# CHAPTER I

# INTRODUCTION

## 1.1 GENERAL

Evapotranspiration (ET) is the loss of water to the atmosphere by the combined processes of evaporation from soil and plant surfaces and transpiration from plants. It is one of the major components of the hydrologic cycle and its accurate estimation is essential for many studies such as hydrologic water balance, irrigation system design and management, crop yield simulation, and water resources planning and management. Many factors affect ET, including weather parameters such as solar radiation, air temperature, humidity and wind speed; crop factors such as crop type, variety, density and the stage of growth; and management and environmental conditions such as soil conditions, salinity, fertility, crop disease and pests (Allen et al., 1998). Because of the interdependence of most of these factors and their spatial and temporal variability, it virtually may not be possible to formulate an equation that can be used to estimate crop evapotrnspiration ($ET_c$) for different crops under different conditions. Further, it may not also be easy to directly measure $ET_c$ because of the difficulties in quantifying atmospheric evaporative demand and plant transpiration. Although lysimeter provides more reliable $ET_c$ measurement, the extensive setup and maintenance limits its application. Therefore, a two step approach is applied to estimate $ET_c$, the atmospheric demand is quantified through the calculation of reference ET, and the surface characteristics are incorporated into a crop factor or also called as crop coefficient ($K_c$).

Reference ET, or reference crop ET, is defined as the rate at which water, if readily available, would be removed from the soil and plant surface of a specific crop, arbitrarily called as reference crop (Jensen et al, 1990). The two reference crops in widespread use are clipped, cool-season grass (Doorenbos and Pruitt, 1977) and full cover alfalfa (Wright, 1982), with the reference ET for these crops commonly abbreviated as $ET_0$ and $ET_r$, respectively. Recently the Food and Agricultural Organization of the United Nations (FAO) has encouraged adoption of a hypothetical reference surface closely resembling an extensive surface of green grass of uniform height - 8 to 15 cm tall - actively growing, completely shading the ground, and with adequate water (Allen et al, 1998). Crop coefficients depend on several factors including the crop type, stage of growth of the crop, canopy cover and density, soil moisture, and the $ET_0$ equation used. The accuracy of $ET_c$ estimation therefore depends upon the derivation of proper $K_c$ and $ET_0$ computation.

Numerous $ET_0$ equations based on different approaches have been developed and are being used by researchers and practitioners according to the availability of historical and current weather data. These equations range in sophistication from simple empirical radiation, temperature or pan evaporation based to complex resistance based equations. However, these equations and versions in existence, have resulted in some confusion as to the appropriate equation to apply to a particular climate and region. Therefore, the effective quantitative estimation of $ET_0$ still remains a tough task to be achieved, especially in a regional context since it depends upon the factors such as the water supply to the evaporating surfaces, soil water content and rainfall distribution. The widely used reference equations for accurate estimation of $ET_0$ are of the combination type and the one recommended by FAO 56 is the Penman-Montieth (PM) equation. This equation is somewhat more physically based in that it attempts to incorporate the physiographical and aerodynamic characteristics of the reference surface. However, the difficulty in using the equation, in general, is the lack of accurate and complete data at as many sites as needed. Systematic and/or random errors in solar radiation, relative humidity, air temperature, and/or wind speed can lead to significant errors in the estimated $ET_0$ (Saxton, 1975; Meyer et al, 1989).

Further, $ET_0$ estimation methods other than PM method continue to remain in practice because of simpler data requirements. Under these conditions, a simple empirical equation that requires as few parameters as possible is therefore preferable. In addition, the values of crop coefficients are often tied not only to the type of reference surface but also to the particular equation used to calculate $ET_0$. Consequently, the transferability of crop coefficients from one region to another requires consistent methods for calculating $ET_0$. Also, the regional crop coefficients are essential for accurate estimation of irrigation requirement of different crops in the command area. The coefficients suggested by earlier investigators for different crops are generally used at locations where local data are not available. Therefore, there is a strong need for local calibration of crop coefficients under given climatic conditions.

