.20	4.51	4.70	4.85	4.98	5.10	5.21	5.33	5.48
9	Gamma	4.71	4.84	4.94	5.03	5.13	5.24	5.36	5.52	5.79
10	Gumbel	4.90	5.16	5.35	5.51	5.67	5.83	6.00	6.21	6.51
11	Gumbel	4.25	5.18	5.73	6.11	6.41	6.65	6.85	7.03	7.18
12	Normal	4.92	5.12	5.29	5.45	5.61	5.79	5.99	6.26	6.70
13	Normal	5.12	5.35	5.52	5.66	5.79	5.92	6.07	6.23	6.46
14	Gamma	5.30	5.49	5.64	5.78	5.92	6.08	6.27	6.51	6.90
15	Gumbel	5.47	5.69	5.85	5.99	6.12	6.24	6.38	6.54	6.76
16	Gamma	5.34	5.70	5.96	6.18	6.39	6.59	6.82	7.07	7.43
17	LogNormal	5.94	6.17	6.33	6.48	6.61	6.76	6.91	7.10	7.36
18	LogNormal	5.93	6.20	6.40	6.58	6.75	6.93	7.12	7.35	7.68
19	Gamma	4.92	5.30	5.59	5.84	6.08	6.33	6.60	6.93	7.40
20	LogNormal	4.57	5.09	5.46	5.78	6.08	6.37	6.69	7.06	7.58
21	Normal	4.27	4.87	5.30	5.67	6.01	6.35	6.72	7.15	7.74
22	Normal	3.56	4.10	4.53	4.94	5.35	5.81	6.34	7.04	8.16
23	Gamma	3.66	4.22	4.62	4.97	5.29	5.61	5.96	6.36	6.92
24	Normal	2.97	3.40	3.71	3.98	4.23	4.47	4.74	5.05	5.48
25	Normal	2.96	3.24	3.44	3.61	3.77	3.93	4.10	4.30	4.58
26	Gamma	2.05	2.47	2.77	3.03	3.27	3.51	3.77	4.07	4.49
27	Normal	2.14	2.46	2.69	2.89	3.07	3.26	3.45	3.68	4.00
28	LogNormal	2.19	2.41	2.59	2.75	2.91	3.09	3.28	3.52	3.89
29	Normal	2.33	2.53	2.68	2.82	2.95	3.08	3.23	3.40	3.66
30	Gumbel	2.18	2.58	2.86	3.11	3.34	3.57	3.81	4.10	4.49
Total(l/y/tree)		164	177	187	195	203	211	220	230	245

Table 4.39 The values of pomegranate ET (litres/day/tree) for 2nd year pomegranate tree at different probability levels for Nasik district

M W	Pdf's	Probability levels								
		10%	20%	30%	40%	50%	60%	70%	80%	90%
31	Normal	2.3	2.7	3.1	3.4	3.7	4.0	4.4	4.9	5.6
32	Normal	2.7	3.0	3.2	3.4	3.5	3.7	4.0	4.2	4.6
33	Normal	3.2	3.6	3.9	4.1	4.3	4.5	4.8	5.0	5.4
34	Weibull's	3.1	3.4	3.7	3.9	4.1	4.3	4.6	4.9	5.3
35	Gamma	3.3	3.8	4.1	4.5	4.8	5.1	5.5	6.0	6.6
36	LogNormal	4.8	5.2	5.4	5.7	5.9	6.2	6.4	6.7	7.1
37	Normal	4.5	5.0	5.4	5.8	6.1	6.4	6.7	7.1	7.7
38	Normal	5.0	5.6	6.0	6.4	6.8	7.3	7.9	8.6	9.7
39	LogNormal	5.9	6.6	7.0	7.3	7.6	7.8	8.1	8.3	8.6
40	LogNormal	5.6	6.5	7.1	7.7	8.2	8.7	9.2	9.8	10.7
41	Weibull's	6.0	6.7	7.2	7.6	8.1	8.5	8.9	9.4	10.2
42	Normal	8.4	8.9	9.3	9.6	9.9	10.2	10.6	11.0	11.7
43	Normal	9.1	9.7	10.2	10.6	11.0	11.4	11.9	12.4	13.3
44	Normal	9.4	10.1	10.5	10.9	11.3	11.7	12.1	12.6	13.4
45	LogNormal	9.6	10.1	10.5	10.9	11.2	11.6	12.0	12.5	13.2
46	LogNormal	9.7	10.3	10.6	11.0	11.3	11.6	11.9	12.3	12.8
47	Normal	8.9	9.8	10.3	10.8	11.1	11.5	11.8	12.1	12.5
48	Gamma	9.1	9.6	9.9	10.2	10.5	10.8	11.1	11.5	12.0
49	Gamma	8.1	8.7	9.2	9.7	10.2	10.7	11.3	12.1	13.4
50	Normal	9.2	9.6	9.8	10.1	10.3	10.6	10.8	11.2	11.6
51	Gumbel	9.0	9.6	10.1	10.4	10.6	10.9	11.1	11.4	11.7
52	Gumbel	9.0	9.6	10.2	10.6	11.1	11.7	12.3	13.2	14.5
1	Gamma	7.8	8.4	8.8	9.1	9.4	9.7	9.9	10.1	10.4
2	Normal	7.9	8.4	8.8	9.0	9.3	9.6	9.9	10.2	10.7
3	LogNormal	8.5	9.0	9.3	9.5	9.7	9.9	10.1	10.3	10.5
4	Gumbel	9.0	9.3	9.4	9.6	9.8	9.9	10.1	10.3	10.6
5	Normal	8.9	9.2	9.5	9.7	10.0	10.2	10.4	10.7	11.1
6	Gamma	8.8	9.3	9.7	10.0	10.3	10.6	11.0	11.4	12.0
7	Gumbel	9.1	9.5	9.8	10.0	10.3	10.5	10.8	11.0	11.4
8	Gumbel	8.6	9.2	9.6	9.9	10.2	10.4	10.7	10.9	11.2
9	Gamma	9.1	9.3	9.5	9.7	9.9	10.1	10.3	10.7	11.2
10	Gumbel	8.8	9.2	9.6	9.9	10.2	10.4	10.8	11.1	11.7
11	Gumbel	6.9	8.4	9.3	9.9	10.4	10.7	11.1	11.4	11.6
12	Normal	9.0	9.3	9.6	9.9	10.2	10.6	10.9	11.4	12.2
13	Normal	9.4	9.8	10.1	10.3	10.6	10.8	11.1	11.4	11.8
14	Gamma	9.7	10.1	10.3	10.6	10.9	11.2	11.5	11.9	12.7
15	Gumbel	10.1	10.5	10.8	11.0	11.2	11.5	11.7	12.0	12.4
16	Gamma	8.01	8.55	8.94	9.27	9.58	9.89	10.22	10.61	11.15
17	LogNormal	8.91	9.25	9.50	9.71	9.92	10.13	10.37	10.64	11.04
18	LogNormal	8.90	9.31	9.61	9.87	10.13	10.39	10.68	11.03	11.53
19	Gamma	7.39	7.95	8.38	8.76	9.12	9.49	9.90	10.39	11.10
20	LogNormal	6.86	7.63	8.19	8.67	9.11	9.56	10.04	10.59	11.37
21	Normal	6.41	7.30	7.95	8.50	9.01	9.53	10.08	10.72	11.61
22	Normal	5.34	6.14	6.79	7.40	8.03	8.71	9.51	10.56	12.24
23	Gamma	5.48	6.32	6.93	7.45	7.94	8.42	8.94	9.55	10.39
24	Normal	4.46	5.11	5.57	5.97	6.34	6.71	7.11	7.57	8.22
25	Normal	4.44	4.85	5.15	5.41	5.65	5.89	6.15	6.45	6.87
26	Gamma	3.07	3.70	4.16	4.54	4.91	5.27	5.66	6.11	6.74
27	Normal	3.21	3.69	4.04	4.33	4.61	4.88	5.18	5.52	6.00
28	LogNormal	3.28	3.62	3.89	4.13	4.37	4.63	4.92	5.28	5.83
29	Normal	3.49	3.80	4.02	4.22	4.42	4.62	4.84	5.11	5.49
30	Gumbel	3.27	3.86	4.29	4.66	5.00	5.35	5.72	6.15	6.74
Total (l/y/tree)		360	388	408	426	442	459	477	498	529

during initial stage and tends to increase during crop development stages. It is observed from the Table that at 70% probability level weekly pomegranate ET ranges from 3.37 to 39.10 litres/day/tree. Maximum values of pomegranate ET are observed in 20th week. These values are 41.2, 39.9, 37.9 and 34.8 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. Minimum values of the pomegranate ET are observed in 31st week. These are 3.74, 3.37, 2.82 and 2.07 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. The total pomegranate ET at 70% probability level over a period of 52 weeks of phonological stages is 1427.3 litres/year/tree.

4.4.6.4.4 4th Year

Weekly values of pomegranate ET at different probability levels are presented in Table 4.41 for 4th year tree. It is seen from the table that the weekly values of pomegranate ET are low during initial stage and tends to increase during crop development stages. It is observed from the Table that at 70% probability level weekly pomegranate ET ranges from 4.68 to 56.9 litres/day/tree. Maximum values of pomegranate ET are observed in 15th week. These values are 58.7, 56.9, 53.9 and 49.6 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. Minimum values of the pomegranate ET are observed in 31st week. These are 5.2, 4.68, 3.92 and 2.87 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. The total pomegranate ET at 70% probability level over a period of 52 weeks of phonological stages is 1984.3 litres/year/tree.

4.4.6.4.5 5th Year

Weekly values of pomegranate ET at different probability levels are presented in Table 4.42 for 5th year tree. It is seen from the table that the weekly values of pomegranate ET are low during initial stage and tends to increase during crop development stages. It is observed from the Table that at 70% probability level weekly pomegranate ET ranges from 5.79 to 76.0 litres/day/tree. Maximum values of pomegranate ET are observed in 20th week. These values are 78.4, 76.0, 72.1 and 66.2 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. Minimum values of the pomegranate ET are observed in 31st week. These are 6.42, 5.79, 4.84 and 3.55 litres/day/tree at probability levels 80%, 70%, 50% and 20%, respectively. The total pomegranate ET at 70% probability level over a period of 52 weeks of phonological stages is 2576.2 litres/year/tree.

Table 4.40 The values of pomegranate ET (litres/day/tree) for 3rd year pomegranate tree at different probability levels for Nasik district

M W	Pdf's	Probability levels								
		10%	20%	30%	40%	50%	60%	70%	80%	90%
31	Normal	1.7	2.1	2.3	2.6	2.8	3.1	3.4	3.7	4.3
32	Normal	2.5	2.7	2.9	3.1	3.3	3.4	3.6	3.9	4.3
33	Normal	3.5	3.9	4.2	4.5	4.7	4.9	5.2	5.5	5.9
34	Weibulls	4.1	4.5	4.8	5.1	5.4	5.6	5.9	6.3	6.9
35	Gamma	5.1	5.8	6.3	6.8	7.3	7.8	8.4	9.1	10.1
36	LogNormal	8.3	9.0	9.5	9.9	10.3	10.7	11.1	11.6	12.3
37	Normal	8.5	9.5	10.3	10.9	11.5	12.1	12.7	13.4	14.5
38	Normal	10.3	11.4	12.3	13.2	14.1	15.0	16.1	17.6	19.9
39	LogNormal	13.9	15.4	16.4	17.1	17.8	18.4	18.9	19.5	20.3
40	LogNormal	14.2	16.4	18.0	19.3	20.6	21.9	23.2	24.8	27.0
41	Weibull's	15.7	17.6	19.0	20.1	21.2	22.3	23.5	24.8	26.7
42	Normal	23.5	24.8	25.8	26.7	27.6	28.5	29.5	30.7	32.5
43	Normal	25.2	26.9	28.2	29.4	30.5	31.7	32.9	34.5	36.8
44	Normal	26.8	28.5	29.8	31.0	32.1	33.2	34.4	35.9	38.0
45	LogNormal	27.6	29.1	30.3	31.3	32.3	33.3	34.5	35.8	37.8
46	LogNormal	27.8	29.3	30.4	31.4	32.2	33.1	34.1	35.2	36.7
47	Normal	25.3	27.9	29.4	30.6	31.6	32.6	33.5	34.5	35.7
48	Gamma	25.8	27.1	28.1	28.9	29.7	30.6	31.5	32.6	34.1
49	Gamma	22.9	24.6	26.1	27.4	28.8	30.2	32.0	34.3	37.9
50	Normal	25.9	27.0	27.9	28.6	29.3	29.9	30.7	31.6	32.8
51	Gumbel	25.4	27.3	28.5	29.4	30.2	30.9	31.6	32.3	33.2
52	Gumbel	25.5	27.3	28.8	30.2	31.6	33.1	34.9	37.3	41.1
1	Gamma	22.0	23.8	25.0	25.9	26.6	27.3	27.9	28.7	29.5
2	Normal	22.5	23.8	24.8	25.6	26.4	27.1	27.9	28.9	30.2
3	LogNormal	23.9	25.3	26.1	26.8	27.4	27.9	28.4	29.0	29.6
4	Gumbel	25.6	26.3	26.9	27.3	27.8	28.3	28.8	29.4	30.2
5	Normal	26.0	27.0	27.8	28.5	29.1	29.8	30.5	31.3	32.5
6	Gamma	26.8	28.3	29.4	30.3	31.3	32.2	33.2	34.5	36.2
7	Gumbel	28.7	30.0	30.9	31.7	32.4	33.1	33.9	34.8	36.1
8	Gumbel	27.3	29.3	30.6	31.5	32.4	33.1	33.9	34.6	35.6
9	Gamma	29.3	30.1	30.7	31.3	31.9	32.6	33.3	34.4	36.0
10	Gumbel	29.2	30.7	31.8	32.8	33.7	34.7	35.7	36.9	38.7
11	Gumbel	24.2	29.5	32.6	34.8	36.5	37.9	39.1	40.0	40.9
12	Normal	31.8	33.1	34.2	35.2	36.2	37.4	38.7	40.5	43.3
13	Normal	28.7	30.0	31.0	31.8	32.5	33.3	34.0	35.0	36.3
14	Gamma	29.7	30.8	31.6	32.4	33.2	34.1	35.1	36.5	38.7
15	Gumbel	30.7	32.0	32.9	33.6	34.4	35.1	35.8	36.7	38.0
16	Gamma	29.98	31.99	33.45	34.69	35.86	37.02	38.26	39.72	41.74
17	LogNormal	33.35	34.60	35.53	36.34	37.12	37.91	38.78	39.82	41.31
18	LogNormal	33.29	34.80	35.93	36.92	37.88	38.86	39.93	41.23	43.10
19	Gamma	27.43	29.53	31.12	32.52	33.87	35.25	36.77	38.60	41.24
20	LogNormal	25.33	28.18	30.24	32.00	33.65	35.29	37.05	39.11	41.97
21	Normal	23.65	26.94	29.32	31.35	33.24	35.14	37.17	39.55	42.84
22	Normal	19.65	22.60	24.98	27.23	29.52	32.03	34.98	38.84	45.01
23	Gamma	20.18	23.27	25.51	27.42	29.20	30.99	32.89	35.13	38.23
24	Normal	16.34	18.71	20.41	21.87	23.23	24.59	26.05	27.75	30.11
25	Normal	16.31	17.85	18.95	19.90	20.78	21.67	22.61	23.72	25.25
26	Gamma	11.28	13.58	15.24	16.66	17.99	19.32	20.74	22.40	24.71
27	Normal	11.60	13.33	14.58	15.65	16.65	17.64	18.71	19.96	21.69
28	LogNormal	11.75	12.97	13.93	14.80	15.67	16.59	17.63	18.92	20.89
29	Normal	12.46	13.53	14.34	15.06	15.75	16.46	17.25	18.20	19.58
30	Gumbel	11.60	13.72	15.25	16.55	17.77	18.99	20.30	21.82	23.94
Total (l/y/tree)		1080	1164	1224	1276	1325	1374	1427	1491	1582

Table 4.41 The values of pomegranate ET (litres/day/tree) for 4th year pomegranate tree at different probability levels for Nasik district

M W	Pdf's	Probability levels								
		10%	20%	30%	40%	50%	60%	70%	80%	90%
31	Normal	2.4	2.9	3.2	3.6	3.9	4.3	4.7	5.2	6.0
32	Normal	3.8	4.1	4.4	4.7	4.9	5.2	5.5	5.9	6.4
33	Normal	5.4	6.1	6.5	6.9	7.2	7.6	8.0	8.4	9.0
34	Weibull's	6.1	6.7	7.2	7.6	8.0	8.5	8.9	9.5	10.3
35	Gamma	7.3	8.4	9.2	9.9	10.6	11.4	12.2	13.2	14.7
36	LogNormal	11.9	12.9	13.6	14.2	14.8	15.4	16.0	16.7	17.7
37	Normal	12.2	13.7	14.7	15.6	16.5	17.3	18.2	19.3	20.8
38	Normal	15.4	17.1	18.4	19.7	21.0	22.4	24.1	26.2	29.7
39	LogNormal	19.3	21.5	22.9	23.9	24.8	25.6	26.4	27.2	28.3
40	LogNormal	19.6	22.6	24.8	26.6	28.4	30.1	31.9	34.1	37.1
41	Weibull's	21.5	24.1	26.0	27.6	29.1	30.6	32.2	34.1	36.7
42	Normal	32.2	34.0	35.4	36.6	37.8	39.1	40.4	42.1	44.4
43	Normal	34.5	36.9	38.6	40.2	41.7	43.3	45.1	47.3	50.4
44	Normal	36.5	38.9	40.6	42.2	43.7	45.2	46.8	48.9	51.7
45	LogNormal	37.0	39.1	40.6	42.0	43.3	44.7	46.2	48.1	50.8
46	LogNormal	37.2	39.3	40.7	42.0	43.2	44.3	45.6	47.1	49.1
47	Normal	34.1	37.4	39.6	41.2	42.5	43.8	45.0	46.3	47.9
48	Gamma	34.8	36.5	37.8	38.9	40.0	41.1	42.4	43.8	45.9
49	Gamma	30.9	33.2	35.2	36.9	38.8	40.8	43.2	46.2	51.2
50	Normal	35.0	36.5	37.6	38.5	39.4	40.4	41.4	42.6	44.3
51	Gumbel	34.3	36.8	38.4	39.6	40.7	41.6	42.6	43.5	44.8
52	Gumbel	34.3	36.8	38.7	40.6	42.5	44.6	47.0	50.2	55.3
1	Gamma	30.8	33.3	34.9	36.2	37.2	38.2	39.1	40.1	41.3
2	Normal	31.7	33.6	35.0	36.2	37.2	38.3	39.5	40.9	42.7
3	LogNormal	34.0	36.0	37.2	38.2	39.0	39.8	40.5	41.3	42.2
4	Gumbel	36.2	37.2	38.0	38.7	39.3	40.0	40.7	41.6	42.8
5	Normal	37.4	38.9	40.0	41.0	41.9	42.9	43.9	45.1	46.9
6	Gamma	37.5	39.6	41.1	42.5	43.8	45.1	46.5	48.3	50.7
7	Gumbel	39.0	40.7	41.9	43.0	44.0	45.0	46.0	47.3	49.0
8	Gumbel	37.7	40.5	42.2	43.6	44.7	45.8	46.8	47.9	49.2
9	Gamma	40.2	41.2	42.1	42.9	43.7	44.6	45.7	47.1	49.3
10	Gumbel	40.5	42.6	44.1	45.5	46.8	48.1	49.5	51.3	53.7
11	Gumbel	33.4	40.7	45.0	48.0	50.3	52.2	53.8	55.1	56.3
12	Normal	39.3	41.0	42.3	43.6	44.9	46.3	47.9	50.1	53.6
13	Normal	41.0	42.8	44.2	45.3	46.4	47.4	48.6	49.9	51.7
14	Gamma	42.5	44.0	45.2	46.3	47.5	48.8	50.2	52.2	55.3
15	Gumbel	43.9	45.6	46.9	48.0	49.0	50.0	51.1	52.4	54.2
16	Gamma	42.70	45.58	47.65	49.42	51.08	52.73	54.51	56.58	59.45
17	LogNormal	47.49	49.26	50.58	51.74	52.85	53.98	55.21	56.69	58.81
18	LogNormal	47.40	49.55	51.16	52.58	53.94	55.33	56.87	58.71	61.37
19	Gamma	39.00	42.00	44.25	46.24	48.16	50.12	52.28	54.89	58.64
20	LogNormal	35.99	40.04	42.97	45.47	47.81	50.14	52.64	55.57	59.63
21	Normal	33.57	38.24	41.61	44.50	47.19	49.88	52.76	56.13	60.81
22	Normal	27.81	31.98	35.36	38.54	41.78	45.33	49.51	54.97	63.70
23	Gamma	28.51	32.89	36.05	38.75	41.27	43.79	46.49	49.64	54.02
24	Normal	23.08	26.42	28.83	30.88	32.80	34.73	36.78	39.19	42.53
25	Normal	22.88	25.04	26.59	27.92	29.16	30.40	31.72	33.27	35.43
26	Gamma	15.77	19.00	21.33	23.31	25.17	27.03	29.02	31.34	34.57
27	Normal	16.17	18.59	20.33	21.82	23.21	24.60	26.09	27.83	30.24
28	LogNormal	16.40	18.10	19.44	20.66	21.87	23.14	24.60	26.41	29.15
29	Normal	17.27	18.76	19.89	20.88	21.84	22.83	23.92	25.24	27.15
30	Gumbel	16.02	18.94	21.05	22.85	24.54	26.22	28.02	30.13	33.05
Total(l/y/tree)		1501	1617	1701	1774	1841	1910	1984	2073	2200

Table 4.42 The values of pomegranate ET (litres/day/tree) for 5th year pomegranate tree at different probability levels for Nasik district

MW	Pdf's	Probability levels								
		10%	20%	30%	40%	50%	60%	70%	80%	90%
31	Normal	3.0	3.5	4.0	4.4	4.8	5.3	5.8	6.4	7.4
32	Normal	5.1	5.6	5.9	6.3	6.6	7.0	7.4	7.9	8.6
33	Normal	7.4	8.2	8.8	9.4	9.9	10.3	10.9	11.5	12.3
34	Weibull's	8.7	9.6	10.2	10.8	11.4	12.0	12.7	13.5	14.7
35	Gamma	10.2	11.6	12.7	13.7	14.7	15.8	16.9	18.3	20.4
36	LogNormal	15.7	17.0	17.9	18.8	19.5	20.3	21.1	22.0	23.4
37	Normal	16.5	18.5	19.9	21.1	22.3	23.4	24.6	26.1	28.1
38	Normal	19.6	21.7	23.5	25.1	26.7	28.5	30.6	33.4	37.8
39	LogNormal	24.3	27.1	28.8	30.1	31.2	32.2	33.2	34.3	35.6
40	LogNormal	24.6	28.4	31.2	33.5	35.7	37.9	40.2	43.0	46.8
41	Weibull's	26.3	29.4	31.7	33.7	35.5	37.3	39.3	41.5	44.7
42	Normal	38.8	41.0	42.7	44.1	45.6	47.1	48.7	50.7	53.6
43	Normal	41.6	44.3	46.5	48.4	50.2	52.1	54.2	56.8	60.7
44	Normal	44.3	47.1	49.3	51.2	53.0	54.8	56.8	59.3	62.7
45	LogNormal	45.4	47.9	49.8	51.5	53.1	54.8	56.7	58.9	62.2
46	LogNormal	45.8	48.4	50.2	51.7	53.2	54.6	56.2	58.0	60.5
47	Normal	41.8	46.0	48.5	50.5	52.2	53.7	55.3	56.9	58.8
48	Gamma	42.6	44.7	46.2	47.6	49.0	50.4	51.9	53.6	56.1
49	Gamma	37.7	40.6	42.9	45.1	47.4	49.8	52.7	56.5	62.5
50	Normal	42.6	44.4	45.8	46.9	48.0	49.2	50.4	51.9	53.9
51	Gumbel	41.6	44.7	46.7	48.2	49.4	50.6	51.7	52.9	54.4
52	Gumbel	41.6	44.6	47.0	49.2	51.5	54.1	57.0	60.9	67.1
1	Gamma	37.7	40.8	42.8	44.3	45.5	46.7	47.8	49.1	50.5
2	Normal	39.1	41.4	43.1	44.5	45.9	47.2	48.7	50.3	52.7
3	LogNormal	42.1	44.6	46.2	47.4	48.4	49.3	50.2	51.2	52.4
4	Gumbel	45.1	46.4	47.4	48.3	49.1	49.9	50.8	51.8	53.4
5	Normal	46.6	48.5	49.9	51.1	52.2	53.4	54.7	56.2	58.4
6	Gamma	47.8	50.4	52.4	54.1	55.8	57.5	59.3	61.5	64.7
7	Gumbel	51.0	53.2	54.8	56.2	57.5	58.8	60.2	61.8	64.1
8	Gumbel	49.2	52.9	55.2	56.9	58.4	59.8	61.1	62.5	64.3
9	Gamma	53.7	55.1	56.3	57.4	58.5	59.7	61.1	63.0	65.9
10	Gumbel	54.1	56.9	59.0	60.8	62.6	64.3	66.3	68.6	71.8
11	Gumbel	44.1	53.8	59.4	63.4	66.5	69.0	71.1	72.9	74.5
12	Normal	53.1	55.4	57.2	58.9	60.6	62.5	64.8	67.7	72.4
13	Normal	55.3	57.8	59.5	61.1	62.5	63.9	65.5	67.3	69.7
14	Gamma	57.2	59.2	60.8	62.3	63.9	65.6	67.6	70.2	74.4
15	Gumbel	58.9	61.3	63.0	64.4	65.8	67.2	68.6	70.4	72.7
16	Gamma	57.16	61.01	63.78	66.16	68.37	70.59	72.96	75.74	79.59
17	LogNormal	63.50	65.88	67.64	69.19	70.67	72.18	73.83	75.81	78.65
18	LogNormal	63.32	66.19	68.35	70.24	72.05	73.92	75.97	78.43	81.99
19	Gamma	53.30	57.39	60.47	63.19	65.81	68.49	71.45	75.01	80.14
20	LogNormal	49.08	54.62	58.61	62.02	65.20	68.39	71.80	75.79	81.33
21	Normal	45.69	52.05	56.64	60.57	64.23	67.90	71.82	76.41	82.77
22	Normal	37.95	43.64	48.25	52.58	57.01	61.86	67.56	75.00	86.92
23	Gamma	38.88	44.85	49.16	52.83	56.27	59.71	63.39	67.69	73.66
24	Normal	31.55	36.11	39.40	42.21	44.83	47.46	50.27	53.56	58.12
25	Normal	31.25	34.19	36.32	38.13	39.82	41.51	43.33	45.45	48.39
26	Gamma	21.55	25.95	29.13	31.84	34.38	36.92	39.63	42.81	47.21
27	Normal	22.21	25.52	27.91	29.96	31.87	33.78	35.82	38.21	41.52
28	LogNormal	22.60	24.94	26.78	28.46	30.13	31.89	33.89	36.39	40.16
29	Normal	23.84	25.90	27.45	28.82	30.15	31.51	33.02	34.84	37.48
30	Gumbel	22.21	26.27	29.19	31.69	34.03	36.36	38.86	41.78	45.84
Total(l/y/tree)		1944	2097	2206	2300	2389	2479	2576	2692	2858

4.5 STOCHASTIC MODEL FOR GENRATION AND FORECASTING OF ET_r

As emphasized in chapter–I for real time irrigation scheduling and planning of the available water resources, it is necessary to know the forecast of pomegranate ET atleast for 1 year ahead of time and generation of required number of sequence of ET of pomegranate. If the forecasts of ET_r are known, the pomegranate ET can be forecasted with the help of k_c values of pomegranate accordingly to its different growth stages and age developed in this study.

As the Penman-Monteith method is recommended by FAO, the weekly reference crop evapotranspiration data estimated by this method were considered for generating and forecasting. The stochastic models of Seasonal ARIMA model were fitted to weekly ET_r values. These models and procedure to select the appropriate model are described in section 3.7. The results obtained from the stochastic modeling of ET_r for generation and forecasting are presented and discussed for Solapur, Ahmednagar, Pune and Nasik districts.

4.5.1 Stochastic Models for Generation and Forecasting of ET_r

As stated in section 3.7, it was decided to fit ARIMA class of models to reference crop evapotranspiration (ET_r) data for the generation and forecasting. According to Box and Jenkins (1994), the modeling process to fit the stochastic models of ARIMA class involves the following five steps:

1. Standardization and normalization of time series variables
2. Identification of the model
3. Determination of the parameters of selected models
4. Diagnostic checking of the model
5. Selection of the best model

The details of each of these steps are described in section 3.7.2: In this section the results of fitting ARIMA class models to weekly reference crop evapotranspiration (ET_r) series are discussed.

4.5.2 Selection of Reference Crop Evapotranspiration Method for Stochastic Modeling

As stated in section 3.4.1, the climatological parameters required to estimates reference evapotranspiration were available for 20 to 33 years for Solapur, Ahmednagar, Pune and Nasik districts. The reference crop evapotranspiration (ET_r) by using following six methods were estimated.

Penman-Monteith,

Modified Penman,

Hargreaves-Samani,

FAO Pan Evaporation,

Blanney-Criddle and

FAO Radiation

The time series of weekly ET_r estimated by using Penman-Monteith method was used for stochastic modeling for generating and forecasting. The weekly values of ET_r estimated by Penman-Monteith were divided into two groups for each district. The weekly ET_r data of first twenty-three (i.e.1984 – 2006), thirty-one (i.e.1976 - 2006), eighteen (i.e.1988 – 2005) and twenty-one (i.e.1986 – 2006) years were used for developing ARIMA models and the data for remaining one year i.e.2007, 2007, 2006 and 2007 were used for verifying prediction results as obtained by the selected models i.e. validation of selected model for Solapur, Ahmednagar, Pune and Nasik districts.

To know the appropriateness of stochastic modeling of reference crop evapotranspiration (ET_r), the time series were divided into the different groups for Solapur, Ahmednagar, Pune and Nasik districts as details below.

Solapur

1. 1984-1988
2. 1989-1993
3. 1994-1998
4. 1999-2003
5. 2004-2007

Ahmednagar

1. 1976-1980
2. 1981-1985
3. 1986-1990
4. 1991-1995
5. 1996-2000
6. 2001-2007

Pune

1. 1988-1992
2. 1993-1997
3. 1998-2006

Nasik

1. 1986-1990
2. 1991-1995
3. 1996-2000
4. 2001-2007

The statistical properties such as mean, standard deviation, skewness and kurtosis were estimated for each week of these groups. The weekly mean, standard deviation, skewness and kurtosis for each group are plotted and shown in Figs. 4.26 to 4.29 for Solapur, Ahmednagar, Pune and Nasik districts, respectively.

It is observed from these figures that there is no specific pattern of changes in the weekly statistical properties over the different groups. Therefore, the stochastic modeling of evapotranspiration time series was considered as the adequate.

4.5.3 Standardization and Normalization of Time Series Variables

As stated in section 3.7.2.1, the ARIMA model has the provision to differentiate the time series. Hence, standardization and normalization were not performed.

4.5.4 Identification of the Model

One of the basic conditions for applying ARIMA class of models for particular time series is its stationarity. The autocorrelation function (ACF) and partial autocorrelation function (PACF) were examined to known the stationarity of time series.

As stated in section 3.7.2.2, time series with seasonal variation (in this case weekly) may be considered stationary if ACF and PACF are zero after lags k =2s+2. ACF and PACF are considered zero if they lie within the range specified by equations (3.28) and (3.29). The ACF and PACF of ET_r time series were estimated for different lags. These are shown with upper and lower limits in Figs. 4.30 to 4.33 for Solapur, Ahmednagar, Pune and Nasik districts, respectively. It is seen from figure that ACF, lie outside the limit after lags k =2s+2 i.e. 106 for original time series. Thus, ARIMA model cannot be applied to the original time series of reference crop evapotranspiration. Therefore, the time series was transformed using following differencing schemes for Solapur, Ahmednagar, Pune and Nasik districts.

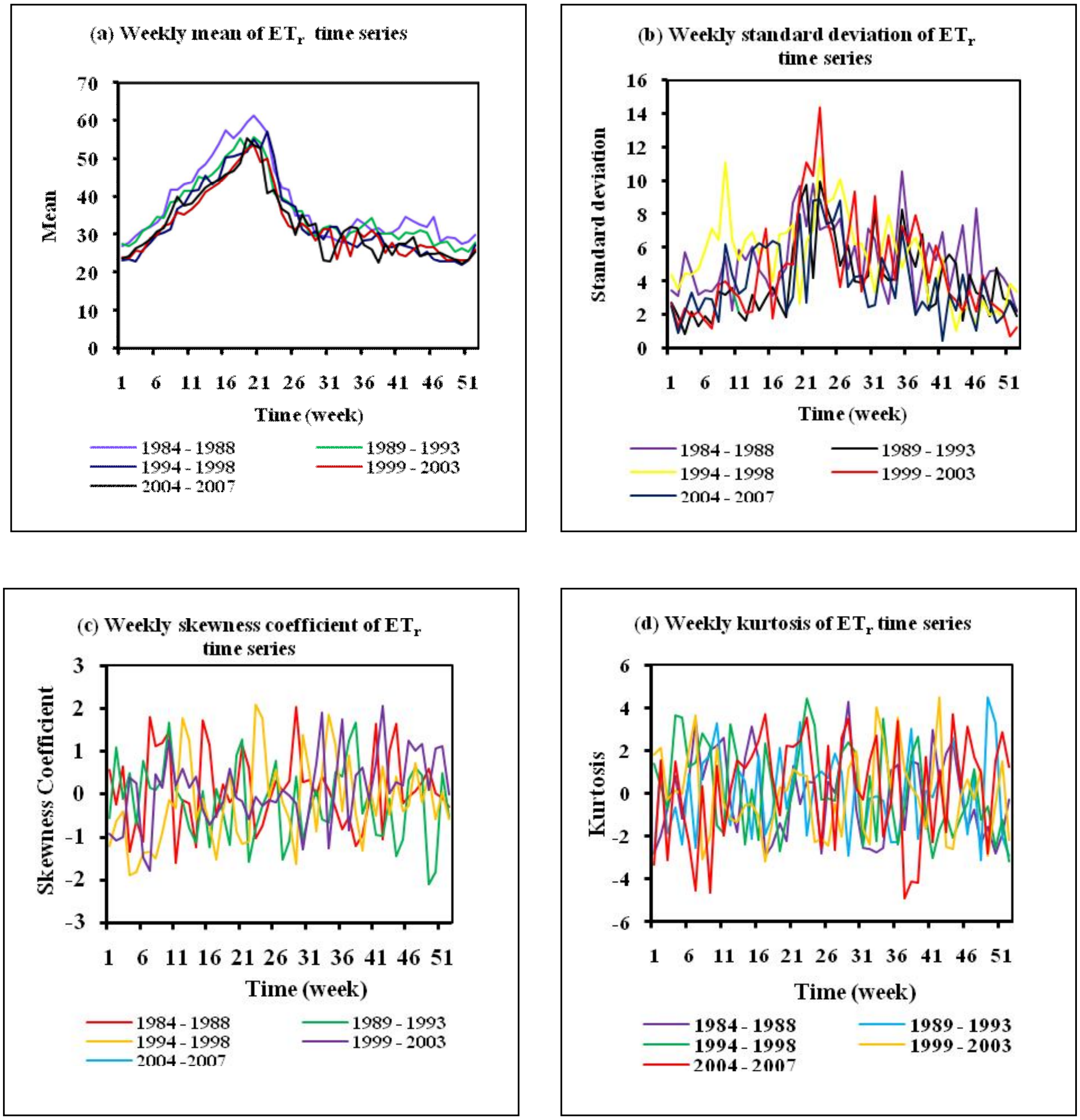

Fig. 4.26 The weekly mean, standard deviation, skewness coefficient and kurtosis of different groups of ET$_r$ time series for Solapur district

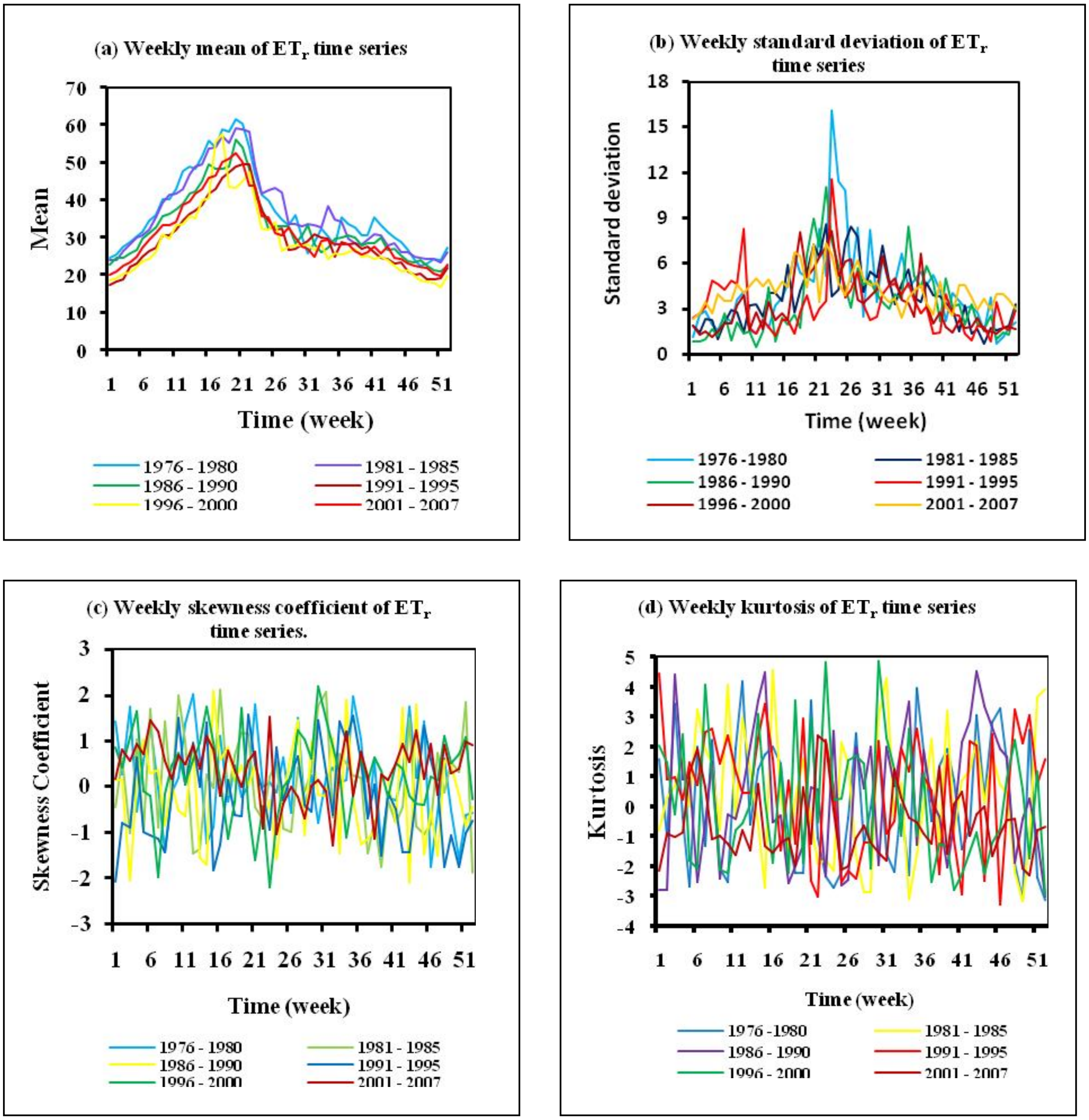

Fig. 4.27 The weekly mean, standard deviation, skewness coefficient and kurtosis of different groups of ET$_r$ time series for Ahmednagar district

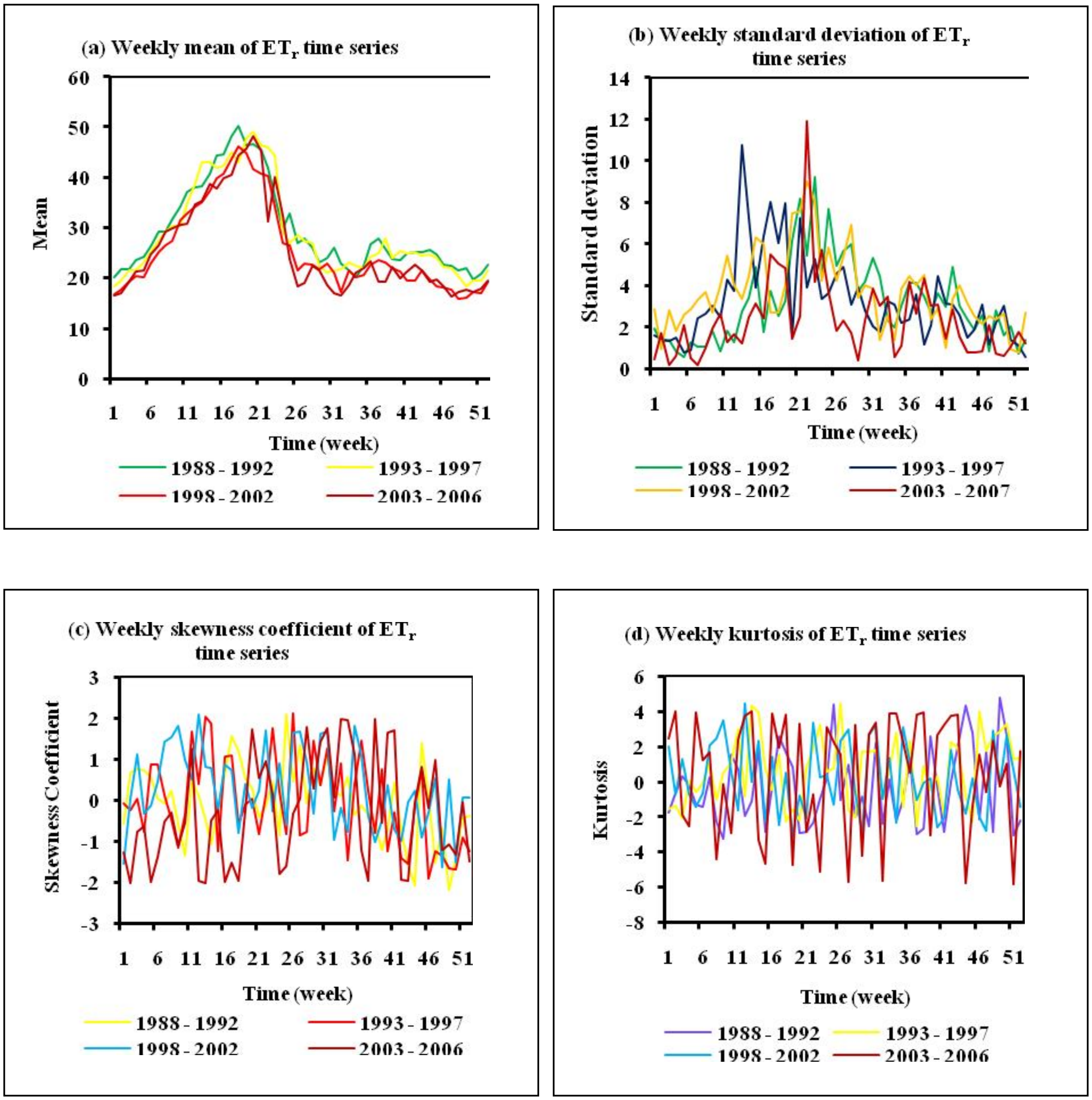

Fig. 4.28 The weekly mean, standard deviation, skewness coefficient and kurtosis of different groups of ET_r time series for Pune district

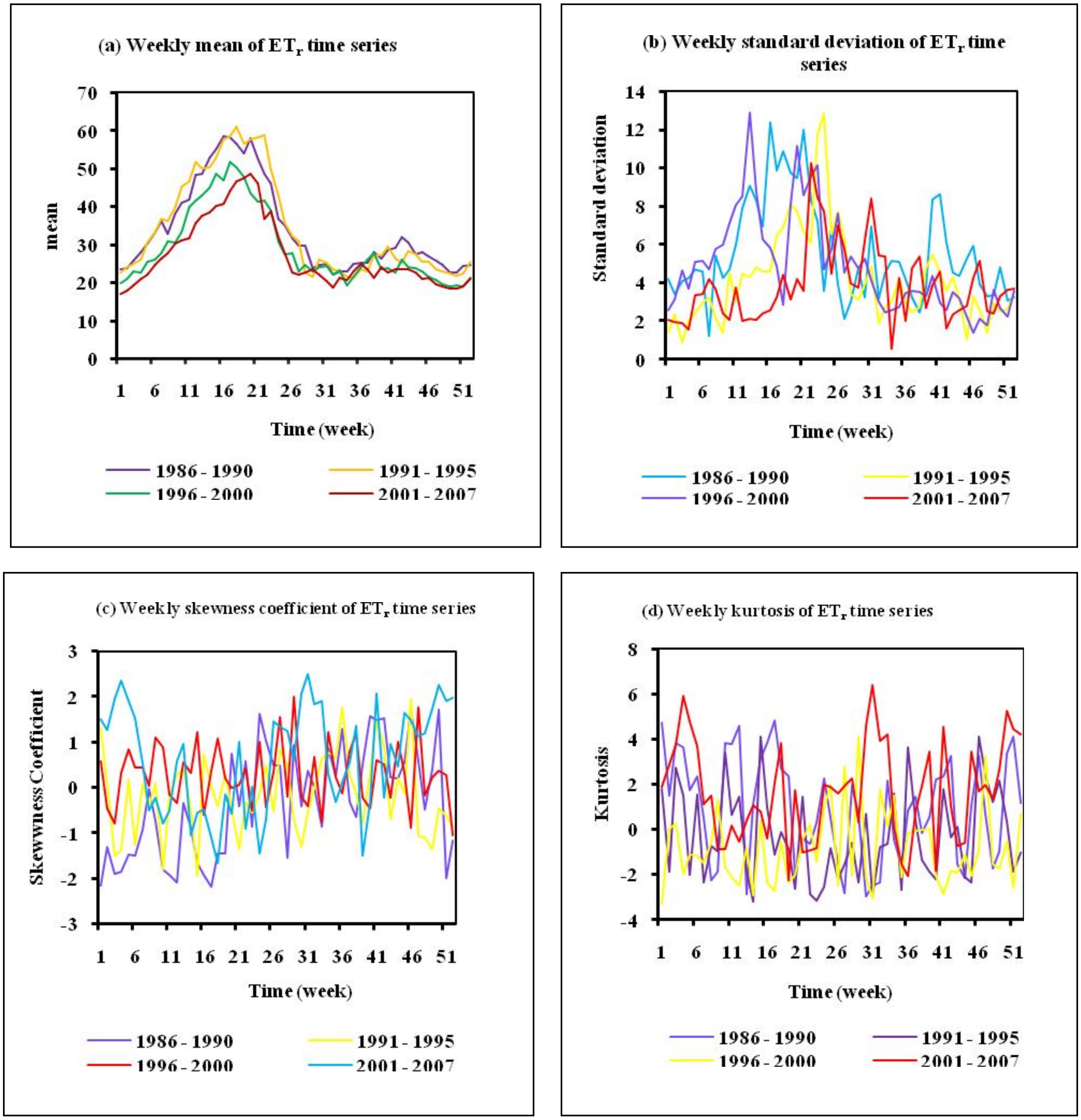

Fig. 4.29 The weekly mean, standard deviation, skewness coefficient and kurtosis of different groups of ET_r time series for Nasik district

1. d= 0; D=1
2. d= 1; D=1
3. d= 1;D=0

The ACF and PACF along with the upper and lower limits as estimated by equations (3.26) and (3.27) are shown in Figs. 4.34 to 4.36, 4.37 to 4.39, 4.40 to 4.42 and 4.43 to 4.45 for above shown differencing schemes. It is observed from the figures that ACF of d = 0, D = 1 and d = 1, D =1 lie within the limits of range specified by equations (3.28) and (3.29) after lags 104. However, for d =1, D=0, ACF do not lie within the limits after the lags 104. Therefore, following differencing schemes were used for developing ARIMA model for weekly evapotranspiration time series for Solapur, Ahmednagar, Pune and Nasik districts.

Solapur

i. d = 0; D = 1
ii. d = 1; D = 1

Ahmednagar

i. d = 0; D = 1
ii. d = 1; D = 1

Pune

i. d = 0; D = 1
ii. d = 1; D = 1

Nasik

i. d = 0; D = 1
ii. d = 1; D = 1

On the basis of information obtained from ACF and PACF and using the guidelines provided in section 3.4.3.2, the orders of autoregressive (AR) and moving average (MA) terms were identified as one. Based on this, several forms of ARIMA models were identified as given below for Solapur, Ahmednagar, Pune and Nasik districts.