## 1.2 PURPOSE AND SCOPE OF THE PRESENT WORK

Most of the earlier studies evaluated and compared various popular radiation, temperature, pan evaporation and physically based evapotranspiration estimation methods for different regions. The best methods of each category were recommended for different study regions. The method selected, however, should produce reliable results with a minimum of climatic data and also be applicable over a wide range of climatic conditions. The choice of the method, therefore, depends mainly on its suitability for the region, on the availability of climatic data, reliability and limitations of the method. Before applying the appropriate method to a region to provide reliable $ET_0$ estimation, the method has to be properly evaluated based on the locally collected lysimeter measured $ET_0$ data accompanied by meteorological data. In the absence of lysimeter data, the more physically based PM method which yields consistently accurate $ET_0$ estimates across a wide range of climatic conditions, is generally adopted as the competent method for evaluation of several $ET_0$ estimation methods. The present study aims to evaluate the applicability of Blaney Criddle, Jensen-Haise and Hargreaves (temperature based), Priestley-Taylor, radiation and Makkink (radiation based), Pan evaporation and Christiansen (pan evaporation based) and modified Penman (physically based) with respect to PM method for daily, weekly and monthly $ET_0$ estimates to the Tirupati, Nellore, Rajamundry, Anakapalli and Rajendranagar regions of Andhra Pradesh.

The study also focuses on the development of relationships between the PM method and other $ET_0$ estimation methods for daily, weekly and monthly time steps to provide an easy conversion facility. This facilitates an easy to use any method for which meteorological data are available and then to get results comparable with PM method.

Many of the empirical formulae may be reliable in the areas and over the periods for which they were developed. The advantage of these methods is that they can be used in areas where climatic records are limited. However, the accuracy is reduced if they are applied outside the range of calibration, which means that there is need for local adjustment. Large errors can be expected when they are extrapolated to other climatic areas and periods if the constants involved in the formulae are not recalibrated. Therefore, it is found necessary to analyze and compare the various forms of $ET_0$ estimation methods with PM method and to modify the coefficients, such that they can be used in the study area. The present study recalibrates the equations by modifying the coefficients with respect to PM method for different time steps to make them applicable to the study regions of Andhra Pradesh. The simple forms of the equations thus calibrated may be adopted with minimum climatic data and, accuracy comparable with PM method.

Simple regression techniques may, sometimes, provide adequate estimation of $ET_0$. Further, regional level developed empirical $ET_0$ estimation methods are more practical despite their inherent inability to understand the internal structure of the process. The implementation of regression methods considering all the predictor variables may, however, lead to overfit and consequent reduction in the predictive capability. Therefore, the climatic parameters influencing the region have to be identified before formulating the regional $ET_0$ estimation models. The present study aims at identifying the meteorological parameters influencing $ET_0$ in the regions based on multiple correlation analysis and, developing simple linear regression daily, weekly and monthly $ET_0$ models in terms of these parameters for the study regions.

Most of the $ET_0$ estimation methods, however, do not effectively represent the complete nonlinear dynamics inherent in the $ET_0$ process. Artificial neural networks (ANNs) which are capable of representing the complex and nonlinear process effectively and, which may not be always possible with the application of traditional statistical techniques, are used in recent times as a successful soft computing tool in the $ET_0$ modelling. Although ANNs belong to the class of data driven approaches, it is important to determine the dominant network model inputs as this not only reduces the training time but also increases the generalization ability of the network for a given data set. The present study develops optimal ANN models for $ET_0$ estimation for different time steps. The study also compares the performance of the networks with that of simple regression models.

Precise information on $K_c$ values for estimating $ET_c$ for regional scale planning is a major impediment in many regions. The $K_c$ values suggested by earlier investigators based on lysimeter measured $ET_c$ have to be locally calibrated to account for the differences in crop canopy under given climatic conditions. The present study derives daily, weekly and monthly $K_c$ values for different crops commonly grown in the regions of the study area, compares them with those computed based on the procedure recommended in FAO 56. The study also develops $K_c$ models and compares $ET_c$ computed using PM $ET_0$ values and, $K_c$ values derived from the models proposed with that of observed $ET_c$.