1.ARIMA(1,1,1) $(1,1,1)_{52}$	2. ARIMA (1,1,1) $(1,1,0)_{52}$
3.ARIMA(1,1,1) $(1,0,1)_{52}$	4. ARIMA (1,1,1) $(1,0,0)_{52}$
5.ARIMA(1,1,1) $(0,1,1)_{52}$	6. ARIMA (1,1,1) $(0,0,1)_{52}$
7.ARIMA(1,1,0) $(1,1,1)_{52}$	8. ARIMA (1,1,0) $(1,1,0)_{52}$
9.ARIMA(1,1,0) $(1,0,1)_{52}$	10. ARIMA (1,1,0) $(1,0,0)_{52}$
11.ARIMA(1,1,0) $(0,1,1)_{52}$	12. ARIMA (1,1,1) $(0,0,1)_{52}$
13.ARIMA(1,0,0) $(1,1,1)_{52}$	14. ARIMA (1,0,0) $(1,1,0)_{52}$

15.ARIMA(1,0,0) $(1,0,1)_{52}$ 16. ARIMA (1,0,0) $(1,0,0)_{52}$

17.ARIMA(1,0,0) $(0,1,1)_{52}$ 18. ARIMA (1,0,0) $(0,0,1)_{52}$

19.ARIMA(1,0,1) $(1,1,1)_{52}$ 20. ARIMA (1,0,1) $(1,1,0)_{52}$

21ARIMA(1,0,1) $(1,0,1)_{52}$ 22. ARIMA (1,0,0) $(1,0,0)_{52}$

23.ARIMA(1,0,1) $(0,1,1)_{52}$ 24. ARIMA (1,0,1) $(0,0,1)_{52}$

25 ARIMA(0,1,1) $(1,1,1)_{52}$ 26. ARIMA (0,1,1) $(1,1,0)_{52}$

27.ARIMA(0,1,1) $(1,0,1)_{52}$ 28. ARIMA (0,1,1) $(1,0,0)_{52}$

29 ARIMA(0,1,1) $(0,1,1)_{52}$ 30. ARIMA (0,1,1) $(0,0,1)_{52}$

31.ARIMA(0,0,1) $(1,1,1)_{52}$ 32. ARIMA (0,0,1) $(1,1,0)_{52}$

33 ARIMA(0,0,1) $(1,0,1)_{52}$ 34. ARIMA (0,0,1) $(1,0,0)_{52}$

35.ARIMA(0,0,1) $(0,1,1)_{52}$ 36. ARIMA (0,0,1) $(0,0,1)_{52}$

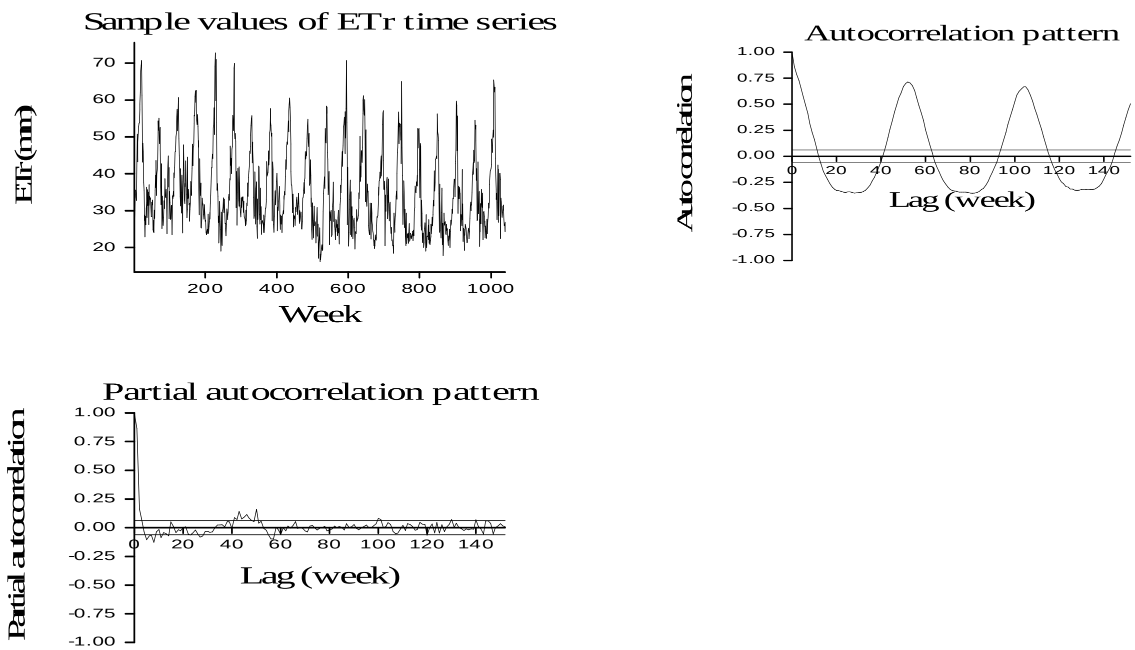

Fig. 4.30 ET_r time series, autocorrelation pattern and partial autocorrelation pattern of original time series of ET_r (d=0, D=0) for Solapur district

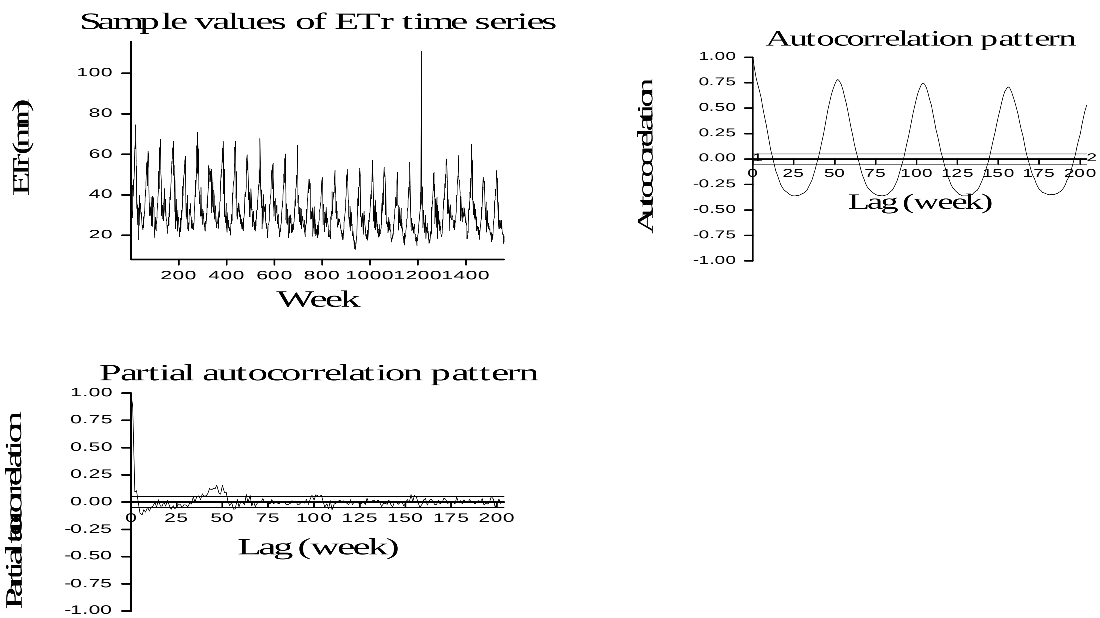

Fig. 4.31 ET_r time series, autocorrelation pattern and partial autocorrelation pattern of original time series of ET_r (d=0, D=0) for Ahmednagar district

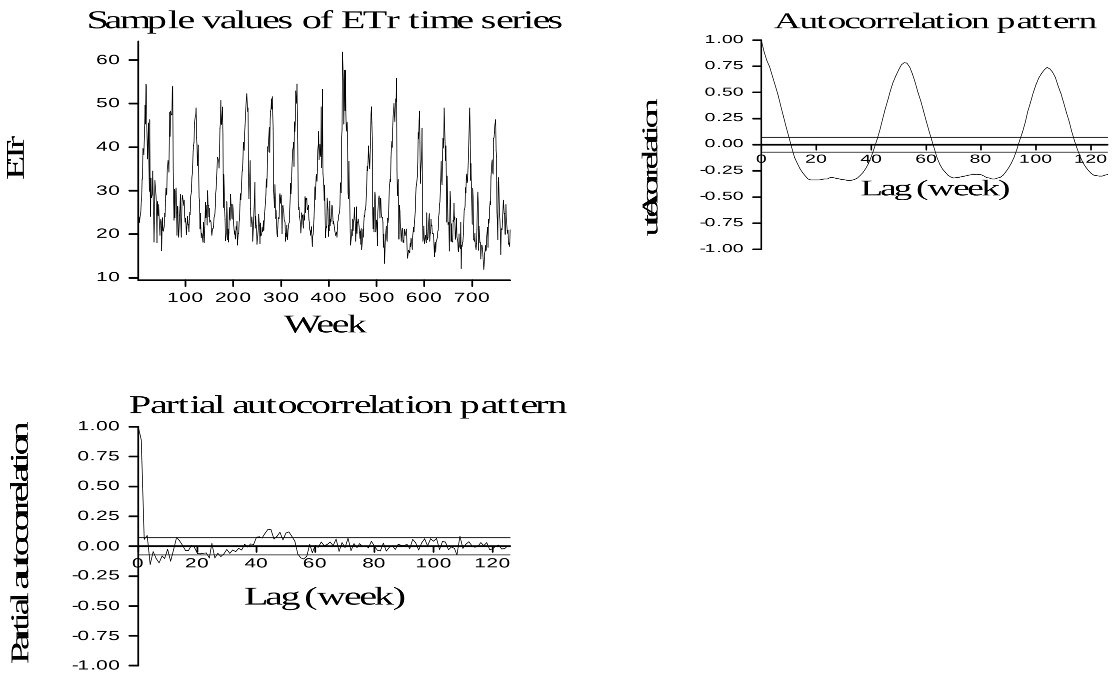

Fig. 4.32 ET_r time serie, autocorrelation pattern, partial autocorrelation pattern of original time series of ET_r (d=0, D=0) for Pune district

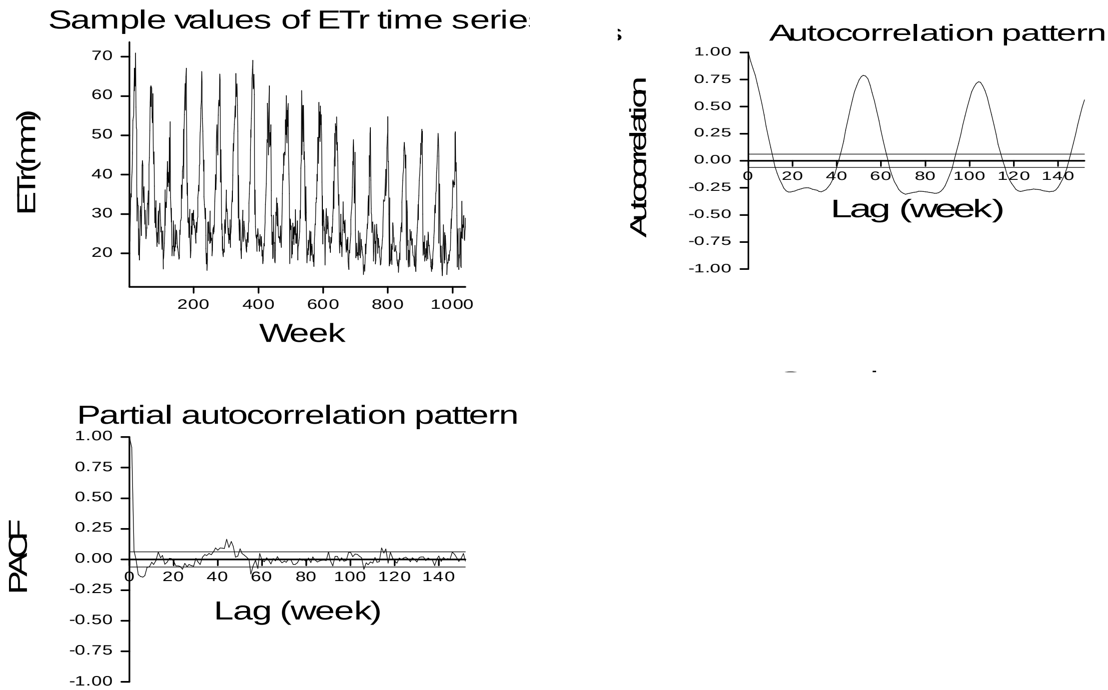

Fig. 4.33 ET_r time series and autocorrelation pattern, partial autocorrelation pattern and original time series of ET_r (d=0, D=0) for Nasik district

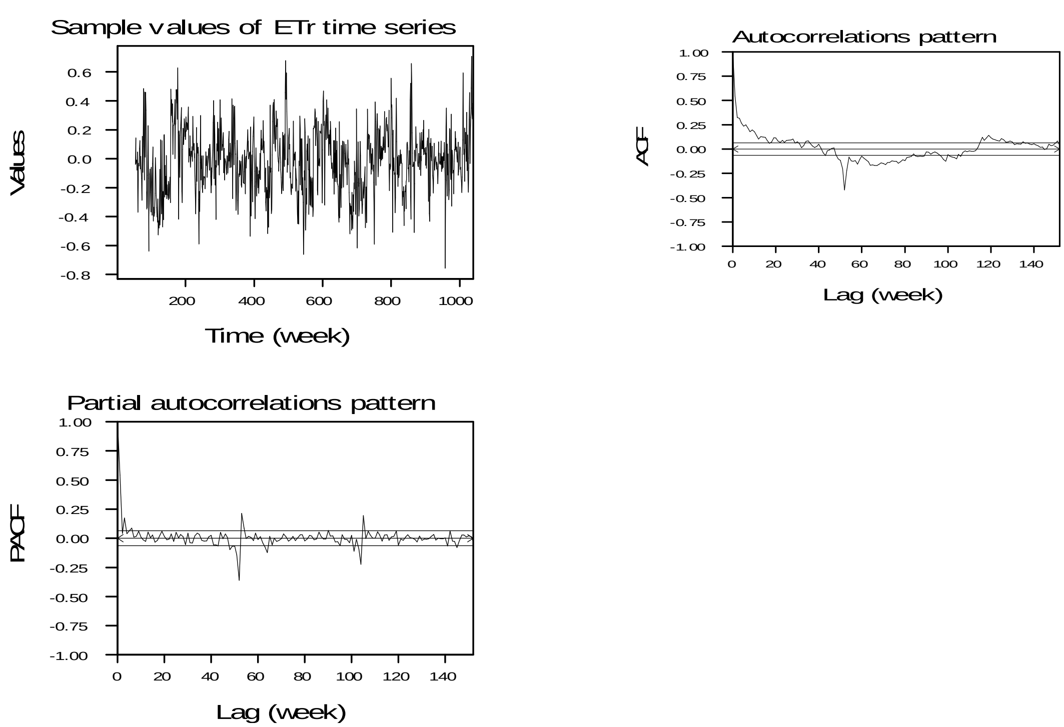

Fig. 4.34 ET_r time series, autocorrelation pattern and partial autocorrelation pattern of the differenced time series of ET_r for Solapur district (d=0, D=1)

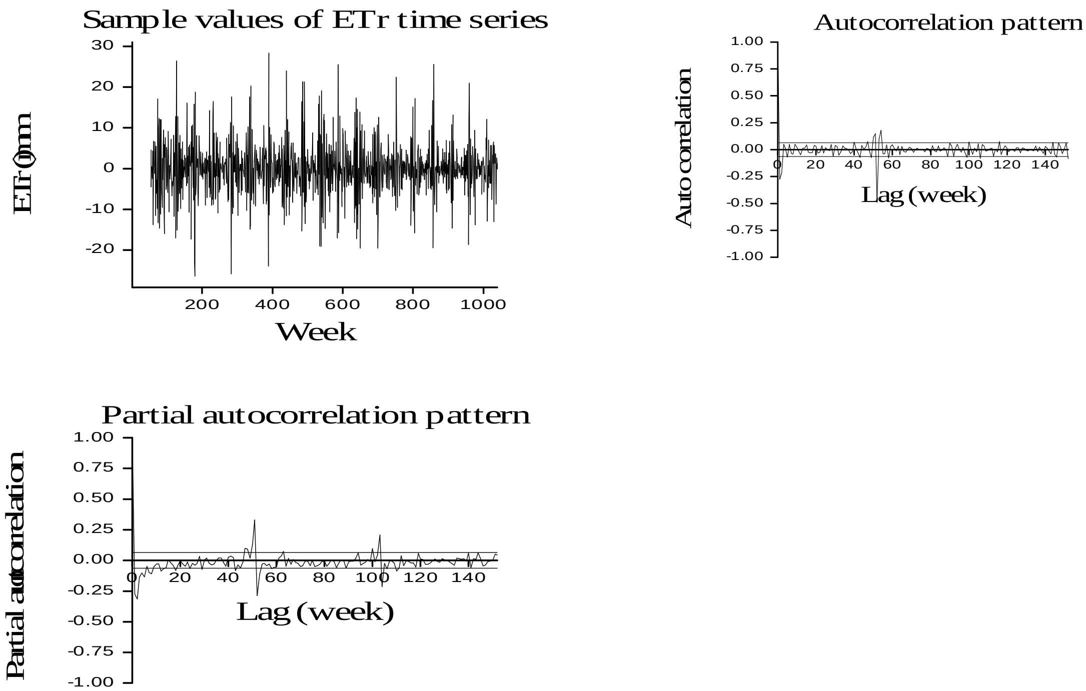

Fig. 4.35 ET_r time series, autocorrelation pattern and partial autocorrelation pattern of the differenced time series of ET_r for Solapur district (d=1, D=1)

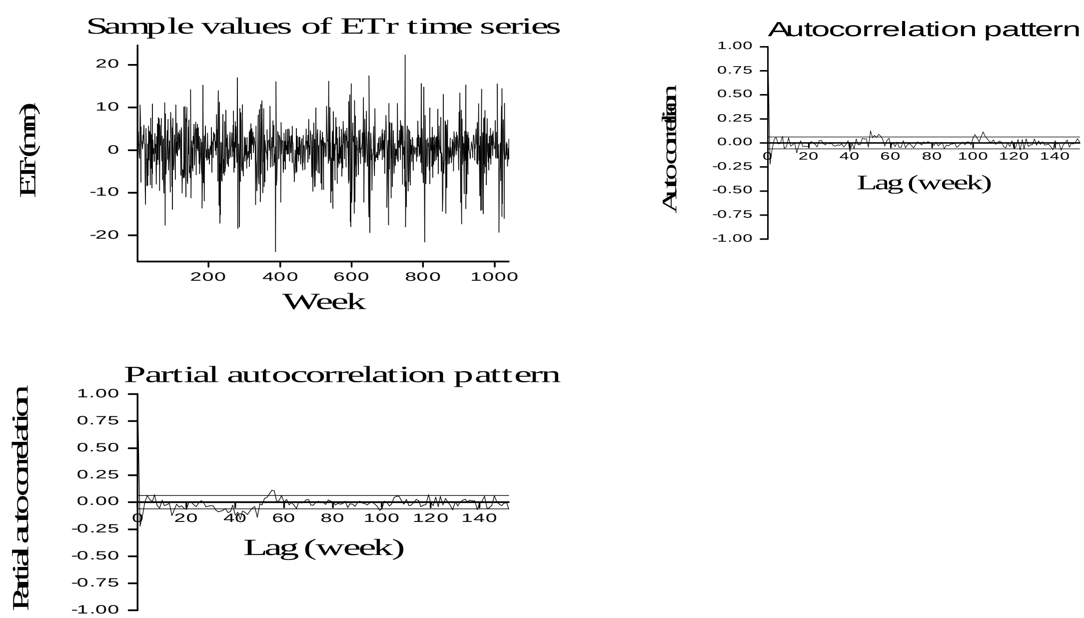

Fig. 4.36 ET_r time series, autocorrelation pattern and partial autocorrelation pattern of the differenced time series of ET_r for Solapur district (d=1, D=0)

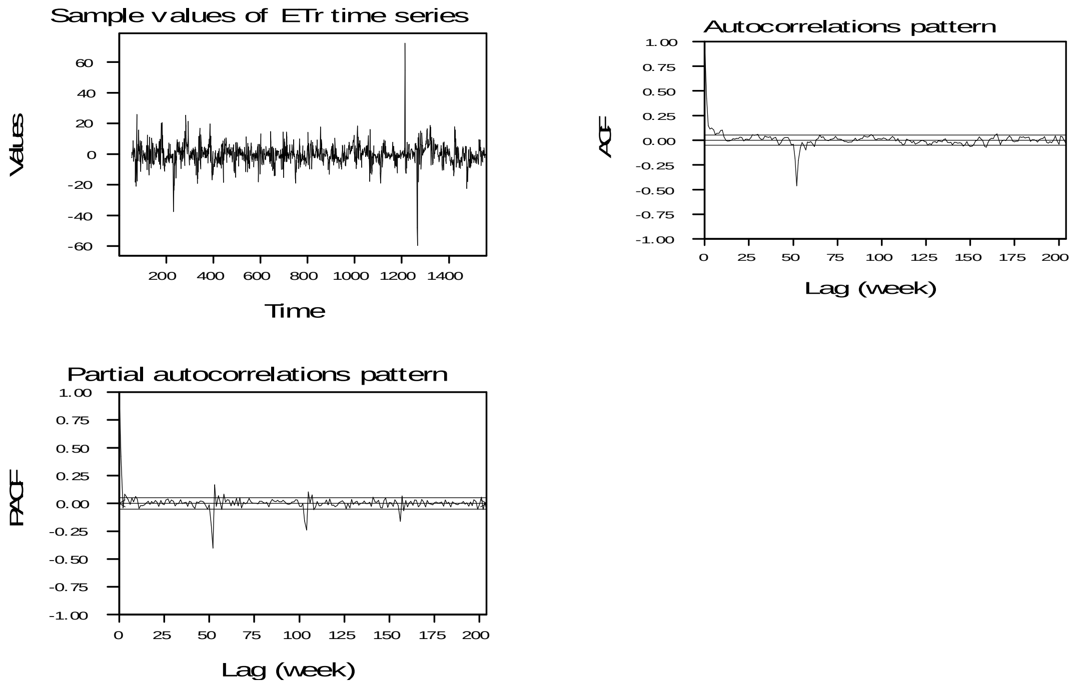

Fig. 4.37 ET_r time series, autocorrelation pattern and partial autocorrelation pattern of the differenced time series of ET_r for Ahmednagar district (d=0, D=1)

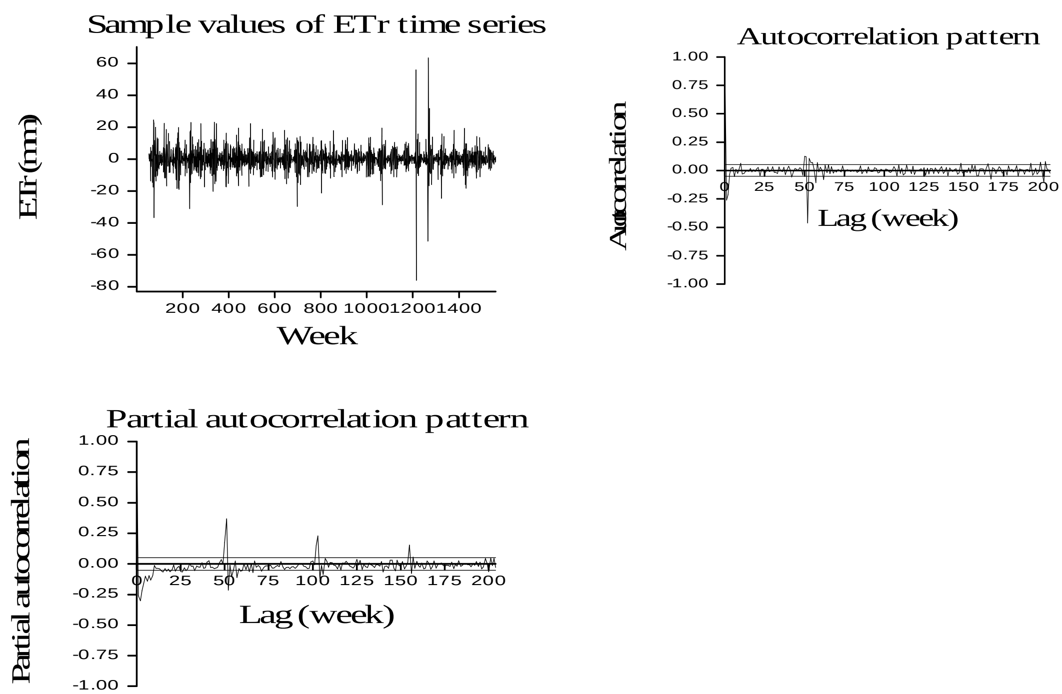

Fig. 4.38 ET_r time series, autocorrelation pattern and partial autocorrelation pattern of differenced time series of ET_r for Ahmednagar district (d=1, D=1)

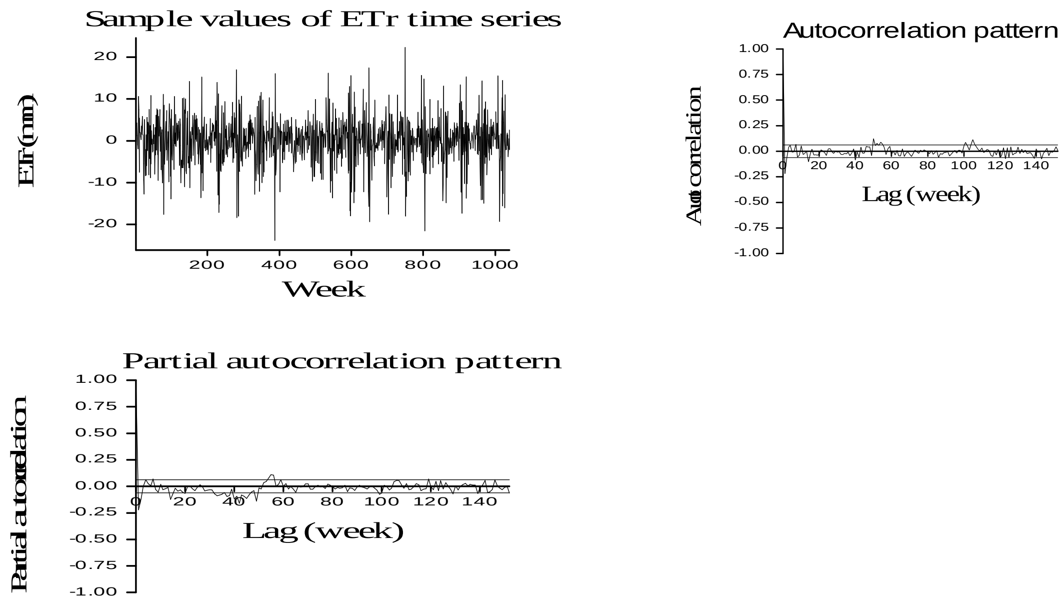

Fig. 4.39 ET_r time series, autocorrelation pattern and partial autocorrelation pattern of the differenced time series of ET_r for Ahmednagar district (d=1, D=0)

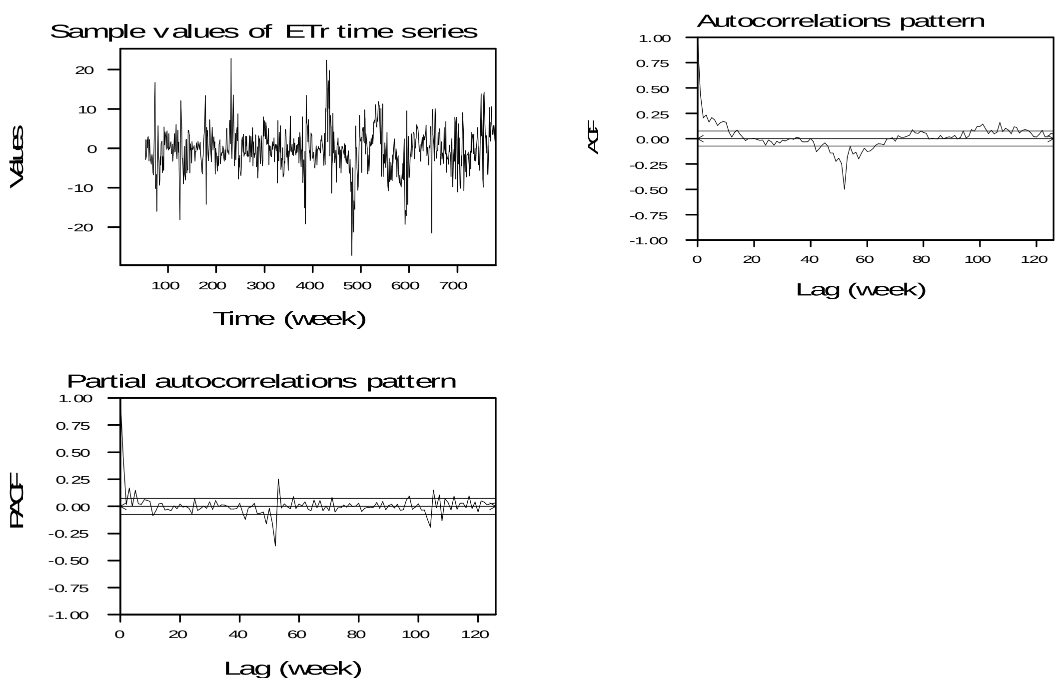

Fig. 4.40 ET_r time series, autocorrelation pattern and partial autocorrelation pattern of the differenced time series of ET_r for Pune district (d=0, D=1)

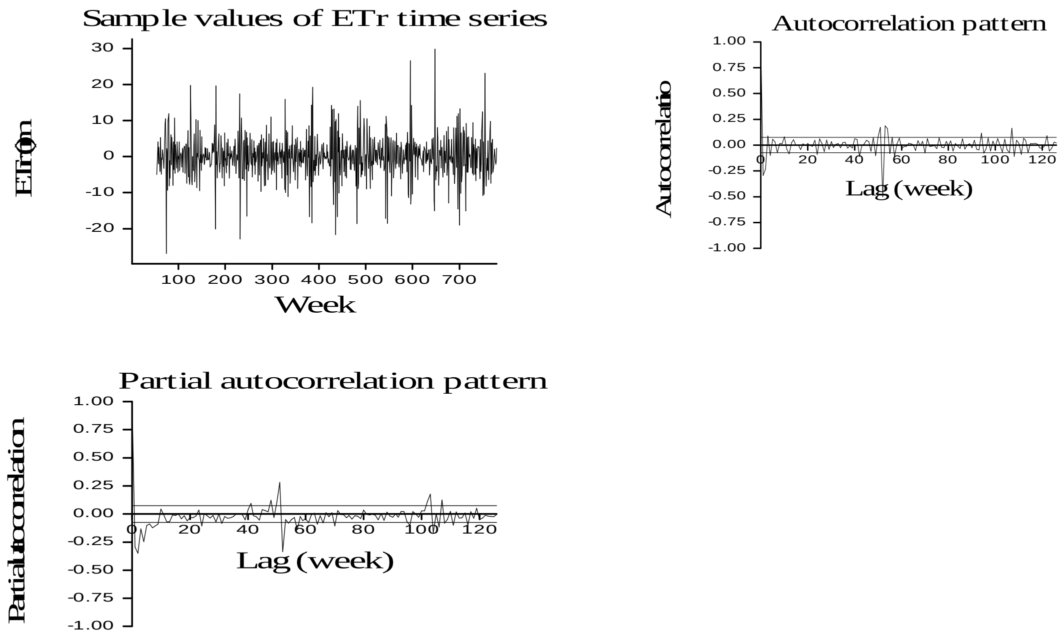

Fig. 4.41 ET_r time series, autocorrelation pattern and partial autocorrelation pattern of differenced time series of ET_r for Pune district (d=1, D=1)

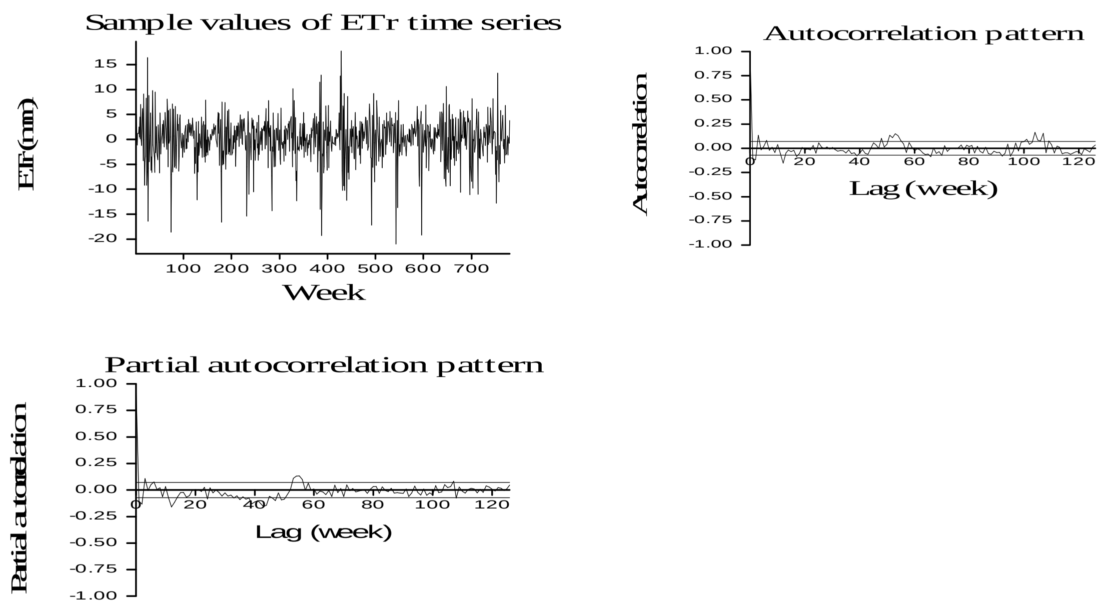

Fig. 4.42 ET_r time series, autocorrelation pattern and partial autocorrelation pattern of the differenced time series of ET_r for Pune district (d=1, D=0)

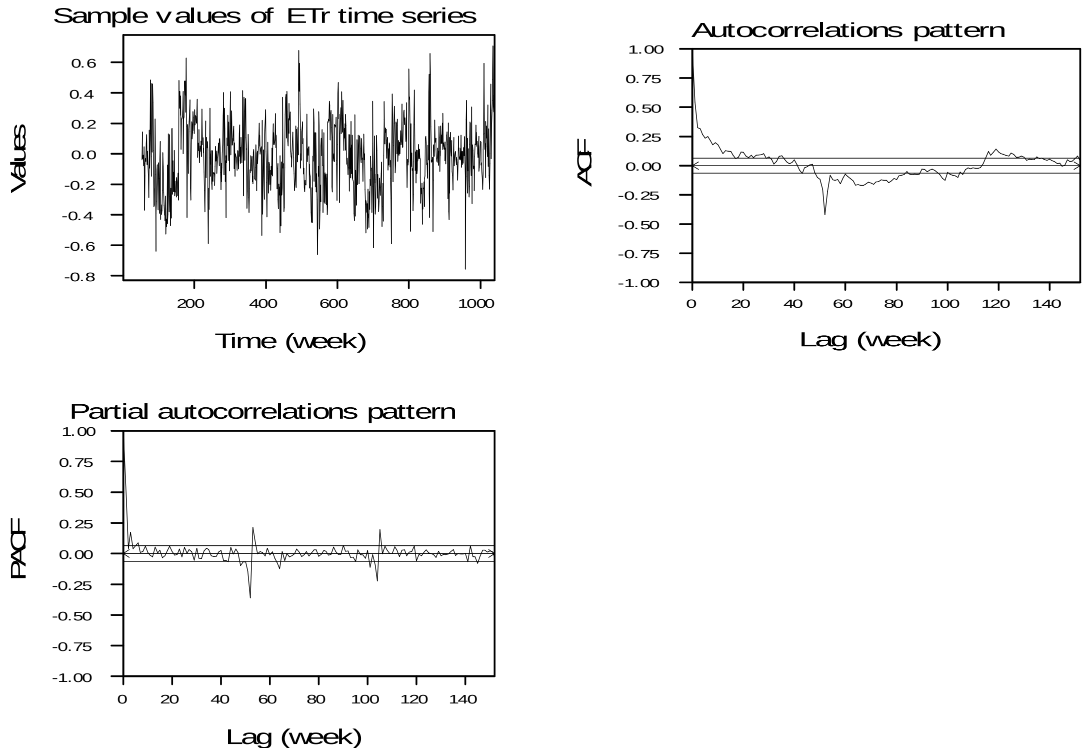

Fig. 4.43 ET_r time series, autocorrelation pattern and partial autocorrelation pattern of difference time series of ET_r for Nasik district (d=0, D=1)

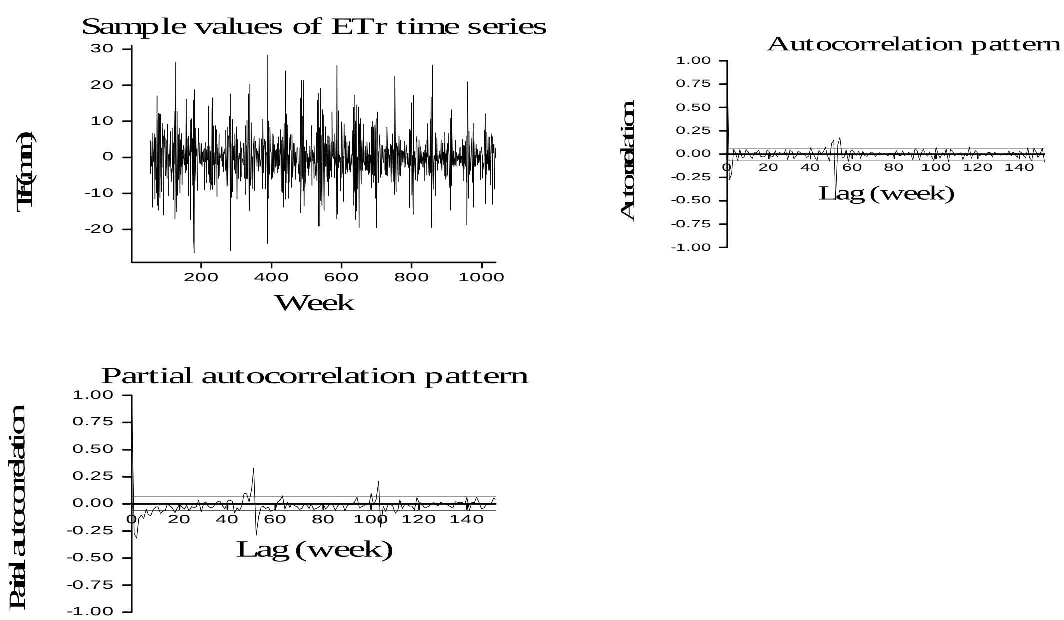

Fig. 4.44 ET_r time series, autocorrelation pattern and partial autocorrelation pattern of difference time series of ET_r for Nasik district (d=1, D=1)

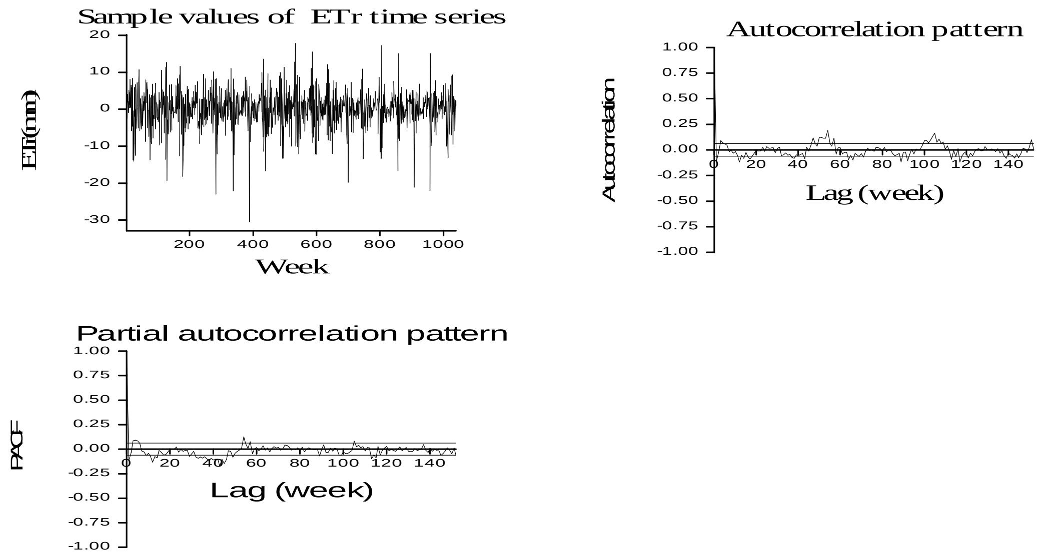

Fig. 4.45 ET_r time series, autocorrelation pattern and partial autocorrelation pattern of difference time series of ET_r for Nasik district (d=1, D=0)

4.5.5 Determination of Parameters of Models for Solapur, Ahmednagar, Pune and Nasik Districts

The following parameters of the selected models were calculated by maximum likelihood method as discussed in section 3.7.2.3

1. $\varnothing_1$ 2. θ_1 3. Φ_1 4. Θ_1 5. c

The values of the parameters for all the thirty six ARIMA models are presented in Appendix–E (Table E-1 to E-3, E-4 to E-6, E-7 to E-9, and E-10 to E-12)

4.5.6 Diagnostic Checking

Once a model has been selected and parameters calculated, the adequacy of model needs to be checked. This is called diagnostic checking. There are several tests to check the adequacy of the model as mentioned in section 3.7.2.4; out of which following three tests were used in this study

Standard error

Autocorrelation function (ACF) and Partial autocorrelation function (PACF) of residual series

Akaike Information Criteria (AIC)

4.5.6.1 Standard error

A high standard error in comparison with the parameters values points out a higher uncertainty in parameters estimation which questions the stability of the model. The model is adequate if it meets the condition given by equation (3.31)

The t values of the parameters equation for the models that were identified for these studies are given in Appendix–E (Table E-1 to E-3, E-4 to E-6, E-7 to E-9, and E-10 to E-12) for Solapur, Ahmednagar, Pune and Nasik districts, respectively. It is observed from the tables of Appendix-E that out of thirty six ARIMA models that were identified 27 models for Solapur and Pune districts, 31 models for Ahmednagar and 23 models for Nasik districts satisfied this test for all the parameters. The models that satisfied t-test are shown in Appendix-E. The model that passed this test are given below.

Solapur

ARIMA(1,1,1)(1,1,0)$_{52,}$ARIMA(1,1,1) (1,0,0)$_{52,}$ARIMA(1,1,1) (0,1,1)$_{52,}$ARIMA(1,1,0)(1,1,0)$_{52,}$ ARIMA(1,1,0)(1,0,1)$_{52}$,ARIMA(1,1,0)(1,0,0)$_{52,}$ARIMA(1,1,0)(0,1,1)$_{52}$ARIMA(1,1,0)(0,0,1)$_{52,}$ ARIMA(1,0,0)(1,1,0)$_{52,}$ARIMA(1,0,0)(1,0,1)$_{52,}$ARIMA(1,0,0)(1,0,0)$_{52,}$ARIMA(1,0,0)(0,1,1)$_{52,}$ ARIMA(1,0,0)(0,0,1)$_{52,}$ ARIMA(1,0,1)(1,1,0)$_{52,}$ARIMA(1,0,1)(1,0,1)$_{52,}$ARIMA(1,0,1)(1,0,0)$_{52,}$ ARIMA(1,0,1)(0,1,1)$_{52}$,ARIMA(1,0,1)(0,0,1)$_{52,}$ARIMA(0,1,1)(1,1,0)$_{52,}$ARIMA(0,1,1)(1,0,1)$_{52,,}$ ARIMA(0,1,1)(1,0,0)$_{52,}$ARIMA(0,1,1)(0,1,1)$_{52,}$ARIMA(0,0,1)(1,1,0)$_{52,}$ARIMA(0,0,1)(1,0,1)$_{52}$, ARIMA(0,0,1) (1,0,0)$_{52,}$.ARIMA(0,0,1) (0,1,1)$_{52,}$ ARIMA (0,0,1) (0,0,1)$_{52}$

Ahmednagar

ARIMA(1,1,1)(1,1,0)$_{52,}$ARIMA(1,1,1) (1,0,1)$_{52,}$ARIMA(1,1,1) (0,1,1)$_{52,}$ARIMA(1,1,1)(0,0,1)$_{52,}$ ARIMA(1,1,0)(1,1,0)$_{52}$,ARIMA(1,1,0)(1,0,1)$_{52,}$ARIMA(1,1,0)(1,0,0)$_{52,}$ARIMA(1,1,0)(0,1,1)$_{52,}$ ARIMA(1,1,0)(0,0,1)$_{52,}$ARIMA(1,0,0)(1,1,1)$_{52,}$ARIMA(1,0,0)(1,1,1)$_{52,}$ARIMA(1,0,0)(1,1,0)$_{52,}$ ARIMA(1,0,0)(1,0,1)$_{52,}$ ARIMA(1,0,0)(1,0,0)$_{52,}$ARIMA(1,0,0)(0,1,1)$_{52,}$ARIMA(1,0,0)(0,0,1)$_{52,}$ ARIMA(1,0,1)(1,1,1)$_{52}$,ARIMA(1,0,1)(1,0,1)$_{52,}$ARIMA(1,0,1)(1,0,0)$_{52,}$ARIMA(1,0,1)(0,0,1)$_{52,,}$ ARIMA(0,1,1)(1,1,0)$_{52,}$ARIMA(0,1,1)(1,0,1)$_{52,}$ARIMA(0,1,1)(1,0,0)$_{52,}$ARIMA(0,1,1)(0,1,1)$_{52}$, ARIMA(0,1 ,1) (0,0,1)$_{52,}$.ARIMA(0,0,1) (1,1,1)$_{52,}$ ARIMA (0,0,1) 1,1,0)$_{52,}$ARIMA(0,0,1)(1,0,1)$_{52,}$ ARIMA (0,0,1) (1,0,0)$_{52,}$ ARIMA(0,0,1) (0,1,1)$_{52,}$ ARIMA (0,0,1) (0,0,1)$_{52}$

Pune

ARIMA(1,1,1)(1,1,0)$_{52,}$ARIMA(1,1,1) (1,0,1)$_{52,}$ARIMA(1,1,1) (1,0,0)$_{52,}$ARIMA(1,1,1)(0,1,1)$_{52}$ ARIMA(1,1,0)(1,1,0)$_{52}$,ARIMA(1,1,0)(1,0,1)$_{52,}$ARIMA(1,1,0)(1,0,0)$_{52,}$ARIMA(1,1,0)(0,1,1)$_{52,}$ ARIMA(1,1,0)(0,0,1)$_{52,}$ARIMA(1,0,0)(1,1,0)$_{52,}$ARIMA(1,0,0)(1,0,1)$_{52,}$ARIMA(1,0,0)(1,0,0)$_{52,}$ ARIMA(1,0,0)(0,1,1)$_{52,}$ARIMA(1,0,0)(0,0,1)$_{52,}$ARIMA(1,0,1)(1,0,1)$_{52,}$ARIMA(1,0,1)(1,0,0)$_{52,}$ ARIMA(1,0,1)(0,1,1)$_{52,}$ARIMA(0,1,1)(1,1,0)$_{52,}$ARIMA(0,1,1)(1,0,1)$_{52,}$ARIMA(0,1,1)(1,0,0)$_{52,}$

ARIMA(0,1,1)$(0,1,1)_{52}$,ARIMA(0,1,1)$(0,0,1)_{52}$,ARIMA(0,0,1)$1,1,0)_{52}$,

Nasik

ARIMA(1,1,1)$(1,1,0)_{52}$,ARIMA(1,1,1)$(0,1,1)_{52}$,ARIMA(1,1,0)$(1,1,0)_{52}$,ARIMA(1,1,0)$(1,0,1)_{52}$, ARIMA(1,1,0)$(1,0,0)_{52}$,ARIMA(1,1,0)$(0,0,1)_{52}$,ARIMA(1,0,0)$(1,1,0)_{52}$,ARIMA(1,0,0)$(1,0,1)_{52}$, ARIMA(1,0,0)$(1,0,0)_{52}$,ARIMA(1,0,0)$(0,1,1)_{52}$,ARIMA(1,0,1)$(1,1,0)_{52}$,ARIMA(1,0,1)$(1,0,1)_{52}$, ARIMA(1,0,1)$(1,0,0)_{52}$,ARIMA(1,0,1)$(0,1,1)_{52}$,ARIMA(1,0,1)$(0,0,1)_{52}$,ARIMA(0,1,1)$(1,1,0)_{52}$,, ARIMA(0,1,1)$(1,0,1)_{52}$,,ARIMA(0,1,1)$(1,0,0)_{52}$,ARIMA(0,1,1)$(0,0,1)_{52}$,ARIMA(0,0,1)$(1,1,0)_{52}$, ARIMA(0,0,1)$(1,0,1)_{52}$, ARIMA(0,0,1) $(0,1,1)_{52}$, ARIMA (0,0,1) $(0,0,1)_{52}$

4.5.6.2 ACF and PACF of residual series

If the model is adequate at describing behavior of evapotranspiration time series, the residuals of model should be correlated i.e. all ACF and PACF should lie within the limits calculated by equations (3.28) and (3.29) after lag k = 2s+2, where s = number of periods. In this case, value of k is 106. The ACF and PACF with limits prescribed by equations (3.28) and (3.29) for all the thirty six models of each district are given in Appendix-F (Figs. F-1 to F-36 for Solapur, F-37 to F-72 for Ahmednagar, F-73 to F-108 for Pune and F-110 to F-144 for Nasik districts).

It is observed from these figures, that the ACF and PACF of the following models lie within the limits prescribed by equations (3.28) and (3.29) after 106 lags.

Solapur

ARIMA(1,1,1) $(1,1,1)_{52}$, ARIMA(1,1,1)$(1,0,1)_{52}$, ARIMA(1,1,1) $(0,1,1)_{52}$, ARIMA(1,1,0)$(1,1,1)_{52}$, ARIMA(1,1,0)$(1,0,1)_{52}$, ARIMA(1,1,0)$(0,1,1)_{52}$, ARIMA(1,0,0)$(1,1,1)_{52}$, ARIMA(1,0,0)$(1,0,1)_{52}$, ARIMA(1,0,1)$(1,1,1)_{52}$, ARIMA(1,0,1)$(1,0,1)_{52}$, ARIMA(1,0,1)$(0,1,1)_{52}$, ARIMA(0,1,1)$(1,1,1)_{52}$, ARIMA(0,1,1)$(1,0,1)_{52}$, ARIMA(0,1,1)$(0,1,1)_{52}$,ARIMA(0,0,1)$(1,1,1)_{52}$,ARIMA(0,0,1)$(1,0,1)_{52}$, ARIMA(0,0,1) $(1,0,0)_{52}$, ARIMA(0,0,1) $(0,1,1)_{52}$

Ahmednagar

ARIMA(1,1,1) $(1,1,1)_{52}$, ARIMA(1,1,1)$(1,0,1)_{52}$, ARIMA(1,1,1) $(0,1,1)_{52}$,ARIMA(1,1,0)$(1,1,1)_{52}$, ARIMA(1,1,0)$(1,0,1)_{52}$, ARIMA(1,1,0)$(0,1,1)_{52}$, ARIMA(1,0,0)$(1,1,1)_{52}$, ARIMA(1,0,0)$(1,0,1)_{52}$, ARIMA(1,0,0)$(0,1,1)_{52}$,ARIMA(1,0,1)$(1,1,1)_{52}$, ARIMA(1,0,1)$(1,0,1)_{52}$, ARIMA(1,0,1)$(0,1,1)_{52}$, ARIMA(0,1,1)$(1,1,1)_{52}$,ARIMA(0,1,1)$(1,0,1)_{52}$,ARIMA(0,1,1)$(0,1,1)_{52}$,ARIMA(0,0,1)$(1,0,1)_{52}$, ARIMA (0,0,1) $(0,1,1)_{52}$

Pune

ARIMA(1,1,1) $(0,1,1)_{52}$, ARIMA(1,1,0)$(1,1,1)_{52}$,ARIMA(1,1,0)$(1,0,1)_{52}$, ARIMA(1,1,0)$(0,1,1)_{52}$, ARIMA(1,0,0)$(1,0,1)_{52}$, ARIMA(1,0,0)$(0,1,1)_{52}$,ARIMA(1,0,1)$(1,0,1)_{52}$, ARIMA(1,0,1)$(0,1,1)_{52}$,

ARIMA(1,0,1)(0,0,1)$_{52}$, ARIMA(0,1,1)(1,1,1)$_{52,}$ARIMA(0,1,1)(1,1,0)$_{52,}$ ARIMA(0,1,1)(1,0,1)$_{52,}$ ARIMA(0,1,1)(0,1,1)$_{52,}$ ARIMA(0,0,1) (0,1,1)$_{52}$

Nasik

ARIMA(1,1,1) (1,1,1)$_{52,}$ ARIMA(1,1,1)(1,0,1)$_{52}$, ARIMA(1,1,1) (0,1,1)$_{52}$, ARIMA(1,1,0)(1,1,1)$_{52,}$ ARIMA(1,1,0)(1,0,1)$_{52}$, ARIMA(1,0,0)(1,1,1)$_{52,}$ ARIMA(1,0,0)(1,0,1)$_{52,}$ ARIMA(1,0,0)(0,1,1)$_{52,}$ ARIMA(1,0,1)(1,1,1)$_{52}$, ARIMA(1,0,1)(1,0,1)$_{52,}$ ARIMA(1,0,1)(0,1,1)$_{52}$,ARIMA(0,1,1)(1,1,1)$_{52,}$ ARIMA(0,1,1)(1,0,1)$_{52,}$ARIMA(0,1,1)(0,1,1)$_{52,}$ARIMA(0,0,1)(1,1,1)$_{52,}$ARIMA(0,0,1)(1,0,1)$_{52}$, ARIMA(0,0,1) (0,1,1)$_{52}$

Thus, it is evident from the figures, that ACF and PACF of the residuals of the above mentioned ARIMA models are mutually independent and pass the adequacy test.

4.5.6.3 Akaike Information Criteria (AIC)

AIC values are computed by using procedure explained in section 3.7.2.4.3 for all the thirty six identified ARIMA models for Solapur, Ahmednagar, Pune and Nasik districts and are presented in Appendix–E (Table E-1 to E-3, E-4 to E-6, E-7 to E-9, and E-10 to E-12) for Solapur, Ahmednagar, Pune and Nasik districts, respectively). The models with less AIC values are considered as the best. First ten models with less AIC that satisfy the standard error and ACF and PACF of residuals criteria as explained in sections 4.5.6.1 and 4.5.6.2 respectively, are selected for further validation. These models are:

Solapur

ARIMA (1,0,1(0,1,1)$_{52}$, ARIMA(1,0,1)(1,0,1)$_{52}$, ARIMA (0,1,1)(0,1,1)$_{52}$, ARIMA(1,0,0)(1,0,1)$_{52}$, ARIMA (1,1,0)(1,0,1)$_{52}$, ARIMA(1,1,0)(0,1,1)$_{52}$, ARIMA (1,1,1)(0,1,1)$_{52}$,ARIMA(0,0,1)(1,0,1)$_{52}$, ARIMA (0,0,1)(1,0,0)$_{52}$, ARIMA (0,0,1)(0,1,1)$_{52}$

Ahmednagar

ARIMA (1,1,1(0,1,1)$_{52}$, ARIMA(1,0,1)(1,1,1)$_{52}$, ARIMA (1,0,0)(0,1,1)$_{52}$, ARIMA(1,0,1)(0,1,1)$_{52}$, ARIMA (1,1,1)(1,0,1)$_{52}$, ARIMA(0,0,1)(0,1,1)$_{52}$, ARIMA (1,0,1)(1,0,1)$_{52}$,ARIMA(1,0,0)(1,0,1)$_{52}$, ARIMA (0,1,1)(0,1,1)$_{52}$, ARIMA (0,1,1)(1,0,1)$_{52}$

Pune

ARIMA (1,0,1(0,1,1)$_{52}$, ARIMA(1,0,0)(0,1,1)$_{52}$, ARIMA (0,0,1)(0,1,1)$_{52}$, ARIMA(1,1,1)(0,1,1)$_{52}$, ARIMA (0,1,1)(0,1,1)$_{52}$, ARIMA(1,0,1)(1,0,1)$_{52}$, ARIMA (1,0,0)(1,0,1)$_{52}$,ARIMA(0,1,1)(1,0,1)$_{52}$, ARIMA (1,1,0)(1,0,1)$_{52}$, ARIMA (1,1,0)(0,1,1)$_{52}$

Nasik

ARIMA (1,0,1(0,1,1)$_{52}$, ARIMA(1,1,1)(0,1,1)$_{52}$, ARIMA (1,0,0)(0,1,1)$_{52}$, ARIMA(1,0,1)(1,0,1)$_{52}$, ARIMA (1,1,1)(1,0,1)$_{52}$, ARIMA(1,1,1)(1,0,1)$_{52}$, ARIMA (1,0,0)(1,0,1)$_{52}$,ARIMA(0,1,1)(1,0,1)$_{52}$, ARIMA (1,1,0)(1,0,1)$_{52}$, ARIMA (0,0,1)(0,1,1)$_{52}$

4.5.7 Selection of the Best Model

Several models qualify based on the diagnostic checking explained in above section. However, for selecting the best models amongst these, the model should forecast evapotranspiration with minimum error. Hence, after passing validation tests, ten models were used for generation of weekly ET_r values for solapur, Ahmednagar, Pune and Nasik districts. For this purpose, the evapotranspiration values were forecast for one year for each district with the help of identified ARIMA models. These values were compared with the historical values for one year for each district by calculating the root mean square error (RMSE) between them as explained in section 3.7.2.5. The RMSE values for all identified models are given in Tables 4.43 for Solapur, Ahmednagar, Pune and Nasik districts, respectively. The historical reference crop evapotranspiration and forecasted reference crop evapotranspiration values are compared in the Appendix –G (Figs. G-1 to G-10, G-11 to G-20, G-21 to G-30 and G-31 to G-40 for Solapur, Ahmednagar, Pune and Nasik districts). It is observed from the figures that seasonal pattern of ET_r series is maintained in generated values by all the ARIMA models.

Based on the values of RMSE, the ARIMA(1,1,0)(1,0,1)$_{52,}$ ARIMA(1,1,1)(0,1,1)$_{52,}$ ARIMA(1,1,1)(0,1,1)$_{52}$ and ARIMA(0,1,1)(0,1,1)$_{52}$ models are selected for forecasting and generation of weekly ET_r values for Solapur, Ahmednagar, Pune and Nasik distrits, respectively. The values of the parameters of the ARIMA models which are finalized for forecasting and generation of weekly ET_r values for Solapur, Ahmednagar, Pune and Nasik districts are:

Solapur

1. ϕ_1 = -0.3054
2. Φ_1 = 0.9895
3. Θ_1 = 0.9336
4. C = - 0.001

Ahmednagar

1. ϕ_1 = 0.3958
2. θ_1 = 0.96836
3. Θ_1 = 0.9467

4. C = 0.000176

Pune

1. $\phi_1 = 0.4091$
2. $\theta_1 = 0.9727$
3. $\Theta_1 = 0.9895$
4. C = 0.00025

Nasik

1. $\theta_1 = 0.559$
2. $\Theta_1 = 0.9475$
3. C = 31.24

Table 4.43 Root mean square error values for the ARIMA models for Solapur, Ahmednagar, Pune and Nasik districts

Solapur	RMSE	Ahmednagar	RMSE	Pune	RMSE	Nasik	RMSE
ARIMA(1,0,1) $(0,1,1)_{52}$	0.6007	**ARIMA(1,1,1) $(0,1,1)_{52}$**	**0.4241**	**ARIMA(1,1,1) $(0,1,1)_{52}$**	**0.55515**	ARIMA(1,1,1) $(0,1,1)_{52}$	0.55497
ARIMA(1,0,1) $(1,0,1)_{52}$	0.6294	ARIMA(1,0,1) $(1,1,1)_{52}$	0.4484	ARIMA(1,0,1) $(1,1,1)_{52}$	0.62055	ARIMA(1,0,1) $(1,1,1)_{52}$	1.36605
ARIMA(0,1,1) $(0,1,1)_{52}$	0.7489	ARIMA(1,0,0) $(0,1,1)_{52}$	0.4407	ARIMA(1,0,0) $(0,1,1)_{52}$	0.59398	ARIMA(1,0,0) $(0,1,1)_{52}$	0.50839
ARIMA(1,0,0) $(1,0,1)_{52}$	0.6267	ARIMA(1,0,1) $(0,1,1)_{52}$	0.4412	ARIMA(1,0,1) $(0,1,1)_{52}$	0.60301	ARIMA(1,0,1) $(0,1,1)_{52}$	0.82154
ARIMA(1,1,0) $(1,0,1)_{52}$	**0.5970**	ARIMA(1,1,1) $(1,0,1)_{52}$	0.4460	ARIMA(1,1,1) $(1,0,1)_{52}$	0.56399	ARIMA(1,1,1) $(1,0,1)_{52}$	1.40149
ARIMA(1,1,0) $(0,1,1)_{52}$	0.6277	ARIMA(0,0,1) $(0,1,1)_{52}$	0.4348	ARIMA(0,0,1) $(0,1,1)_{52}$	0.61092	ARIMA(0,0,1) $(0,1,1)_{52}$	0.74063
ARIMA(1,1,1) $(0,1,1)_{52}$	0.9213	ARIMA(1,0,1) $(1,0,1)_{52}$	0.4785	ARIMA(1,0,1) $(1,0,1)_{52}$	0.56446	ARIMA(1,0,1) $(1,0,1)_{52}$	1.49551
ARIMA(0,0,1) $(1,0,1)_{52}$	0.6289	ARIMA(1,0,0) $(1,0,1)_{52}$	0.4773	ARIMA(1,0,0)($1,0,1)_{52}$	0.58256	ARIMA(1,0,0) $(1,0,1)_{52}$	1.44490
ARIMA(0,0,1) $(1,0,0)_{52}$	0.9720	ARIMA(0,1,1) $(0,1,1)_{52}$	0.4339	ARIMA(0,1,1) $(0,1,1)_{52}$	0.57259	**ARIMA(0,1,1) $(0,1,1)_{52}$**	**0.44861**
ARIMA(0,0,1) $(0,1,1)_{52}$	0.6093	ARIMA(0,1,1) $(1,0,1)_{52}$	0.4663	ARIMA(0,1,1) $(1,0,1)_{52}$	0.56485	ARIMA(0,1,1) $(1,0,1)_{52}$	0.54779
ARIMA(1,1,0) $(1,0,1)_{52}$	**0.5970**	**ARIMA(1,1,1) $(0,1,1)_{52}$**	**0.4241**	**ARIMA(1,1,1) $(0,1,1)_{52}$**	**0.55515**	**ARIMA(0,1,1) $(0,1,1)_{52}$**	**0.44861**

4.5.8 Forecast Values of Evapotranspiration of Pomegranate

Pomegranate evapotranspiration is related to reference crop evapotranspiration through crop factor (k_c). Therefore, for obtatining forecast values of pomegranate ET, forecast ET_r values need to be multiplied by crop factor. The ARIMA models that were finalized to forecast the values of ET_r for Solapur, Ahmednagar, Pune and Nasik districts are presented in section 4.4.8. These models were developed using the climatological data upto 2006. The ET_r values were forecasted with the help of these models for the year 2007 and forecast weekly pomegranate ET values were calculated with the help of weekly k_c values of pomegranate. The water use of pomegranate that was forecasted for the year 2007 for Solapur, Ahmednagar, Pune and Nasik districts are presented in Tables 4.44 to 4.47, respectively. These values are presented for demonstration purpose.

It is to be noted here that to forecast the values of one year ahead say in this case now 2010, the developed seasonal ARIMA models need to be upgraded by using the climatological data upto 2009.

Table 4.44 Forecasted values of ET_c for Solapur district for 1st to 5th year pomegranate trees

MW	Forecasted ET_r (mm/week)	Forecasted ET_r(mm/day)	Forecast ET_c (litres /day/tree)				
			1	2	3	4	5
31	28.25	4.04	2.0	4.0	3.1	4.3	5.3
32	25.42	3.63	1.8	3.9	3.6	5.4	7.3
33	25.55	3.65	1.8	4.2	4.6	7.0	9.6
34	25.00	3.57	1.8	4.3	5.8	8.8	12.0
35	27.41	3.92	2.0	5.0	7.7	11.5	15.5
36	27.48	3.93	2.1	5.4	9.4	13.5	17.8
37	28.16	4.02	2.2	5.8	11.6	16.3	21.4
38	27.19	3.88	2.2	6.0	13.1	18.1	23.3
39	24.72	3.53	2.0	5.7	13.5	18.8	23.7
40	25.52	3.65	2.1	6.2	15.8	21.5	27.0
41	24.77	3.54	2.1	6.4	16.8	23.1	28.2
42	25.56	3.65	2.2	6.9	18.9	25.9	31.3
43	25.55	3.65	2.2	7.3	20.4	28.0	33.6
44	25.29	3.61	2.2	7.7	21.8	29.3	36.1
45	25.17	3.60	2.3	8.0	23.1	30.8	37.9
46	24.46	3.49	2.2	7.8	22.4	30.1	37.0
47	22.62	3.23	2.1	7.3	20.7	27.8	34.2
48	22.44	3.21	2.1	7.3	20.6	27.6	34.0
49	21.80	3.11	2.1	7.0	20.1	26.8	33.0
50	21.36	3.05	2.0	6.9	19.8	26.2	32.4
51	21.53	3.08	2.1	6.9	20.0	26.5	32.7
52	24.38	3.05	2.1	6.9	19.8	26.2	32.4
1	24.03	3.43	2.4	7.4	21.2	28.8	35.3
2	23.75	3.39	2.4	7.0	20.0	27.7	34.1
3	24.53	3.50	2.5	6.9	19.8	27.6	34.1
4	25.92	3.70	2.6	7.0	20.0	28.3	35.0
5	27.84	3.98	2.9	7.1	20.5	29.6	36.9
6	29.27	4.18	3.1	7.1	20.8	30.1	37.7
7	30.38	4.34	3.3	7.1	20.9	30.3	37.9
8	33.05	4.72	3.6	7.2	21.6	31.9	40.4
9	35.38	5.05	3.9	7.3	22.5	33.0	41.9
10	36.27	5.18	4.1	7.0	22.1	32.7	41.5
11	37.71	5.39	4.3	6.9	22.3	32.4	41.7
12	39.85	5.69	3.9	7.1	22.6	32.9	42.2
13	41.75	5.96	4.1	7.5	23.1	32.9	44.3
14	42.28	6.04	4.2	7.7	23.4	33.5	45.2
15	44.01	6.29	4.4	8.0	24.6	35.0	47.0
16	47.31	6.76	4.7	8.8	26.5	37.8	50.6
17	48.23	6.89	4.8	9.1	27.2	38.7	51.7
18	50.00	7.14	5.0	9.5	28.3	40.3	53.8
19	50.69	7.24	5.2	9.7	28.8	41.0	56.1
20	53.03	7.58	5.5	10.3	30.4	43.2	58.9
21	50.29	7.18	5.2	9.9	29.0	41.5	56.1
22	50.26	7.18	5.3	10.0	29.3	42.0	56.5
23	42.56	6.08	4.5	8.6	24.9	35.6	48.1
24	35.87	5.12	3.8	7.4	21.1	29.9	40.8
25	34.14	4.88	3.7	7.1	20.4	28.6	39.0
26	31.58	4.51	3.5	6.7	19.0	26.6	36.3
27	30.59	4.37	3.4	6.5	18.5	25.8	35.5
28	28.56	4.08	3.2	6.2	17.4	24.2	33.4
29	26.57	3.80	3.1	5.9	16.3	22.6	31.2
30	27.27	3.90	3.2	6.1	16.9	23.4	32.4

Table 4.45 Forecasted values of ET_c for Ahmednagar district for 1st to 5th year pomegranate trees

MW	Forecasted ET_r (mm/week)	Forecasted ET_r(mm/day)	Forecast ET_c (litres /day/tree)				
			1	2	3	4	5
31	26.21	3.74	1.8	3.8	2.9	4.0	4.9
32	25.47	3.64	1.8	3.9	3.6	5.4	7.3
33	26.79	3.83	1.9	4.4	4.8	7.4	10.0
34	26.44	3.78	1.9	4.6	6.1	9.4	12.7
35	25.58	3.65	1.9	4.7	7.2	10.7	14.5
36	26.65	3.81	2.0	5.2	9.1	13.1	17.3
37	26.18	3.74	2.0	5.4	10.8	15.2	19.9
38	25.74	3.68	2.1	5.7	12.4	17.1	22.1
39	23.80	3.40	1.9	5.5	13.0	18.1	22.8
40	24.61	3.52	2.0	6.0	15.2	20.7	26.1
41	25.21	3.60	2.1	6.5	17.1	23.5	28.7
42	24.51	3.50	2.1	6.6	18.2	24.9	30.0
43	23.18	3.31	2.0	6.7	18.5	25.4	30.5
44	22.69	3.24	2.0	6.9	19.6	26.3	32.4
45	21.49	3.07	1.9	6.8	19.7	26.3	32.4
46	20.40	2.91	1.9	6.5	18.7	25.1	30.8
47	19.44	2.78	1.8	6.3	17.8	23.9	29.4
48	18.98	2.71	1.8	6.2	17.5	23.3	28.7
49	18.17	2.60	1.7	5.8	16.7	22.3	27.5
50	17.89	2.56	1.7	5.8	16.6	22.0	27.1
51	17.32	2.47	1.7	5.6	16.0	21.3	26.3
52	20.09	2.87	1.9	6.5	18.6	24.7	30.5
1	17.53	2.50	1.7	5.4	15.5	21.0	25.7
2	18.45	2.64	1.8	5.5	15.5	21.5	26.5
3	19.79	2.83	2.0	5.6	16.0	22.3	27.5
4	21.16	3.02	2.2	5.7	16.3	23.1	28.6
5	22.39	3.20	2.3	5.7	16.5	23.8	29.7
6	24.48	3.50	2.6	6.0	17.4	25.2	31.5
7	26.11	3.73	2.8	6.1	17.9	26.1	32.6
8	27.84	3.98	3.0	6.1	18.2	26.9	34.0
9	31.37	4.48	3.5	6.5	19.9	29.3	37.1
10	31.62	4.52	3.5	6.1	19.3	28.5	36.2
11	33.29	4.76	3.8	6.1	19.7	28.6	36.8
12	35.85	5.12	3.5	6.4	20.3	29.6	38.0
13	38.01	5.43	3.7	6.8	21.0	29.9	40.4
14	38.65	5.52	3.8	7.0	21.4	30.6	41.3
15	41.02	5.86	4.1	7.5	22.9	32.7	43.8
16	44.19	6.31	4.4	8.2	24.8	35.3	47.3
17	47.16	6.74	4.7	8.9	26.6	37.8	50.6
18	49.79	7.11	5.0	9.5	28.2	40.1	53.6
19	46.72	6.67	4.8	9.0	26.6	37.8	51.7
20	49.40	7.06	5.1	9.6	28.3	40.3	54.9
21	48.87	6.98	5.1	9.6	28.2	40.4	54.5
22	46.85	6.69	4.9	9.4	27.3	39.2	52.7
23	41.24	5.89	4.4	8.4	24.2	34.5	46.6
24	33.54	4.79	3.6	6.9	19.8	27.9	38.2
25	33.00	4.71	3.6	6.9	19.7	27.6	37.7
26	31.85	4.55	3.5	6.8	19.1	26.8	36.6
27	30.06	4.29	3.4	6.4	18.2	25.4	34.9
28	28.66	4.09	3.2	6.2	17.4	24.3	33.5
29	27.46	3.92	3.2	6.0	16.9	23.4	32.3
30	26.40	3.77	3.1	5.9	16.4	22.6	31.4

Table 4.46 Forecasted values of ET_c for Pune district for 1st to 5th year pomegranate trees

MW	Forecasted ET_r (mm/week)	Forecasted ET_r (mm/day)	Forecast ET_c (litres /day/tree)				
			1	2	3	4	5
31	20.81	2.97	1.4	3.0	2.3	3.2	3.9
32	18.60	2.66	1.3	2.9	2.6	4.0	5.3
33	20.06	2.87	1.4	3.3	3.6	5.5	7.5
34	18.89	2.70	1.4	3.3	4.4	6.7	9.1
35	19.61	2.80	1.5	3.6	5.5	8.2	11.1
36	22.49	3.21	1.7	4.4	7.7	11.1	14.6
37	23.45	3.35	1.8	4.9	9.7	13.6	17.8
38	23.58	3.37	1.9	5.2	11.3	15.7	20.2
39	21.15	3.02	1.7	4.9	11.5	16.1	20.2
40	21.33	3.05	1.8	5.2	13.2	18.0	22.6
41	21.06	3.01	1.8	5.4	14.3	19.6	24.0
42	21.24	3.03	1.8	5.7	15.7	21.5	26.0
43	21.66	3.09	1.9	6.2	17.3	23.7	28.5
44	21.23	3.03	1.9	6.5	18.3	24.6	30.3
45	20.29	2.90	1.8	6.5	18.6	24.8	30.6
46	18.98	2.71	1.7	6.1	17.4	23.3	28.7
47	18.61	2.66	1.7	6.0	17.1	22.9	28.2
48	17.25	2.46	1.6	5.6	15.9	21.2	26.1
49	16.86	2.41	1.6	5.4	15.5	20.7	25.6
50	16.74	2.39	1.6	5.4	15.5	20.6	25.4
51	17.04	2.43	1.6	5.5	15.8	20.9	25.9
52	19.04	2.72	1.8	6.1	17.6	23.4	28.9
1	17.14	2.45	1.7	5.3	15.1	20.6	25.2
2	17.85	2.55	1.8	5.3	15.0	20.8	25.6
3	18.83	2.69	1.9	5.3	15.2	21.2	26.2
4	19.80	2.83	2.0	5.4	15.3	21.6	26.8
5	20.46	2.92	2.1	5.3	15.1	21.7	27.1
6	22.68	3.24	2.4	5.5	16.2	23.4	29.2
7	25.13	3.59	2.7	5.9	17.2	25.1	31.4
8	26.15	3.74	2.9	5.7	17.1	25.2	32.0
9	27.71	3.96	3.1	5.7	17.6	25.9	32.8
10	29.89	4.27	3.3	5.8	18.2	26.9	34.2
11	32.77	4.68	3.7	6.0	19.4	28.1	36.3
12	34.87	4.98	3.4	6.2	19.7	28.8	36.9
13	36.60	5.23	3.6	6.6	20.2	28.8	38.9
14	38.23	5.46	3.8	6.9	21.2	30.3	40.8
15	39.86	5.69	4.0	7.3	22.2	31.7	42.6
16	40.44	5.78	4.0	7.5	22.7	32.3	43.3
17	43.51	6.22	4.4	8.2	24.5	34.9	46.7
18	44.37	6.34	4.5	8.4	25.1	35.7	47.7
19	44.20	6.31	4.5	8.5	25.2	35.8	48.9
20	43.64	6.23	4.5	8.5	25.0	35.6	48.5
21	42.06	6.01	4.4	8.3	24.3	34.7	46.9
22	40.65	5.81	4.3	8.1	23.7	34.0	45.7
23	36.07	5.15	3.8	7.3	21.1	30.2	40.7
24	26.56	3.79	2.8	5.5	15.7	22.1	30.2
25	26.61	3.80	2.9	5.6	15.9	22.3	30.4
26	23.57	3.37	2.6	5.0	14.2	19.8	27.1
27	23.97	3.42	2.7	5.1	14.5	20.2	27.8
28	23.14	3.31	2.6	5.0	14.1	19.6	27.0
29	20.35	2.91	2.3	4.5	12.5	17.3	23.9
30	20.67	2.95	2.4	4.6	12.8	17.7	24.6

Table 4.47 Forecasted values of ET_c for Nasik district for 1st to 5th year pomegranate trees

MW	Forecasted ET_r (mm/week)	Forecasted ET_r(mm/day)	Forecast ET_c (litres /day/tree)				
			1	2	3	4	5
31	26.6	3.8	1.8	3.8	2.9	4.0	5.0
32	25.2	3.6	1.8	3.9	3.6	5.4	7.2
33	26.5	3.8	1.9	4.3	4.7	7.3	9.9
34	25.5	3.6	1.9	4.4	5.9	9.0	12.2
35	27.0	3.9	2.0	5.0	7.6	11.3	15.3
36	29.0	4.1	2.2	5.7	9.9	14.3	18.8
37	28.5	4.1	2.2	5.9	11.7	16.5	21.6
38	29.4	4.2	2.4	6.5	14.1	19.5	25.2
39	29.3	4.2	2.4	6.8	16.0	22.3	28.1
40	30.1	4.3	2.5	7.3	18.6	25.3	31.9
41	30.0	4.3	2.5	7.7	20.4	28.0	34.1
42	30.5	4.4	2.6	8.3	22.6	31.0	37.3
43	30.6	4.4	2.7	8.8	24.4	33.4	40.2
44	29.6	4.2	2.6	9.0	25.5	34.3	42.2
45	28.6	4.1	2.6	9.1	26.2	35.0	43.1
46	28.2	4.0	2.6	9.0	25.8	34.6	42.6
47	27.0	3.9	2.5	8.7	24.8	33.2	40.9
48	26.0	3.7	2.4	8.4	23.9	31.9	39.3
49	25.1	3.6	2.4	8.1	23.1	30.8	38.0
50	25.2	3.6	2.4	8.1	23.4	31.0	38.3
51	25.7	3.7	2.5	8.3	23.8	31.6	39.0
52	27.9	4.0	2.7	9.0	25.8	34.2	42.3
1	25.1	3.6	2.5	7.8	22.2	30.1	36.9
2	25.3	3.6	2.5	7.5	21.3	29.4	36.3
3	26.7	3.8	2.7	7.5	21.5	30.1	37.1
4	27.6	3.9	2.8	7.5	21.3	30.1	37.3
5	30.0	4.3	3.1	7.7	22.1	31.8	39.8
6	32.4	4.6	3.4	7.9	23.1	33.3	41.7
7	34.8	5.0	3.7	8.1	23.9	34.8	43.5
8	35.4	5.1	3.9	7.7	23.1	34.1	43.2
9	37.6	5.4	4.2	7.7	23.9	35.1	44.5
10	40.0	5.7	4.5	7.7	24.4	36.1	45.9
11	42.3	6.0	4.8	7.8	25.0	36.3	46.8
12	46.6	6.7	4.6	8.3	26.4	38.5	49.4
13	47.3	6.8	4.7	8.5	26.1	37.3	50.3
14	48.9	7.0	4.8	8.9	27.1	38.7	52.2
15	51.3	7.3	5.1	9.4	28.6	40.8	54.8
16	52.6	7.5	5.3	9.8	29.5	42.1	56.3
17	55.1	7.9	5.5	10.4	31.0	44.2	59.1
18	55.9	8.0	5.6	10.6	31.6	45.0	60.1
19	54.6	7.8	5.6	10.5	31.1	44.2	60.4
20	55.2	7.9	5.7	10.7	31.6	45.0	61.3
21	52.9	7.6	5.5	10.4	30.6	43.7	59.1
22	49.4	7.1	5.2	9.9	28.7	41.3	55.5
23	47.6	6.8	5.1	9.7	27.9	39.8	53.8
24	38.6	5.5	4.1	8.0	22.8	32.2	44.0
25	34.7	5.0	3.8	7.2	20.7	29.0	39.7
26	31.0	4.4	3.4	6.6	18.6	26.0	35.6
27	29.8	4.3	3.3	6.4	18.1	25.2	34.6
28	28.9	4.1	3.3	6.3	17.6	24.5	33.8
29	27.2	3.9	3.1	6.0	16.7	23.2	32.0
30	27.7	4.0	3.2	6.2	17.2	23.8	33.0

CHAPTER –V

SUMMARY AND CONCULSIONS

The knowledge of water requirement is necessary to match spatial and temporal distribution of water demand with water supply for efficient utilization of water resources. Evapotranspiration is a major component of water requirement. Evapotranspiration varies according to crops, their growth stages, crop condition, soil parameters and climate. It is estimated as the product of reference crop evapotranspiration (ET_r) and crop coefficient (k_c). ET_r takes care of variation in climate and k_c is dependent on crop and its growth stages. Hence, the knowledge of appropriate methods for estimation of ET_r and k_c values is necessary to know the water requirement of crop. In addition to this, it is important for the decision makers and planners if the values of crop evpotranspiration (ET_c) are known at certain probability levels. Further, the evapotranspiration prediction guarantees a reliable project planning, design and operation irrigation systems. The real time operation of any water resources systems needs the forecast of the hydrological variable such as evapotranspiration few time steps ahead. Therefore, the study on "**Stochastic Modeling of Evapotranspiration of Pomegranate (*Punica granatum* L.)"** was undertaken.

Pomegranate is the perennial plant, which stabilizes often after 3-4 years. Therefore, it is necessary to know the crop coefficient (k_c) values up to five years. To establish the separate plantation and obtain the crop coefficient (k_c) values of the same plantation over five years is out of scope for this study. Hence, commercial orchards of different ages (i.e. 1st to 5th years) were selected to develop k_c values for these plantations. Two commercial pomegranate orchards each of 1st, 2nd, 3rd, 4th and 5th years were selected. Five numbers of representative plants were randomly selected from each orchard. Plywood boards of 1.5 x 1.5 m, 2.5 x 2.5 m and 3.5 x 3.5 m sizes with grid marking of size 10 x 10, 20 x 20 and 30 x 30 cm were prepared for the estimation of shaded area. Shaded area was measured at solar noon hour. A plywood board was kept below and the total numbers of shaded grids were measured. The shaded area was then calculated as the total number of grids times the area of each grid. The crop coefficient value was then computed by using the equation $\mathbf{k_c = 0.014x + 0.08}$.

Results of development of crop coefficient values of pomegranate tree indicated that, the k_c values of 1st year pomegranate tree increased from 0.17 to 0.30 due to the development, maturation of the leaf surface and increased number of leaves; foliage and water sprout of the tree during first year. However the k_c values of 2nd, 3rd, 4th and 5th year's tree showed the four distinct phases of k_c. Initially the k_c increases from 0.22, 0.13, 0.14, 0.15 in 31st week to 0.50, 1.01, 1.08, 1.11 in 44th week for 2nd, 3rd, 4th and 5th year's tree, respectively due to increases in number of leaves, flowers, foliage, water sprout, maturation of the leaf surface, luxor and fruits. The k_c values are then almost constant from 45th to 52nd weeks (0.50, 1.08, 1.15, 1.18) due to maturity period. k_c values then reduce from 0.50, 1.08, 1.15, 1.18 in 52nd week to 0.28, 0.65, 0.74, 0.83 in 15th week for 2nd, 3rd, 4th and 5th year's tree, respectively due to harvesting of fruit, removal of number of leaves, foliage, flowers, fruits, water sprouts and luxor. The k_c values again increased from 16th to 30th week (0.29 to 0.35) for 2nd, (0.66 to 0.72) for 3rd, (0.74 to 0.80) for 4th and (0.83 to 0.92) for 5th year's tree, respectively due to application of more irrigation water required for maintaining the plant health for next season.

Doorenbos and Pruitt (1977) have provided the k_c values for deciduous fruit and nut trees for different growth stages. These are: **Initial stage**, **Crop development stage**, **Mid Season** and **Late Season.** The observations were recorded to determine the length of these growth periods. The crop coefficient curves were then constructed using the locally determined length of growth period and corresponding k_c values obtained from the FAO by using the procedure described in guideline for predicting crop water requirements (Doorenbos and Pruitt, 1977). The daily values of k_c were then obtained from the curve. These values were then compared with k_c values determined in this study using shaded area approach.

The k_c values and LAI are dependent on each other. Therefore LAI values were correlated with crop coefficient values. Five representative plants were randomly selected from each of 10 orchards for the estimation of leaf area index. For this purpose the total leaves of a representative plant were divided into small, medium and large size leaves. The numbers of leaves from small, medium and large size were measured. Five representative leaves were then selected from each size and harvested. The area of the harvested leaves was measured by using LI-3000 Licor instrument. The total leaf area was estimated by multiplying the average leaf area of each range (i.e. small, medium and large) with the numbers of leaves in these ranges. The leaf area indices were estimated as the ratio of total leaf area to shaded area (LAI_{SN}) and total leaf area to total area occupied by a tree (LAI_{APP}). The LAI were calculated for each of the representative plant from the selected orchard. The average of LAI of all the representative plant is the LAI value of the selected orchard. The LAI were measured on weekly basis during the period of 31st to 30th meteorological weeks (August, 2008 to July, 2009) for 1, 2, 3, 4 and 5 year's plants of pomegranate.

LAI_{SN} and LAI_{APP} were observed to be 3.51 to 6.84 LAI_{SN} and 0.20 to 0.70 LAI_{APP} for 1st year tree; 4.85 to 9.22 LAI_{SN} and 0.49 to 1.36 LAI_{APP} for 2nd year tree; 3.98 to 5.62 LAI_{SN} and 0.13 to 2.50 LAI_{APP} for 3rd year tree; 3.96 to 4.56 LAI_{SN} and 0.17 to 2.34 LAI_{APP} for 4th year tree; 4.93 to 5.73 LAI_{SN} and 0.23 to 3.33 LAI_{APP} for fifth year tree. The variation in LAI values was due to increases or decreases in foliage, number of leaves and its area for 1st to 5th year's pomegranate trees.

The LAI values were also measured by a direct method. In this method all leaves were removed from representative plant after harvesting of fruits and weighed. LAI_{SN} and LAI_{APP} were then estimated as the ratio of total leaf area of pomegranate tree to shaded area at solar noon hour and total leaf area of pomegranate tree to total area of a tree, respectively. LAI_{SN} increased from 4.55 for 1st year to 6.28 for 2nd year and decreased to 4.81 for 3rd year. LAI_{SN} again increased from 4.81 for to 5.66 for 5th year. However, LAI_{APP} increased from 0.68 for 1st year to 3.41 for 5th year. This is because of the LAI_{SN} is estimated based on shaded area and 2nd year orchard showed more canopy/foliage.

The relationships between k_c and LAI were also developed for the pomegranate trees of different ages. These are: k_c = 0.181LAI + 0.128; 0.335LAI + 0.164; 0.363LAI + 0.144; 0.289LAI + 0.169 and 3.489LAI + 0.129 for 1st to 5th year, respectively. The variation of k_c with leaf area index for the pomegranate tree of different ages shows that the k_c linearly increases with LAI. The relationship between k_c and LAI for the pomegranate tree for all the ages together was also obtained as: k_c = 0.261 LAI + 0.189. These relationships are useful for estimating the values of k_c from the values of LAI for different ages of pomegranate orchard.

The daily records of meteorological parameters viz. maximum and minimum temperature (^{0}C), maximum and minimum relative humidity (%), pan evaporation (mm), wind speed at height of 2 m, actual sunshine hours and rainfall (mm) etc. were collected from the Indian Meteorological Department, Pune, NRC on Pomegranate, Solapur and MPKV, Rahuri for Solapur (1983-2007), Ahmednagar (1975-2007), Pune (1987-2006) and Nasik (1985-2007) districts for this study. Other parameters like geographical locations, viz. latitude, longitude and altitude were also obtained for respective districts.

There are different methods for estimating ET_r; some requiring huge data but considered as accurate and other requiring less data but considered as approximate. The analysis of the performance of the various methods revealed the need for formulating a standard method for the computation of ET_r. For this reason, the FAO Penman-Monteith method (Allen *et al.*, 1998) has been recommended as a standard. Therefore, in this study it was planned to estimate ET_r of pomegranate by different methods and compare those with ET_c values estimated by Penman-Monteith method recommended by FAO as the most accurate one but needs data on many climatological parameters. Other methods viz. Modified Penman, Hargreaves-Samani, Blanney-Criddle, Radiation and FAO Pan Evaporation were also selected for estimation of ET_r as either these methods require more parameters or less parameters. Daily reference crop evapotranspiration (ET_r) values were estimated by these methods. Then daily values were transferred to weekly values. Computer programme was developed in **FORTRAN-90** language to estimate the reference crop evapotranspiration by using above mentioned methods.

The results showed that the trend of variation of ET_r values over the year for all the methods is same. However none of the methods shows the same results. The difference in values of ET_r is due to different climatological variables used in each method. The mean yearly reference crop evapotranspiration (ET_r) values for Solapur district are: 1803.5, 2211.8, 1900.5, 1949.5, 2056.6, and 2239.8 mm for Penman-Monteith, Modified Penman, Hargreaves-Samani, FAO Pan Evaporation, Blanney-Criddle, and FAO Radiation methods, respectively. These values for Ahmednagar district are: 1692.1, 2066.5, 1851.3, 1788.3, 1944.5, and 2166.6 mm; for Pune district are: 1428.7, 1782.5, 1744.5, 1334.6, 1936.6, and 1984.4 mm; and for Nasik district are: 1603.0, 2003.0, 1755.4, 1349.1, 1936.9, and 2079.8 mm.

It is observed from the values of ET_r values for Solapur district that the estimates of ET_r by FAO radiation method are higher, followed by modified penman method, Blanney-Criddle, pan evaporation, Hargraeves-Samani and Penman-Monteith methods. For Ahmednagar district, FAO radiation method are higher, followed by modified penman method, Blanney-Criddle, Hargraeves-Samani, pan evaporation, and Penman-Monteith methods. For Pune district, FAO radiation method are higher, followed by Blanney-Criddle, modified penman method, Hargraeves-Samani, Penman-Monteith, and pan evaporation methods. For Nasik district, FAO radiation method are higher, followed by Modified penman method, Blanney-Criddle, Hargraeves-Samani, Penman-Monteith, and pan evaporation methods.

As one of the objectives of the study was to find out the method of estimation of ET_r that is close to Penman-Monteith method, the estimates of ET_r by different methods was compared with estimates of ET_r by Penman-Monteith method by regression analysis and computing root mean square error. Based on the regression analysis Modified Penman method is highly correlated with Penman-Monteith method for all districts. This is evident due to the fact that both the methods use the same set of data and is based on similar principle. The estimates of Hargreaves-Samani and FAO Radiation are also significantly correlated with ET_r estimates of Penman-Monteith method for Solapur, Ahmednagar and Nasik districts. For Pune district, the estimates of FAO radiation and FAO pan evaporation methods are significantly correlated with Penman-Monteith in addition to modified Penman method. Hence on the basis of regression analysis all the three methods (modified Penman, Hargreaves-Samani and FAO Radiation for Solapur, Ahmednagar and Nasik districts; and modified Penman, FAO radiation and FAO pan evaporation for Pune district) can be used in lieu of Penman-Monteith method. However user needs to decide to select the appropriate method out of these three on the basis of data availability.

However based on least root mean square error values, Hargraves-Samani is the best for Solapur and Nasik districts and Modified Penman method for Ahmednagar and Pune districts. Thus in general, in case of availability of the data on large number of parameters modified Penman method is recommended and in case of availability of only temperature data, Hargreaves-Samani method is recommended.

The farmers need the information on water to be applied to each pomegranate tree. Water to be applied was estimated on weekly basis for the pomegranate trees up to the age of 5 by considering the plant to plant spacing as 3.0 m and row to row spacing as 4.5 m; irrigation efficiency as 90% and area factor as obtained by shaded area. The annual values of water to be applied per tree for 1st to 5th year of pomegranate tree for Solapur district are: 175.61, 401.79, 1104.89, 1551.19 and 2008.19; for Ahmednagar district are: 164.61, 374.02, 1024.89, 1439.78 and 1867.35; for Pune district are: 139.35, 316.78, 874.98, 1229.28 and 1592.57; and for Nasik district are: 156.67, 355.26, 985.46, 1384.85 and 1793.82 litres/year.

The values of ET_r at desired probability are required for the irrigation planning. For this purpose it was proposed in this study to investigate the appropriate probability distribution functions for the ET_r values estimated by Penman-Monteith method. The daily ET_r values were estimated for all the 4 selected districts by Penman-Monteith method for 24, 32, 19 and 22 years ET_r data for Solapur, Ahmednagar, Pune and Nasik districts and daily values then were converted to weekly values. The probability distribution analysis was then performed for weekly ET_r values for 52 standard meteorological weeks. The probability distribution functions that were selected based on the past literature are: Normal, Log Normal, Gamma, Gumbel and Weibull’s probability distribution functions. To know the probability distribution function that fit the ET_r data most, Chi-square test was preformed. The calculated Chi-square value ($\chi_{cal}{}^2$) was compared with tabulated value ($\chi_{tab}{}^2$) at 5% level of significance. If the calculated Chi-square value is less than the tabulated value, the probability distribution function under consideration fits to the data. If more than one probability distribution function fits to data, the probability distribution function with lowest value of calculated Chi square were considered as the best function.

Results of probability distribution analysis indicated that, the probability distribution analysis of ET_r indicate that more than one probability distribution was found suitable for the ET_r values for many weeks. However, it was also observed that there are instances where none of the probability distributions under consideration are found suitable. The ET_r values at different probability levels for the pomegranate under consideration were obtained from the probability distribution functions that give best fit. In case of more than one distribution is the best fit, the distribution selected for estimating ET_r values was in order of Normal, Log Normal, Gamma, Gumbel and Weibull's. This order of preference was decided on the basis of reviews that showed fitting of distributions to hydrological variable in above order. Once the probability distribution function is obtained, the reference crop evapotranspiration values was found at 10, 20, 30, 40, 50, 60, 70, 80, and 90 per cent probability levels for each week.

Normal distribution is the best fit for maximum weeks (25), followed by Log Normal (11), Gumbel (9), Gamma (4) and Weibull's (2) for Solapur district. For Ahmednagar district, Log normal distribution is the best fit for maximum weeks (11), followed by Normal (9), Gumbel (9), Weibull's (8) and Gamma (6). Normal distribution is the best fit for maximum weeks (25), followed by Log Normal (10), Gumbel (8), Weibull's (5) and Gamma (4) for Pune district and for Nasik district, Normal distribution is the best fit for maximum weeks (20) followed by Gamma (11), Log Normal (10), Gumbel (9) and Weibull's (2).

The values of ET_r at different probability levels when multiplied by corresponding k_c factors are useful for appropriate irrigation planning for pomegranate. The maximum and minimum values of daily water to be applied to pomegranate tree at 70% probability level for Solapur district are: 2.26 and 6.21 l/d/tree for 1st year, 4.72 to 9.6 l/d/tree for 2nd year, 3.60 to 34.4 l/d/tree for 3rd year, 5.0 to 48.9 l/d/tree for 4th year, and 6.18 to 66.6 l/d/tree for 5th year, for Ahmednagar district are: 1.65 to 5.7 l/d/tree for 1st year, 3.90 to 8.7 l/d/tree for 2nd year, 3.39 to 32.9 l/d/tree for 3rd year, 4.70 to 46.8 l/d/tree for 4th year, and 5.81 to 50.7 l/d/tree for 5th year, for Pune district are: 1.52 to 5.1 l/d/tree for 1st year, 3.33 to 8.1 l/d/tree for 2nd year, 2.63 to 28.1 l/d/tree for 3rd year, 3.66 to 40.0 l/d/tree for 4th year, and 4.52 to 54.4.2 l/d/tree for 5th year, for Nasik district are: 1.80 to 7.1 l/d/tree for 1st year, 3.95 to 12.3 l/d/tree for 2nd year, 3.37 to 39.10

l/d/tree for 3^{rd} year, 4.68 to 56.9 l/d/tree for 4^{th} year, and 5.79 to 76.0 l/d/tree for 5^{th} year, respectively.

One of the objectives of this study was to develop and validate the stochastic model for generating and forecasting of reference crop evapotranspiration of major pomegranate growing districts of Maharashtra state. Therefore stochastic modeling of weekly ET_r estimated by Penman-Monteith method was performed for the generation and forecasting of weekly ET_r and ET_c values. Stochastic models of Autoregressive Integrated Moving Average (ARIMA) class were developed for generation and forecasting of ET_r values. As the Penman-Monteith method is recommended by FAO, the weekly reference crop evapotranspiration data estimated by this method were considered for generating and forecasting. The stochastic models of Seasonal ARIMA model were fitted to weekly ET_r values. The following procedure as developed by Box and Jenkins (1994) and Hipel and McLeod (1994) were used for fitting the model.

- **Standardization and normalization of time series variables:** The ARIMA model has the provision to differentiate the time series. Hence, standardization and normalization were not performed.
- **Identification of the models**: On the basis of information obtained from ACF and PACF and using the guidelines provided by Gorantiwar (1984), the orders of autoregressive (AR) and moving average (MA) terms were identified as one.

  Guidelines: If the autocorrelation function cuts off, fit ARIMA (0,d,q) $(0,1,Q)_{52}$ model to the data, where q is the lag after which the autocorrelation function first cuts off, and Q is the after which seasonal ACF cutoff. If the autocorrelation function cuts off, fit ARIMA (p,d,0) $(P,1,0)_{52}$ model to the data, where p is the lag after which the partial autocorrelation function first cuts off, and p is the lag after which the partial autocorrelation function first cuts off, and P is the lag after which seasonal PACF cuts off. If neither the autocorrelation or partial autocorrelation functions cuts off, fit the ARIMA (p,d,q) $(P,1,Q)_{52}$ model for a grid of values of p, P, q and Q.

Accordingly, following thirty six ARIMA models were selected for fitting for each district.

ARIMA(1,1,1) $(1,1,1)_{52}$,ARIMA(1,1,1)$(1,1,0)_{52,}$ARIMA(1,1,1)$(1,0,1)_{52,}$
ARIMA(1,1,1)$(1,0,0)_{52,}$ARIMA(1,1,1)$(0,1,1)_{52}$,ARIMA(1,1,1)$(0,0,1)_{52,}$

ARIMA(1,1,0)(1,1,1)$_{52}$,ARIMA(1,1,0)(1,1,0)$_{52}$,ARIMA(1,1,0)(1,0,1)$_{52}$,
ARIMA(1,1,0)(1,0,0)$_{52}$,ARIMA(1,1,0)(0,1,1)$_{52}$,ARIMA(1,1,1)(0,0,1)$_{52}$,
ARIMA(1,0,0)(1,1,1)$_{52}$,ARIMA(1,0,0)(1,1,0)$_{52}$,ARIMA(1,0,0)(1,0,1)$_{52}$,
ARIMA(1,0,0)(1,0,0)$_{52}$,ARIMA(1,0,0)(0,1,1)$_{52}$,ARIMA(1,0,0)(0,0,1)$_{52}$,
ARIMA(1,0,1)(1,1,1)$_{52}$,ARIMA(1,0,1)(1,1,0)$_{52}$,ARIMA(1,0,1)(1,0,1)$_{52}$,
ARIMA(1,0,0)(1,0,0)$_{52}$,ARIMA(1,0,1)(0,1,1)$_{52}$,ARIMA(1,0,1)(0,0,1)$_{52}$,
ARIMA(0,1,1)(1,1,1)$_{52}$,ARIMA(0,1,1)(1,1,0)$_{52}$,ARIMA(0,1,1)(1,0,1)$_{52}$,
ARIMA(0,1,1)(1,0,0)$_{52}$,ARIMA(0,1,1)(0,1,1)$_{52}$,ARIMA(0,1,1)(0,0,1)$_{52}$,
ARIMA(0,0,1)(1,1,1)$_{52}$,ARIMA(0,0,1)(1,1,0)$_{52}$, ARIMA(0,0,1) (1,0,1)$_{52}$,
ARIMA (0,0,1) (1,0,0)$_{52}$,ARIMA(0,0,1) (0,1,1)$_{52}$, and ARIMA (0,0,1) (0,0,1)$_{52}$.

- **Determination of the parameters of selected models:** The following parameters of the selected models were calculated by maximum likelihood method.

  1. $\emptyset_1$ 2. θ_1 3. Φ_1 4. Θ_1 5. C

- **Diagnostic checking:** Once a model has been selected and parameters calculated, the adequacy of the model has to be checked. This process is called diagnostic checking. There are number of diagnostic checking methods to test the suitability of the estimated model. Examination of standard error, ACF and PACF of residuals and Akaike Information Criteria (AIC) tests were used for diagnostic checking.

First ten models with less AIC that satisfy the standard error and ACF and PACF of residuals criteria were selected for further validation. These models are:

Solapur

ARIMA (1,0,1(0,1,1)$_{52}$, ARIMA(1,0,1)(1,0,1)$_{52}$, ARIMA (0,1,1)(0,1,1)$_{52}$, ARIMA(1,0,0)(1,0,1)$_{52}$, ARIMA (1,1,0)(1,0,1)$_{52}$, ARIMA(1,1,0)(0,1,1)$_{52}$, ARIMA (1,1,1)(0,1,1)$_{52}$,ARIMA(0,0,1)(1,0,1)$_{52}$, ARIMA (0,0,1)(1,0,0)$_{52}$, ARIMA (0,0,1)(0,1,1)$_{52}$

Ahmednagar

ARIMA (1,1,1(0,1,1)$_{52}$, ARIMA(1,0,1)(1,1,1)$_{52}$, ARIMA (1,0,0)(0,1,1)$_{52}$, ARIMA(1,0,1)(0,1,1)$_{52}$, ARIMA (1,1,1)(1,0,1)$_{52}$, ARIMA(0,0,1)(0,1,1)$_{52}$, ARIMA (1,0,1)(1,0,1)$_{52}$,ARIMA(1,0,0)(1,0,1)$_{52}$, ARIMA (0,1,1)(0,1,1)$_{52}$, ARIMA (0,1,1)(1,0,1)$_{52}$

Pune

ARIMA (1,0,1(0,1,1)$_{52}$, ARIMA(1,0,0)(0,1,1)$_{52}$, ARIMA (0,0,1)(0,1,1)$_{52}$, ARIMA(1,1,1)(0,1,1)$_{52}$, ARIMA (0,1,1)(0,1,1)$_{52}$, ARIMA(1,0,1)(1,0,1)$_{52}$, ARIMA (1,0,0)(1,0,1)$_{52}$,ARIMA(0,1,1)(1,0,1)$_{52}$, ARIMA (1,1,0)(1,0,1)$_{52}$, ARIMA (1,1,0)(0,1,1)$_{52}$

Nasik

ARIMA (1,0,1(0,1,1)$_{52}$, ARIMA(1,1,1)(0,1,1)$_{52}$, ARIMA (1,0,0)(0,1,1)$_{52}$, ARIMA(1,0,1)(1,0,1)$_{52}$, ARIMA (1,1,1)(1,0,1)$_{52}$, ARIMA(1,1,1)(1,0,1)$_{52}$, ARIMA (1,0,0)(1,0,1)$_{52}$,ARIMA(0,1,1)(1,0,1)$_{52}$, ARIMA (1,1,0)(1,0,1)$_{52}$, ARIMA (0,0,1)(0,1,1)$_{52}$

Selection of the model: The RMSE criterion was used for selecting the most appropriate model of ARIMA amongst all the models that passed the adequacy test or diagnostic checking. RMSE shows how close the actual values of ET_r are with predicted ET_r. Lower the values of RMSE, better is the model. The actual and forecast values were compared by RMSE. Based on the values of RMSE, the ARIMA(1,0,1)(0,1,1)$_{52,}$ ARIMA(1,1,1)(0,1,1)$_{52,}$ ARIMA(1,1,1)(0,1,1)$_{52}$ and ARIMA(0,1,1)(0,1,1)$_{52}$ models are selected for forecasting and generation of weekly ET_r values for Solapur, Ahmednagar, Pune and Nasik districts, respectively. The values of the parameters of the ARIMA models which are finalized for forecasting and generation of weekly ET_r values for Solapur, Ahmednagar, Pune and Nasik districts are:

Solapur

$\phi_1 = 0.8139$, $\theta_1 = 0.4623$, $\Theta_1 = 0.9546$, C = - 0.33

Ahmednagar

$\phi_1 = 0.3958$, $\theta_1 = 0.96836$, $\Theta_1 = 0.9467$, C = 0.000176

Pune

$\phi_1 = 0.4091$, $\theta_1 = 0.9727$, $\Theta_1 = 0.9895$, C = 0.00025

Nasik

$\theta_1 = 0.559$, $\Theta_1 = 0.9475$, C = 31.24

This study was focused on developing crop coefficient for various ages of pomegranate plants; computing and comparing the reference crop evapotranspiration (ET_r) values by different methods; probability distribution analysis and stochastic modeling for evapotranspiration for major pomegranate growing districts of Western part of Maharashtra State. The following specific conclusions were derived from the results of the study,

1. The crop coefficient values for 1st to 5th year's tree were found to be in the range of 0.17 to 0.30, 0.22 to 0.50, 0.13 to 1.08, 0.14 to 1.15 and 0.15 to 1.18, respectively.
2. The k_c values of 1st year pomegranate tree increased from 0.17 to 0.30 due to the development, maturation of the leaf surface and increased number of leaves; foliage and water sprout of the tree during first year.
3. The k_c values of 2nd, 3rd, 4th and 5th year's tree showed the four distinct phases of k_c. Initially the k_c increases from 0.22, 0.13, 0.14, 0.15 in 31st week to 0.50, 1.01, 1.08, 1.11

in 44^{th} week for 2^{nd}, 3^{rd}, 4^{th} and 5^{th} year's tree, respectively due to increases in number of leaves, flowers, foliage, water sprout, maturation of the leaf surface, luxor and fruits. The k_c values are then almost constant from 45^{th} to 52^{nd} weeks (0.50, 1.08, 1.15, 1.18) due to maturity period. Then k_c values then reduce from 0.50, 1.08, 1.15, 1.18 in 52^{nd} week to 0.28, 0.65, 0.74, 0.83 in 15^{th} week for 2^{nd}, 3^{rd}, 4^{th} and 5^{th} year's tree, respectively due to harvesting of fruit, removal of number of leaves, foliage, flowers, fruits, water sprouts and luxor. The k_c values again increased from 16^{th} to 30^{th} week (0.29 to 0.35) for 2^{nd}, (0.66 to 0.72) for 3^{rd}, (0.74 to 0.80) for 4^{th} and (0.83 to 0.92) for 5^{th} year's tree, respectively due to application of more irrigation water required for maintaining the plant health for next season. The weekly Kc values developed in this study for the pomegranate trees of 1^{st} to 5^{th} year age can be used for the estimation of pomegranate crop evapotranspiration from the estimates of the reference crop evapotranspiration for the major pomegranate growing districts of Maharashtra.

4. The leaf area index values estimated by indirect method were observed to be 3.51 to 6.84 for LAI_{SN} i.e. LAI based on shaded area and 0.20 to 0.70 for LAI_{APP} i.e. LAI based on total area for 1^{st} year tree; 4.85 to 9.22 for LAI_{SN} and 0.49 to 1.36 for LAI_{APP} for 2^{nd} year tree; 3.98 to 5.62 for LAI_{SN} and 0.13 to 2.50 for LAI_{APP} for 3^{rd} year tree; 3.96 to 4.56 for LAI_{SN} and 0.17 to 2.34 for LAI_{APP}, for 4^{th} year tree; 4.93 to 5.73 for LAI_{SN} and 0.23 to 3.33 for LAI_{APP} for fifth year tree. The variation in LAI values was due to increases or decreases in foliage, number of leaves and its area for 1^{st} to 5^{th} year's pomegranate trees.
5. The LAI_{SN} values estimated by direct method increased from 4.55 for 1^{st} year to 6.28 for 2^{nd} year and decreased to 4.81 for 3^{rd} year. LAI_{SN} again increased from 4.81 for to 5.66 for 5^{th} year. However, LAI_{APP} increased from 0.68 for 1^{st} year to 3.41 for 5^{th} year. This is because of the LAI_{SN} is estimated based on shaded area and 2^{nd} year orchard showed more canopy/foliage.
6. The variation of k_c with leaf area index for the pomegranate tree of different ages shows that the k_c linearly increases with LAI.
7. The relationship between k_c and LAI for the pomegranate tree for all the ages together was obtained as: k_c = 0.26 LAI + 0.189. These relationships are useful for estimating the values of k_c from the values of LAI for different ages of pomegranate orchard.
8. The trend of variation of ET_r values over the year for all the methods (i.e. Penman-Monteith, Modified Penman, Hargreaves-Samani, Pan Evaporation, Blanney-Criddle and FAO Radiation methods) is same. However none of the methods shows the same results.

The difference in values of ET_r is due to different climatological variables used in each method.

9. For Solapur district, the estimates of ET_r by FAO radiation method are higher, followed by modified penman method, Blanney-Criddle, pan evaporation, Hargraeves-Samani and Penman-Monteith methods. For Ahmednagar district, FAO radiation method are higher, followed by modified penman method, Blanney-Criddle, Hargraeves-Samani, pan evaporation, and Penman-Monteith methods. For Pune district, FAO radiation method are higher, followed by Blanney-Criddle, modified penman method, Hargraeves-Samani, Penman-Monteith, and pan evaporation methods. For Nasik district, FAO radiation method are higher, followed by Modified penman method, Blanney-Criddle, Hargraeves-Samani, Penman-Monteith, and pan evaporation methods.
10. On the basis of regression analysis other methods (modified Penman, Hargreaves-Samani and FAO Radiation for Solapur, Ahmednagar and Nasik districts; and modified Penman, FAO radiation and FAO pan evaporation for Pune district) can be used in lieu of Penman-Monteith method. However user needs to decide to select the appropriate method out of these three on the basis of data availability.
11. On the basis of the least root mean square error values, Hargraves-Samani is the best for Solapur and Nasik districts and Modified Penman method for Ahmednagar and Pune districts. Thus in general in case of availability of the data on large number of parameters modified Penman method is recommended and in case of availability of only temperature data, Hargreaves-Samani method is recommended.
12. Normal distribution is the best fit for maximum weeks (25), followed by Log Normal (11), Gumbel (9), Gamma (4) and Weibull’s (2) for Solapur district. For Ahmednagar district, Log normal distribution is the best fit for maximum weeks (11), followed by Normal (9), Gumbel (9), Weibull’s (8) and Gamma (6). Normal distribution is the best fit for maximum weeks (25), followed by Log Normal (10), Gumbel (8), Weibull’s (5) and Gamma (4) for Pune district and for Nasik district, Normal distribution is the best fit for maximum weeks (20) followed by Gamma (11), Log Normal (10), Gumbel (9) and Weibull’s (2).
13. The average amounts of water to be applied for the pomegranate tree of 1st to 5th year age at 70% probability level for Solapur district are 3.6, 7.6, 22.7, 31.7, and 41.3 l/d/tree; for Ahmednagar district are 3.3, 7.2, 21.6, 30.1, and 38.9 l/d/tree; for Pune district are 2.9, 6.1, 18.3, 25.5, and 33.3 l/d/tree; for Nasik district are 4.2, 9.2, 27.4, 38.2, and 49.5 l/d/tree.

14. The Seasonal Autoregressive Integrated Moving Average i.e. ARIMA (1,0,1) $(0,1,1)_{52}$, ARIMA (1,1,1) $(0,1,1)_{52}$, ARIMA (1,1,1) $(0,1,1)_{52}$ and ARIMA (0,1,1) $(0,1,1)_{52}$ model were found to be the best model in generating and forecasting the weekly reference crop evapotranspiration estimated by Penman-Monteith method for Solapur, Ahmednagar, Pune and Nasik districts, respectively.
15. The parameters values of the ARIMA models for generation and forecasting of weekly ET_r are $\emptyset_1 =$ 0.8139, $\theta_1 =$ 0.4626, $\theta_1 =$ 0.9546 and C= -0.33 for Solapur district, $\emptyset_1 =$ 0.3958, $\theta_1 =$ 0.96836, $\theta_1 =$ 0.9467 and C= 0.000176 for Ahmednagar district; $\emptyset_1 =$ 0.4091, $\theta_1 =$ 0.9727, $\theta_1 =$0.9895 and C= 0.00025 for Pune district and $\theta_1 =$ 0.559, $\theta_1 =$ 0.9475 and C= 31.24 for Nasik district.

REFERENCES

Adeboye, O. B., J. A. Osunbitan, K. O. Adekalu and D. A. Okunade. 2009. Evaluation of FAO -56 Penman-Monteith and temperature based models in estimating reference evapotranspiration. *Agricultural Engineering International: The CIGR Ejournal.* **11**(1291):1-7.

Agrawal, M. C., V. S. Katiyar and Rambabu. 1988. Probability analysis of annual maximum daily rainfall of U.P. Himalaya. *Indian Journal of Soil Conservation.* **16**(1):35-43.

Akaike, H. 1974. A new look at the statistical model identification. *IEEE Trans. Autom. Control.AC*-**19**(6): 716-723.

Ali, S. and B. K. Sethy. 2007. Evaluation of probability density functions for describing rainfall data in south-eastern Rajasthan. *Indian Journal of Soil Conservation.* **35**: 116-121.

Alkaeed, O., Flores, C., Jinno, K. and A. Tsutsumi. 2006. Comparison of several reference evapotranspiration methods for Itoshima Peninsula Area, Fukuota, Japan. *Memoirs of the Faculty of Engineering, Kyushu University.* **66**(1):1-13.

Allen, R. G. 2000. Ref-ET: Reference evapotranspiration calculation software. Version 2.0. *Report .University of Idaho.*pp. 76.

Allen, R. G. and D. K. Fisher.1990. Low cost electronic weighing lysimeters. *Trans. ASCE.* **33**(6):1823-1833.

Allen, R. K., L. S. Pereira, D. Raes and M. Smith. 1998. Crop evapotranspiration. Guideline for computing crop water requirements. *FAO Irrigation and Drainage* Paper No. **56**. United Nations Food and Agricultural Organization, Rome, pp.158.

Allen, R. K., W. O. Pruitt., J. L. Wright., T. A. Howell., F. Ventura., R. Snyder., D. Itenfisu., P. Steduto., J. Berengena., J. B. Yrisarry., M. Smith., L. S. Pereira., D. Raes., A, Pereira., I, Alves., I. Walther and R. Elliot. 2006. A recommendation on the standardized surface resistance for hourly calculation of reference ET_o by the FAO56 Penman-Monteith method. *Agricultural Water Management.* **81**:1-22.

Alves, J. Jr., M.V. Folegatti, L. R. Parsons, W. Bandaranayake, C. R. da. Silva, T. J. A. da Silva and L.F.S.M. Camppeche. 2006. Determination of crop coefficient for grafted Tahiti lime trees and soil evaporation coefficient of Rhodic Kandiudalf clay soil in Sao Paulo, Brazil. *Irrigation Science*.**25** (4):419-428.

Amatya, D. M. and R. W. Skaggs. 1995. Comparison of methods for estimating REF-ET. *Journal of Irrigation and Drainage Engineering.* **121**(6): 427 - 435.

Amiro, B. D. and E. E. Wuschke. 1987. Evapotranspiration from a boreal forest drainage basin using energy balance/eddy covariance technique. *Boundary-Layer Meteorology.* **38**:125-139.

Anonymous. 2004 (a). Economic Survey of India. pp.55.

Anonymous. 2004 (b). Irrigation Status Report, Maharashtra State-India. *Irrigation Department*, Maharashtra.pp.5.

Aslyng, H. C. and K. J. Kristensen. 1961. Water balance recorder. *Journal of Irrigation and Drainage Division.* Proce.ASCE. **87**:15-21.

Asner, G. P., M. O. Jonathan, Scurlock and J. A. Hicke. 2004. Global synthesis of leaf area index observations: implications of ecological and remote sensing studies. *Agricultural and Forest Meteorology.* **121** (1-2): 19-35.

Ayars, J. E., R. S. Johnsons, C. J. Phene, T. J. Trout, D. A. Clark and R. M. Mead. 2003. Water use by drip irrigated late season Peaches. *Irrigation Science.* **22**:187-194.

Ayars, R. S. and D. W. Westcot. 1994. Water quality for agriculture. *FAO Irrigation and Drainage paper 29,* FAO. Rev., 1-130.

Bender, M. and S. Simonovle.1994. Time–series modeling for long-range stream flow forecasting. *Journal of Water Resources Planning and Management*, ASCE, **120**(6):857-870.

Bhardwaj, S. P. and G. Shastry.1979. Development and installation of simple mechanical weighing lysimeter. *Transaction of ASAE*.**22** (4):797-802.

Bhatt, V. K., A. K. Tiwari and A. K. Sharma. 1996. Probability model for prediction of annual maximum rainfall for Datia. *Indian Journal of Soil Conservation*. **24:** 25-27.

Bhakar, S. R. 2000. Modeling of Evaporation and Evapotranspiration under climatic conditions of Udaipur. Thesis of Doctor of Philosophy submitted to faculty of Agricultural Engineering, Department of Soil and Water Engineering, CTAE, MPUAT,Udaipur, pp. 327.

Bhakar, S. R. and R. V. Singh. 2003. Estimation of reference evapotranspiration under the sub-humid climatic conditions of Rajasthan. Proceedings 37th ISAE Convention,held during January 29-31, 2003 at CTAE, Udaipur.

Bhakar, S. R. and R. V. Singh. 2005. Estimation of reference evapotranspiration under sub-humid climatic conditions of Rajasthan. *Drainage and Irrigation Water Management*. Edited by Virendra Kumar, Jaspal Singh and S.R.Bhakar, Himanshu Publications, Udaipur. pp. 193 – 203.

Bhakar, S. R., R. V. Singh and Hari Ram. 2006. Stochastic modeling of wind speed at Udaipur region. *Journal of Agricultural Engineering*. **43**: 1-7.

Bidlake, W. R. and W. M. Woodham. 1990. Evapotranspiration from areas of native vegetation in west-central Florida. Water supply Papers of the U.S. Geological Survey, **2430**: 1-35.

Blaney, H. F. and W. V. Morin. 1942. Evaporation and consumptive use of water empirical formulae's. *Trans. of Ameri. Geophys. Union.* **23**:76-83.

Blaney, H. F. and W. D. Criddle. 1962. Evaporation from free water surface at high altitudes. *Trans. of ASCE*. **123**:243-265.

Box, G. E. P. and G. M. Jenkins. 1976. Time Series Analysis, Forecasting and Control. Revised Edition, Holden-Day, San Francisco, California, United States. pp.553.

Box, G. E. P. and G. M. Jenkins. 1994. Time Series Analysis, Forecasting and Control. Holden-Day, San Francisco, California, pp. 553.

Brursaert, W. H. 1982. Evaporation into the atmosphere. R. Defield Publising Compony, Dondrecht, Holland, pp. 299.

Changnon, S, A., F. A. Huff and C. F. Hsu. 1988. Relations between precipitation and ground water in Illinois. *Journal of Climate.* **1**(12):1239-1250.

Challa, O., S. Vadivelu and J. Sehgal. 1995. Soil of Maharashtra for optimum land use. NBSS Pub.-54. Soils of India series-5. National Bureau of Soil Survey and Land Use Planning Nagpur. 7-427.

Challa, O., K. S. Gajbhiye and M. Velayutham. 1999. Soil series of Maharashtra. Technical Bull. Publication-79. National Bureau of Soil Survey and Land Use Planning, Nagpur. 7-427.

Chandra. J., V. P. Gupta and R. C. Chowdhary. 1996. Determination of pan coefficient for evapotranspiration at Jodhpur. *Journal of Indian Water Resources Society*. **2**(2): 59-62.

Chaudhary, D. A. and P. T. Desai. 1988. Evaluation of crop coefficients for various crops. B.Tech (A.E.) project report submitted to M.P.K.V., Rahuri (M.S) 127.

Chhajed, N. 2004. Stochastic modeling for forecasting Mahi river inflows. M.E.Thesis submitted to MPUAT, Udaipur. pp.88.

Christiansen, J. F. 1968. Pan evaporation and evapotranspiration from climatic data. *Journal of Irrigation and Drainage Division. Proceedings ASCE*. **94**(2):243-265.

Chin, D. A. and S. Zaho. 1995. Evaluation of evaporation pan-network. *Journal of Irrigation and Drainage Engineering.* ASCE.**121**:338-344.

Collier, P. and A. Olioso. 1993. A simple system for automated long-term Bowen ratio measurements. *Agricultural and Forest Meteorology.* **66**(1): 81-92.

Conceicao, N., T. A. Paco, A. L. Silva and M. I. Ferreira. 2006. Crop coefficient of Pear orchards (*pyrus communis L.*) using eddy covariance. Abstract published in 5th International Symposium on Irrigation of Horticulture Crops. Mildura, Australia.pp.76.

Consoli, S., N. O'Connell and R. Snyder. 2006. Estimation of evapotranspiration of different sized naval Orange tree orchards using energy balance. *Journal of Irrigation and Drainage Engineering.* **132**(1):2-8.

Coops, N. C., M. L. Smith, K. L. Jacobasen, M. Martin and S. Ollinger. 2000. Estimation of plant and leaf area index using three techniques in a mature native eucalypt canopy. *Canadian Journal of Forest Research.***30** (9):1400-1409.

Cittadini, E. D. and P. L. Peri. 2006. Estimation of leaf area in sweet cherry using a non-destructive method. *INTA, Argentina*.**35** (1):143-150.

Dabral, P. P. and K. A. Rao. 1995. Forecasting of rainfall for Mohurgong and Gulma Tea Estates. *Journal of Research (BAU)*. **7**(1):39-42.

Dalvi, R. R. and C. B. Thakur. 1990. Probability analysis of reference crop evapotranspiration. B.Tech. Thesis submitted to M.P.K.V., Rahuri, 208.

Davis, J. M. and P. N. Rappoport. 1974. The use of time series analysis techniques in forecasting meteorological drought. *Monthly Weather Review*. **102**:176-180.

Deora, B. S., R. V. Singh and S. R. Bhakar. 2009. Stochastic modeling of water deficit under climatic condition of S. K. Nagar (Gujarat). *Indian Journal of Soil Conservation*. **37**(1): 1-9.

Devendra Kumar, Raj Kumar and Sanjay Kumar. 1998. Monthly rainfall probability analysis of Aonla (Bareilly) Rohikhand region. *Indian Journal of Soil Conservation*. **26**(2):156-161.

de Azevedo, P. V., C. B. de Souza, B. B. de Silva and V. P. R. de Silva. 2007. Water requirements of Pineapple crop grown in tropical environment, Brazil. *Agricultural Water Management*. **88**(1-3): 201-208.

de Silva, V. P. R., P.V. de Azevedo and B. B. de Silva. 2007. Surface energy fluxes and evapotranspiration of a Mango orchard grown in a semi arid environment. *Agronomy Journal*. **99**:1391-1396.

Doorenbos, J. and W. O. Pruitt. 1975. Guidelines for predicting Crop Water Requirement: *FAO Irrigation and Drainage* Paper No.24, FAO, Rome, Italy. pp. 179.

Doorenbos, J. and W. O. Pruitt. 1977. Guidelines for predicting Crop Water Requirement: *FAO Irrigation and Drainage* Paper No.24, FAO, Rome, Italy. pp. 156.

Dovey, S. B. and B. D. Toit. 2006. Calibration of LAI-2000 canopy analyzer with leaf area index in a young of Eucalypt stand. *Trees-Structure and Function*. **20**(3):273-277.

Dyer, A. J. 1974. A review of flux profile relationship. *Boundary layer meteorology*. **7**: 363-372.

Echeverria, C. P. and S. O. Farias. 2009. Estimation of actual evapotranspiration for a drip irrigated Merlot vineyard using a three-source model. *Irrigation Science*. **28**(1):65-78.

Elango, L., S. Ramachandran and M. Sreenivasan. 1996. Time series analysis of ground water quality parameters. *Proceeding of conference on Hydroinformatics,* Zurich. pp. 613-620.

Erraki, S., G. Chehbouni, N. Guemouria, J. Ezzahar, B. Duchemin, G. Boulet, R. Hadria, A. Lakhal, A. Chehbouni and J. C. Rodriguez. 2004. Measurement of evapotranspiration and development of crop coefficients of olive (*olea europaea* L.) orchards in semi arid region. *Project INCO-WADEMED*. **19**: 1-7.

Fritschen, L. J. 1966. Evapotranspiration rates of fields crop determined by the Bowen ratio method. *Agronomy Journal*. **58**(3):339-342.

Garcia, M., Drik Raes and Sven Erik Jacobsen. 2003. Evapotranspiration analysis and irrigation requirement of quinoa in the Bolivian highlands. *Agricultural Water Management*. **60**:119-134.

Garcia, M., R. Allen and C. Herbas. 2004. Dynamics of reference evapotranspiration in the Bolivian highlands (Altiplano). *Agricultural and forest meteorology*. **25**(1-2):67-82.

Grantz, D. A. and L. E. Williams. 1993. An empirical protocol for indirect measurements of leaf area index in Grape (Vitis Vinifera L). *HortScience*. **28** (8): 777-779.

Grismer, M. E., R. L. Snyder and B. A. Faber. 2000. Avocado and Citrus orchards along the coast may use less water. *California Agriculture*. May-June. 25-29.

Gorwantiwar, S. D. 1984. Investigating applicability of some operational hydrology models to WB streams. M.Tech. Thesis submitted to IIT, Kharagpur. Pp.90

Gorwantiwar, S. D., M. Majumdar and P. S. Pampattiwar. 1995. Application of autoregressive models of different orders to annual stream flows of Barkar river with their logarithmic transformation. *Journal of Applied Hydrology*. **8**:33-39.

Gouranga, K. and N. V. K. Chakravarthy. 2002. Computation of PET by different methods and its comparison with pan evaporation rates under semi-arid environments of Delhi region. *Indian Journal of Soil Conservation*. **30**(2):127-131.

Goyal, R. K. 2004. A reference evapotranspiration model for arid region of Rajasthan *Indian Journal of Soil Conservation*. **32**(1):10-15.

Goyal, R. K. 2005. Determination of pan coefficient for estimation of reference evapotranspiration for Jodhpur (Rajasthan). *Journal of Agrometeorology*. **7**:307-310.

Gupta, S. K., S. D. Dalal and R. Babu. 1968. Analysis of point rainfall data of Dehradun. *Irrigation and Power Journal*. **25**(3):291-300.

Gupta, J. C. and J. Singh. 1990. Frequency analysis of climatological data for irrigation planning. *IE(I) Agricultural Engineering Journal*. **71**(8):31-33.

Gupta, S. K. 1992. A comparison of frequency analysis procedures for rainfall data analysis. *Indian Journal of Agricultural Engineering*. **2**:197-202.

Gupta, R. K. and R. Kumar. 1994. Stochastic analysis of weekly evaporation values. *Indian Journal of Agricultural Engineering*. **4** (3-4):140-142.

Haman, D. Z., R. T. Pritchard, A. G. Smajstrla, F. S. Zazueta and P. M. Lyrene. 1997. Evapotranspiration and crop coefficients for young Blueberries in Florida. *Applied Engineering in Agriculture*. **13**(2):209-216.

Hamdi, M. R., A. N. Bdour and Z. S. Tarawneh. 2008. Developing reference crop evapotranspiration time series simulation model using class A pan: A case study for the Jordan valley/Jordan. *Jordan Journal of Earth and Environmental Sciences*. **1** (1):33-44.

Hameed, T., M. A. Marino and R. N. Shumway. 1994. Evapotranspiration–function–noise modeling. *Journal of Irrigation and Drainage Engineering*. ASCE. **121**(2):159-169.

Hamon, W. R. 1961. Estimating potential evapotranspiration. *Journal of the Hydraulics Division,*ASCE. **87**(HY3):107-120.

Hanks, R. J. and R. W. Shawcroft. 1965. An economical lysimeter for evapotranspiration studies. *Journal of Agronomy*.**57**:634-636.

Hashmi, M. A. and L. A. Garcia. 1998. Spatial and temporal errors in estimating regional evapotranspiration. *Journal of Irrigation and Drainage Engineering.* **124**(2): 108-114.

Hardofa, T. 2003. Modeling of evaporation over Ethopia.Ph.D.(Ag.) Thesis, College of Technology And Engineering, Maharana Pratap University of agriculture and Technology, Udaipur. pp.92.

Hargreaves, G. H. 1975. Moisture availability and crop production. *Transaction of ASAE*. **18**(5):980-984.

Hargreaves, G. H. and Z. A. Samani. 1985. Reference crop evapotranspiration from temperature. *Applied Engineering in Agriculture,* ASAE. **1**(2):96-99.

Hargreaves, G. L. and R. G. Allen. 2003. History and evaluation of Hargreaves evaporation equation. *Journal of Irrigation and Drainage Engineers*. ASCE. **129**(1):53-63.

Hatfield, J. L. and R. G. Allen. 1997. Evapotranspiration estimates under deficits water supplies. *Journal of Irrigation and Drainage Engineers*. ASCE. **122**(5):301-308.

Hipel, K. W., A. I. McLeod and W. C. Lennox. 1977. Advances in Box Jenkins modeling: 1. Model construction. *Water Resource Research.* **13**: 567-575.

Hipel, K. W. and A. I. McLeod. 1994. Time series modeling of water resources and environmental systems. Amsterdam: Elsevier. pp.1013.

Hudelson, B. D., M. K. Clayton, K. P. Smith, D. I. Rouse and C. D. Upper. 1989. Nonrandom patterns of bacterial brown spot in snap bean row segments. *Phytopathology*.**79**:674-681.

Hutson, J. L., G. C. Green and W. S. Meyer. 1980. A weighing lysimeters facility at Roodeplaat for crop evapotranspiration studies. *Water SA* **6**:41-46.

Hussain, Q. and P. M. Mushabbir. 1990. Grass ET estimates using Penman-type equation in Central Sudan. *Journal of Irrigation and Drainage Engineering*. **125**:324-329.

Ingle, S. T. 1993. Probabilistic analysis of climatological parameters for estimation of irrigation water requirement for Konkan region. M.Tech. Thesis submitted to M.P.K.V, Rahuri, pp.110.

Irmak, S., A. Irmak, R. G. Allen and J. W. Jones. 2003. Solar and net radiation -based equations to estimate reference evapotranspiration in humid climates. *Journal of Irrigation and Drainage Engineering.* ASCE. **129**(5): 336-347.

Ismail, S. M. 1993. Reference evapotranspiration study in Al-Qassim Region. *Journal of King Saud University*. **5**(2):141-151.

Jat, M. L. and R. V. Singh. 2005. Probability models for prediction of water deficit for Jaipur and Kota in Rajasthan. *Indian Journal of Soil Conservation*. **33**(3):264-266.

Jackson, R. D., S. B. Idso, R. J. Reginato and P. J. Pinter Jr. 1980. Remotely sensed crop temperatures and reflectance as inputs to irrigation scheduling. Proc. Am. Soc. Civil Engg. *Irrigation and Drainage. Div. Conference.* Boise. Idaho. 390 – 397.

Jensen, M. E. and H. R. Haise 1963. Estimating evapotranspiration from solar radiation. *Journal of Irrigation and Drainage Division*. ASCE, **89**(4):15-41.

Jensen, M. E., R. D. Burdman and R. G. Allen.1990. Evapotranspiration and Irrigation Water Requirements. ASCE Manuals and Reports on Engineering Practices No.70 ASCE.New York, p.332.

Jeevarathnam, K. and K. Jayakumar. 1979. Probability analysis of annual maximum daily rainfall for Ootacamund. *Indian Journal of Soil Conservation*.**7** (1):10-16.

Jha, V., R. V. Singh and S. R. Bhakar. 2003. Stochastic modeling of soil moisture. *Journal of Agricultural Engineering.* **40**(4): 51-56.

Johnson, L. E and L. L. Pierce. 2004. Indirect measurement of leaf area index in California North Coast Vineyards. *HortScience*.**39** (2):236-238.

Johnson, R. S., L. E. Williams, J. E. Ayars and T. J. Trout. 2005. Weighing lysimeters aid study of water relations in tree and vine crops. *California Agriculture.***59** (2):133-136.

Kaledhonkar, M. J., S. K. Kamra, R. K. Yadav and K. N. Tiwari. 1996. Probability of historic drought for south western Orissa in India. *Journal of Indian Water Resources Society*. **2**(4):19-24.

Kamte, P. P. and S. D. Dahale. 1984. A stochastic model on drought. *Mausam.* **35**: 387-390.

Kar, G. and R. Singh. 2002. Prediction of monsoon and post monsoon rainfall and soil characterization for sustainable crop planning in upland rainfed rice ecosystem. *Indian Journal of Soil Conservation.* **30**: 8-15.

Khadelwal, M. K. 1988. Determination of agricultural land drainage coefficient through rainfall analysis. *Journal of Agricultural Engineering.* ISAE. **25**(4):42-47.

Khadelwal, M. K., A. M. Shekh, Vyash Pandey and M. S. Zaman.1999. Selection of appropriate method for computation of potential evapotranspiration and assessment of rainwater harvesting potential for middle Gujrat. *Journal of Agro meteorology.* **1**(2):163-166.

Kashyap, P. S. and R. K. Panda. 2001. Evaluation of crop evapotranspiration estimation methods and development of crop-coefficient for potato crop in sub humid region. *Agricultural Water Management*. **50**: 9 – 25.

Katimon, A. and A. S. Demun. 2004. Water use trend at university technology Malaysia: Application of ARIMA model. *Journal Technology*. 41(B):47-56.

Kang, S., X. Hu, T. Du, J. Zhang and P. Jerie. 2005. Transpiration coefficient and ratio of transpiration to evapotranspiration of pear tree (*Pyrus communis* L.) under alternative partial root-zone drying conditions. *Experimental Agricultural.* **41**(2): 187-197.

Katz, R. W. and R. H. Skaggs. 1981. On the use of autoregressive moving average processes to model meteorological time series. *Monthly Weather Review.* **109**: 479-484.

King, K. M., C. M. Tanner and V. E. Suomi. 1956. A floating Lysimeter and evaporation recorder. *Trans.Am.Geo.Union.* **37**(6):736-742.

Korven, H. C. and W. L. Pelton. 1972. Hydraulic load cell lysimeter. *Canadian Agricultural Engineering.***14**:33-36.

Kumar, V. 1993. Selection of the best fit probability density function for the annual runoff events of eastern red soil region watersheds. *Indian Journal of Soil Conservation*. **21**(2):29-35.

Kumar, D., R. Kumar and S. Kumar. 1998. Monthly rainfall probability analysis of Aonla (Bareily) Rohilkhand region. *Indian Journal of Soil Conservation*. **26**: 156-161.

Kumar, D. 2001. Modeling of maize evapotranspiration under climatic conditions of Udaipur. M.E. (Ag.) Thesis, College of Technology and Engineering, Maharana Pratap University of Agricultural and Technology, Udaipur.pp.98.

Kundu, P. S. 1973. Probability analysis of annual rainfall data. *Journal of Agriculture Engineering*. ISAE. **10**(2):21-36.

Kuruvilla, E. C., P. K. P. Kumar, M. D. Nandeshwar and E. J. James. 1989. Estimation of evapotranspiration and crop coefficient using the data from some experimental watersheds of Western Ghats in Kerala. *IE (I). Journal –AG* .**70**(1):18-23.

Koutsoyiannis, D. 2001. Coupling stochastic models of different time scale. *Water Resources Research*. **37**(2): 379-391.

Kulshrestha, M. S., R. K. George and A. M. Shekh. 2007. Weekly rainfall probability analysis by gamma distribution and artificial neural network. *Journal of Agrometeorology.***9**(2):196-2002.

Lenka, N. K., R. K. Panda, S. Sudhishri and A. Dass. 2009. Comparison of some empirical methods for estimation of ET_0 in high lands of Eastern Ghats of Orissa. *Indian Journal of Soil Conservation.* **37**(1):22-25.

Linacre, E. T. 1977. A simple formula for estimating evaporation rates in various climates, using temperature data alone. *Agricultural meteorology.* **18**:409-424.

Lowing, M. J. 1987. Casebook of methods for computing hydrological parameters for water projects. Paris, France, United Nations Educational, Scientific and Cultural Organization. pp.109.

Lopez-Urrea, R., F. Martin de Santa, Olalla Fabeiro and A. Mortalla. 2006. An evaluation of two hourly reference evapotranspiration equations for semiarid Reyenga,W.,F.X.Dunin,B.C.Bautovich, C.R.Rath, and L.B.Husle. 1988. A weighing lysimeter a generating eucalyoptus forest; design construction and performanace. Hydrol.Processes 2:301:314 conditions. *Agricultural and forest meteorology*. **86** (3):277-282.

Lu, J., G. Sun, S. G. McNulty and D. M. Amatya. 2007. A comparison of six potential evapotranspiration methods for regional use in the Southeastern United States. *Journal of American Water Resources Association.* **41**(3):621-633.

Maass, J. M., J. M. Vose, W. T. Swank and A. M. Yrizar. 1995. Seasonal changes of leaf area index in tropical deciduous forest in West Maxico. *Forest Ecology and Management.***74** (1-3):171 –180.

Maithy, S. P. and A. C. Panda. 1975. Prediction of evapotranspiration from pan evaporation for potato. *Journal of Agricultural Engineering Research.* **22**(1):19-21.

Maithy, S. P., K. K. Ghosh and P. K. Jana. 1979. Comparison of measured and estimated evapotranspiration. *Journal of Agricultural Engineering*. **26**(4):157-161.

Maier, H. R. and G. C. Dandy. 1995. Comparison of Box-Jenkins procedure with artificial neural network methods for univariate time series modeling, Research Report No. R 127, Department of Civil and Environmental Engineering, University of Adelaide, Australia, pp.120.

Malek, E. 1993. Comparison of Bowen-ration –energy balance and stability corrected aerodynamic methods for measurements of evapotranspiration. *Theoretical and Applied Climatology*. **48** (2-3):167-178.

Malek, E. 1994. Calibration of the Penman wind function using the Bowen ratio energy balance method. *Journal of Hydrology.* **163** (3-4): 289 -298.

Makkink, G. F. 1957. Ekzameno dla formula de Penamn. *Netherland Journal of Agricultural Science.* **5**: 290-305.

Magali Garcia, Rick Allen and Carlos Herbas. 2004. Dynamics of reference evapotranspiration in the Bolivian highlands (Altiplano).Agricultural and forest meteorology. 25(1-2):67-82.

Martinez-Cob, A. and J. M. Faci. 2010. Evapotranspiration of hedge pruned olive orchards in semi-arid area of NE Spain. *Agricultural Water Management.* **97**(3): 410-418.

Matalas, C. N. 1963. Probability distributions of low flows. *Geological Survey* Professional Paper 434 –A, U.S. Govt. printing office, Washington.

McMillion, W. D. and H. A. Paul. 1962. Floating lysimeters. *Agricultural Engineering.* **42**:498-499.

Meshram, D. T., V. V. AppaRao, B. G. Bagle and D. G. Dhandhar. 2006. Frequency analysis for one to five consecutive days' annual maximum rainfall for Panchmahals of Central Gujarat. *Journal of Agro meteorology*. **8**(2):237-242.

Michalopoulou, H. and G. Paaioannou. 1991. Reference crop evapotarnspiration over Greece. *Agricultural Water Management.* **20**:209-221.

Miguel, A. M., J. C Tracy and S. A. Taghavi.1993. Forecasting of reference crop evapotranspiration. *Agricultural Water Management.* **24**: 163-187.

Mottram, R. and J. M. De Jagger. 1973. A sensitive recording lysimeter. *Agro. Chemo Physica*. **5**:9-14.

Morton, F. I. 1976. Climatological estimates of evapotranspiration. *Journal of Hydrulics Division*. Proceeding of the ASAE **102**(3):275-291.

Mohan, S. and N. Arumugam. 1995. Forecasting weekly reference crop evapotranspiration series. *Journal of Hydrological Sciences.* **40**(6): 689-702.

Mohan, S., H. Raman and K. Nagrajan. 1998. Stochastic linear programming model for irrigation planning. *Journal of Indian Water Resources Society*. **18**(4-3):9-15.

Montanari, A., R. Rosso and M. S. Taqqu. 1997. Fractional differenced ARIMA models applied to hydrological time series: Identification, Estimation and Simulation. *Water Resources Research.* **33**(5): 1035-1044.

Montanari, A., R. Rosso and M. S. Taqqu. 2000. A seasonal fractional ARIMA model applied to the Nile river monthly flows at Aswan. *Water Resources Research.* **36**(5): 1249-1259.

Miranda, F. R., R. S. Gondim and C. A. G. Costa. 2006. Evapotranspiration and crop coefficients for Tabasco Pepper (*Capsicum frutescens L.) Agricultural Water Management.* **82**(1-2):237-246.

Mutua, F. M. 1998. Transfer function hydrologic modeling: A case Study. *Journal of Applied Hydrology*. **11**(2): 11-15.

Miguel, A. M, J. C Tracy and S. A. Taghavi 1993.Forecasting of reference crop evapotranspiration. *Agricultural Water Management*. **24**: 163-187.

Mishra, A. K., T. K. Sarkar and A. K. Bhattacharya. 1999. Stochastic rainfall forecasting for weekly water resources assessment in lower Assam. *Indian Journal of Soil Conservation.* 2**7**(2):99-111.

Mishra, A. K., A. K. Sarkar and A. K. Bhattacharya. 2000. Estimation of actual crop evapotranspiration using continuous crop coefficient functions. *Indian Journal of Soil Conservation.* **28** (2):117-125.

Narulkar, M. S. 1995. Optimum real time operation of multi-reservoir systems for irrigation scheduling. Ph.D.Thesis submitted to I.I.T., Bombay.

Naor, A., M. Peres, Y. Greenblat, I. Doron, Y. Gal and R. A. Stern. 2000. Irrigation and crop load interactions in relation to pear yield and fruit size distribution. *Journal of Horticultural Science and Biotechnology*. **75**(5):2000-2007.

Netzer, Y., C. Chongren, M. Shenker, B. A. Bravdo and A. Schwartz. 2008. Water use and development of seasonal crop coefficients for superior seedless grapevines trained to an open-gable trellis system. *Irrigation Science*. **27**(2):109-120.

O'Connell, M. G., I. Goodwin and G. M. Dunn. 2006. Towards a better understanding of cro water requirement in orchards: a case study from the Goulburn Valley. *Australian Journal of Experimental Agriculture*. **46**(3):405-413.

Oliveira, M. and M. Santos. 1995. A semi-empirical method to estimate canopy leaf area of Vineyard. *American Journal of Enology and Viticulture*.**46** (3):389-391.

Orgaz, F., L. Testi, F. Villalobos and E. Fereres. 2005. Water requirement of Olive orchards.II. Determination of crop coefficient for irrigation scheduling. *Irrigation Science*. **24**:77-84.

Pandey, P. K. 2002. Modelling of Blackgram evapotranspiration under climatic conditions of Udaipur. M.E. Thesis submitted to MPUAT, Udaipur.

Patil, R. M. 2003. Stochastic modeling of water deficit for Rahuri region. M.E. Thesis submitted to MPUAT, Udaipur.

Parmele, L. H. and J. L. McGuinness. 1974. Comparison of measured and estimated daily potential evapotranspiration in a humid region. *Journal of Hydrology*.**22**:229-251.

Penman, H. L. 1948. Natural evaporation from open water, bare soil and grass. Proc.Royal Soc.London,Sev.A. **193**:120-145.

Petillio, M. G. and J. R. Castel. 2007. Water balance and crop coefficient estimation of citrus orchard in Uruguay. *Spanish Journal of Agricultural Research.* **5**(2): 232-243.

Pokorny. R., I. Tomaskova and K. Havrankova. 2008. Temporal variation and efficiency of leaf area index in young mountain Norway Spruce stand. *European Journal of Forest Research.* **127**(5): 359–367.

Priestley, C. H. B. and R. J. Taylor. 1972. On the assessment of surface heat flux and evaporation using large-scale parameters. *Weather Rev*. **100**:81-92.

Pruitt, W. O. and D. E. Angus. 1960. Large weighing lysimeters for measuring evapotranspiration. *Transaction of ASAE.* **3**:13-18.

Pruitt, W. O., S. V. Oettingen and D. L. Morgan. 1972. Central California evapotranspiration frequencies. *Journal of Irrigation and Drainage Division*, Proceeding of the ASCE.

Pruitt, W. O. 1992. Development of crop coefficients using lysimeters. Lysimeters for evapotranspiration and Environmental Measurement. (Ed. Allen, R.G., T. A. Howell, W. O.Pruitt,L.A.Watter and M.E.Jensen) ASCE,New York.pp.182- 200.

Rana, R. S. and D. R.Thakur. 1998. Rainfall analysis for crop planning in Kullu Valley, Himachal Pradesh. *Indian Journal of Soil Conservation*. **26**: 144-146.

Ray, C. R., Sengopal and R. Lal. 1980. Rainfall analysis for crop planning at Gopalpur (Orissa). *Journal of Agriculture Engineering*, ISAE. **17**(3-4):1-8.

Ray, S. S. and V. K. Dadhwal. 2001. Estimation of crop evapotranspiration of irrigation command area using remote sensing and GIS. *Agricultural Water Management*. **49**(3):239-249.

Rajkumar, K. M. and D. Kumar. 2007. Time series modeling of daily rainfall during north-east monsoon season of Baptala, Andhra Pradesh. *Indian Journal of Soil Conservation*.**35** (1):21-25.

Raghupathi, H. B. and B. S. Bhargava 1999. Comparison of CVA, DRIS and CND norms for diagnosis of nutrient balance in Pomegranate. *Journal of the Indian Society of Soil Science*. **47**(3):488-492.

Raghuwanshi, N. S. and W. W. Wallender. 2000. Forecasting daily evapotranspiration for a grass reference crop. *International Agricultural Engineering Journal*. **9**(1):1-16.

Reddy, K. M. and D. Kumar. 1999. Time series analysis of monthly rainfall for Bimo watershed of Ramganga river. *Journal of Agriculture Engineering*, ISAE. **36**(4):19-29.

Ritchie, J. T. and E. Burnett. 1968. A precision weighing lysimeters for row crops water use studies. *Agronomy Journal*.**60**:545-549.

Rosenberg, N. J., H. E. Hant and K. W. Brown.1968. Evapotranspiration. Review of Research.Nebr.Agr.Exp.Station Misc.Bull.No,20 p.80.

Rosenberg, N. J., B. L. Blad and S. B. Verma. 1983. Microclimate, the Biological Environment. Second edition. John Wiley and Sons, New York. pp-495.

Salas, J. D., J. W. Dellur, V. Yevjevich and W. L. Lane. 1980. Applied modeling of Hydrological Time Series. Water Resources Publication, Littleton, Coloredo; pp. 484.

Salam, M. A. and S. A. Mazrooe. 2006. Evapotranspiration estimates and water balance of Kuwait. *Journal of Agrometeorology*. **8**: 243-247.

Slavisa, T. 1998. Comparison of prediction models of reference crop evapotranspiration. *The Scientific Journal of FACTA Universities*. Yogoslavia. **1**(5):617-625.

Sampson, D. A. and H. L. Allen. 1995. Direct and indirect estimates of leaf area index for lodge pole and loblolly pine stands. *Trees-Structure and Function*. **9**(3):119-122.

Samani, N. E., Raeissi and A. R. Soltani. 1995. Stochastic synthesis of droughts for reservoir storage design. *Journal of Applied Hydrology*. **8**: 9-8.

Samani, Z. 2000. Estimating solar radiation and evapotranspiration rates using minimum climatological data. *Journal of Irrigation and Drainage Engineering*. *ASCE*. **126**(4): 265- 267.

Sahoo, P. K. and S. Mohan. 1995. Stochastic modeling of weekly evapotranspiration series. *Journal of Applied Hydrology*. **8**(1-4):67-82.

Saghravani, S. R., S. Mustapha, S. Ibrahim and E. Randjbaran. 2009. Comparison of daily and monthly results of three evapotranspiration models in tropical zone: A case study. *American Journal of Environmental Science*. **5**(6):698-705.

Satpute, G. U. 2004. Characterization of drought under different agro-climatic zones of Maharashtra. PhD Thesis. Maharana Pratap University of Agriculture. Dept.of Soil and Water Engineering, C. T. A. E. Udaipur. pp.184.

Sepaskhah, A. R. and S. M. Kashefipour. 1995. Evapotranspiration and crop coefficient of sweet lime under drip irrigation. *Agricultural Water Management.* **27**:331-340.

Seung H. Y., Jin Y. C. and Min-Won J. 2008. Estimation of design water requirement using FAO56PM and optimum probability distribution function in South Korea. *Agricultural Water Management.* **95**(7):845-853.

Sehgal, J. 1996. Pedology concepts and application. Kalyani Publisers, New Dehli. pp.251

Sharda, V. N. and L. S. Bhushan. 1984. Estimating evapotranspiration requirements for Agra region using climatological data. *Indian Journal of Soil Conservation.***12** (1):23-30.

Sharma, M. L. 1985. Estimating evapotranspiration. In: Advances in Irrigation, D. Hillel (Editor), Academic Press, New York, **3**:213-281.

Sharma, Arun Kumar. 1998. Stochastic modeling for forecasting Jakham river inflows.Ph.D thesis submitted to Department of Soil and Water Conservation Engineering, College of Technology and Agricultural Engineering, Rajasthan Agricultural University, Bikaner.pp. 259.

Shouse, P., A. R. Jury and L. H. Stotzey 1980. Use of deterministic and empirical model to predict PET in an advective environment. *Agronomy Journal*. **71**:994-998.

Shih, S. F. 1984. Data requirement for evapotranspiration estimation. *Journal of Irrigation and Drainage Engineering. ASCE.***110** (3): 263-269.

Simona, C., N. O'Connell and R. Snyder. 2006. Measurement of light interception by Novel orange orchard canopies: case study of Lindsay, California. *Journal of Irrigation and Drainage Engineering*. **132**(1):9-20.

Singh, R. V. and K. N. Sukhla. 1978. Installation of non–weighing lysimters for measurement of evapotranspiration. *Journal of Agricultural Engineer,* ISAE. **18**:45-53.

Singh, K. A., R. N. Rai and R. C. Solanki. 1989. Crop planning in relation to rainfall pattern –A case study at Gangtok (Sikkim). *Indian Journal of Soil Conservation.* **17**(3):51-54.

Singh, C. V. 1998. Long term estimation of monsoon rainfall using stochastic models. *International Journal of Climatology*. **18**: 1611-1624.

Singh, R. S., Y. S. Ramakrishna and R. S. Purohit. 1991. Rainfall characteristics analysis of Kutch (Gujarat) region of India. *Annals of Arid Zone*. **30**: 93-100.

Singh, R. V. 2000. Watershed Planning and Management, Yash Publication House.Bikaner. pp-470.

Singh, C. V. 1998. Long term estimation of monsoon rainfall using stochastic models. *International Journal of Climatology*. **18**: 1611-1624.

Singh A. 2008. Economic feasibility of growing capsicum crop under drip irrigation in West Bengal, India. *Irrigation and Drainage Systems.* **22**(2):179-188.

Slavisa, T. 1998. Comparison of prediction models of reference crop evapotranspiration. *The Scientific Journal of FACTA Universities,*Yogoslavia. **1**(5):617-625.

Slavisa, T. and S. Vladimir. 2008. Simple daily ET_0 estimation techniques. FACTA UNIVERCITIES. **6**(2):187-192.

Sommer, K. J. and A. R. J. Lang. 1994. Comparative analysis of two indirect methods of measuring leaf area index as applied to minimum and spur pruned grape vines. *Australian Journal of Plant Physiology.* **21**(2):197-206.

Srinivasan, K. 1995. Stochastic modeling of Monsoon River flows. *Journal of Applied Hydrology.* **8:**51-57.

Srinivasan, K. and B. S. Thandaveswara. 1995. Stochastic modeling of monsoon dependent flows of south Indian rivers. *Journal of Institution of Engineer* (India). **75**: 220-227.

Steele, D. D., A. H. Sajid and L. D. Prunty. 1996. New corn evapotranspiration crop curves for Southern Dakota. *Transaction of ASAE.* **39**(3):931-936.

Subbaiah, R. and D. D. Sahu. 2002. Stochastic model for weekly rainfall of Junagadh. *Journal of Agrometeorology*. **4**: 65-73.

Subbaiah, R. 2004. Stochastic modeling of evapotranspiration. *Journal of Agro meteorology*.**6** (2):153-161.

Subudhi, C. R., P. C. Pradhan, B. Behera, P. C. Senapati and G. S. Singh. 1996. Rainfall characteristics at Phulbani. *Indian Journal of Soil Conservation.* **24**(1):41-43.

Suresh, R. and A. K. Thakur. 1992. A note on analysis of rainfall for crop planning of Pusa Farm (Bihar). *Indian Journal of Soil Conservation.* **31**(1):84-85.

Suresh, R. 2003. Probability model for predicting annual maximum daily rainfall for Pusa Farm (Bihar). *Indian Journal of Soil Conservation:* **31**(1): 84-85.

Spano, D., R. L. Snyder, P. Duce and K. T. Paw U. 1997. Surface renewal analysis for sensible heat flux density using structure functions. *Agricultural and Forest Meteorology.* **86** (3-4): 259 – 271.

Spano, D., R. L. Snyder, P. Duce and K. T. Paw U. 2000. Estimating sensible and latent heat flux densities from grapevine canopies using surface renewal method. *Agricultural and Forest Meteorology.* **104**(3): 171 – 183.

Tambile, R. H., U. G. Deshmukh, H .S. Acharva, A. R. Mantri and B. P. Sawant. 1991. Probability analysis of annual rainfall data at Parbhani (Maharashtra) for crop planning. *Journal of Indian Water Resources Society*. **11**(2):33-35.

Tarantino, E. 1992. Grass reference measurement in Italy.Lysimeters for evapotranspiration rates and environmental measurement (Ed.Allen,R.G., T.A.Howell, W.O.Pruitt, I. A. Walter and M. E. Jensen) ASCE, New York.pp.200-209.

Teixeira, A. H. de C., W. G. M. Bastiaanssen, M. S. B. Moura, J. M. Soares, M. D. Ahmad and M. G. Bos. 2008. Energy and water balance measurements for water productivity analysis in irrigated mango trees, Northwest Brazil. *Agricultural and Forest Meteorology*.**148** (10): 1524-1537.

Thornthwaite, C. W. and B. Holzman 1942. Measurement of evaporation from land and water surface, USDA Tech. Bull. **817**. pp-75.

Thorntwaite, C. W. 1948. An approach toward a rational classification of climate. *The Geographical Review*. **38**(1):55-94.

Turc, L. 1961. Estimation of irrigation water requirements, potential evapotranspiration:A simple climatic formula evolved up to date. Ann. Agronomy. 12:13-49

Van Bavel, C. H. M. and L. E. Myers. 1962. An automatic weighing lysimeters. *Agriculture Engineering.* **43**:580-583 and 586-588.

van Bavel, C. H. M. 1966. Potential Evapotranspiration: The combination concept and its experiments verification. *Water Resources Research.* **2**(3): 455-467.

Van der Keur P., S. Hansen, K. Schelde and A. Thomsen. 2001. Modification of DAISY SVAT model for potential use of remotely sensed data. *Agricultural Forest Meteorology*.**106**:215-231.

Villalobos, F. J., F. Orgaz and L. Mateos. 1995. Non-destructive measurement of leaf area in Olive (Olea europaea L.) trees using a gap inversion method. *Agricultural and Forest Meteorology*. **73**(1-2):29-42.

Verma, A. 2004. Stochastic modeling on monthly rainfall of Kota, Rajasthan. M. E. Thesis Submitted to GBPUAT, Pantanagar.

Villa Nova, N. A., A. B. Pereira and C. C. Shock. 2007. Estimation of Reference Evapotranspiration by an Energy Balance Approach. *Bio-systems Engineering*. **96**(4):605-615.

Villalobos, F. J., L. Testi and M. F. Moreno-Perez. 2009. Evaporation and canopy conductance of Citrus Orchards. *Agricultural Water Management*.**96** (4):565-573.

Wadatkar, S. B. and R. V. Singh. 2006. Frequency analysis of weekly pan evaporation of different agro- climatic zones in Maharashtra. *Indian Journal Soil Conservation*. **34**(3):204-206.

Wang, J., T. W. Sammis, A. A. Andales, L. J. Simmons, V. P. Gutschick and D. R. Miller. 2007. Crop coefficients of open canopy Pecan orchards. *Agricultural Water Management*. **80** (1-3):253 -262.

Watson, D. J. 1947. Comparative physiological studies in the growth of field crops. I: Variation in net assimilation rate and leaf area between species and varieties, within and between years. *Annals of Botany*. **11**:41-76.

Watson, I. and A. D. Burnett.1995. Hydrology: An environmental approach. Boca Raton, FL: CRC Press.pp.122.

Willims, L. E. 2000. Grapevine water relations. In: L. P. Christensen (ed.) Raisin Production Manual. DANR Publications, University of California, Oakland, CA. pp.121-126

Willims, L. E. 2001. The effect of trellis type and canopy size on grapevine water requirements. *Central Coast Viticulture and Enology Issues Conference.*pp.77-83.

William, L. E. and J. E. Ayars 2005. Grapevine water use and the crop coefficient are linear functions of the shaded area measured beneath the canopy. *Agricultural and Forest Meteorology*. **132**:201-211.

Williams, L. and S. Johnson 2005. Weighing lysimeter aid study of water relations in tree and vine crops. *California Agriculture.* **59**(2):133-136.

Wright, J. L. and M. E. Jensen. 1972. Peak water requirements of crops in Southern Idaho. *Journal of Irrigation and Drainage Division, Proceeding of ASCE.* **98**(2):193-201.

Wright, J. L. 1982. New evapotranspiration crop coefficients. *Journal of Irrigation and Drainage Division, Proceeding of ASCE.* **108**(2):57-75.

Xu, C. Y. and V. P. Singh. 2002. Cross comparison of empirical equations for calculating potential evapotranspiration with data from Switzerland. *Water Resources Management.* **16**:197-219.

Yue, S. and P. Pilon. 2005. Probability distribution type of Canadian annual stream flow. *Hydrological Science Journal.* **50** (3): 427-438.

Zhang, B., S. Kang and L. Zhang. 2008. Comparison of three evapotranspiration models to Bowen ratio –energy balance method for vineyard in an arid desert region of northwest China. *Agricultural and Forest Meteorology.* **148** (10): 1629-1640.