The daily climatic data and crop evapotranspiration data at the meteorological stations of the regions, collected from the India meteorological Department (IMD), Pune were used in the data analysis and model development. A part of the data was used for the purpose of development of models and the rest for validating the models developed. The statistical resemblance of the training and testing data sets in terms of mean, variance and skewness was ensured while making the division. The performance of the models was evaluated by commonly used numerical and graphical performance indicators. The meteorological centers selected for the present study are shown in Fig 1.1. A brief description of the meteorological centers is also presented in Table 1.1. The periods of data and their divisions into training and testing data sets along with crop details are tabulated in Table 1.2.

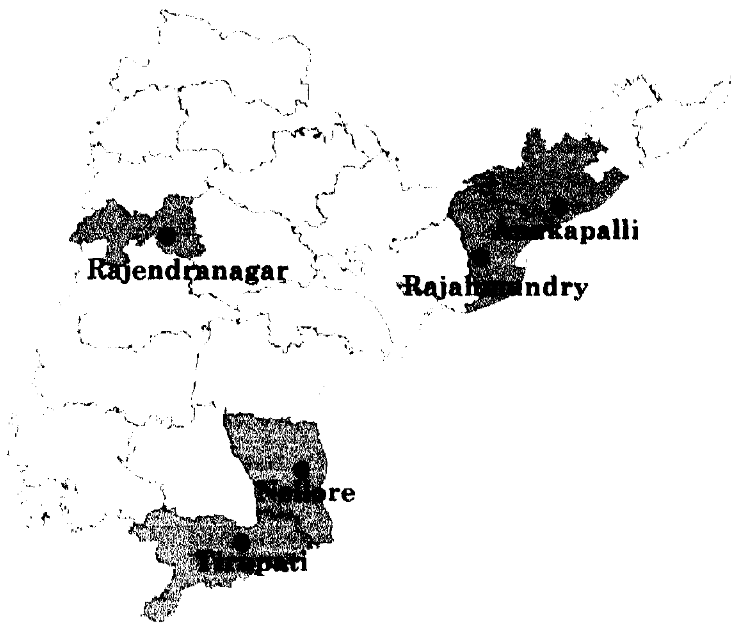


**Fig.1.1 Location map of the meteorological centers**

**Table 1.1 Brief description of the meteorological centers**

| Meteorological center | Longitude | Latitude | Altitude | Mean daily relative humidity | Mean daily temperature | Mean daily wind velocity | Mean daily sunshine hours | Mean daily vapour pressure | Mean annual rainfall |
|---|---|---|---|---|---|---|---|---|---|
| | (°E) | (°N) | (m) | (%) | (°C) | (kmph) | (hr) | (mm of Hg) | (mm) |
| Tirupati | 79° 05′ | 13° 05′ | 161.0 | 59.5 | 28.2 | 7.9 | 6.8 | 17.6 | 1100 |
| Nellore | 79° 59′ | 14° 22′ | 19.0 | 77.3 | 25.6 | 6.3 | 7.3 | 20.3 | 1170 |
| Rajahmundry | 81° 46′ | 17° 00′ | 14.0 | 70.9 | 27.8 | 6.3 | 7.1 | 20.4 | 1160 |
| Anakapalli | 83° 01′ | 17° 38′ | 25.0 | 71.9 | 27.9 | 4.6 | 7.1 | 20.6 | 1190 |
| Rajendranagar | 78° 23′ | 17° 19′ | 536.0 | 61.8 | 26.2 | 7.3 | 8.0 | 14.9 | 920 |

**Table 1.2 Crop details and period of data collected**

| Meteorological center | Crop | Crop Varieties | Crop season | Crop period (days) | Period of data | Training period | Testing period |
|---|---|---|---|---|---|---|---|
| Tirupati | Groundnut | KDR3, TMV2 JL24,K134, TPT1 | July-Nov | 130 | 1992-2001 | 1992-1998 | 1999-2001 |
| Nellore | Paddy | BULKH/9, NLR9672, NLR9674, NLR27999, IR50, NLR33635, NLR9673 | Sep-Jan | 140 | 1983-2003 | 1983-1997 | 1998-2003 |
| Rajahmundry | Tobacco | JAYASHRE, NLS5, HEMA, MULTIPLE, 1158 | Nov-Mar | 110 | 1990-2001 | 1990-1997 | 1998-2001 |
| Anakapalli | Groundnut | TMV2, K134 | Dec-Apr | 130 | 1980-2001 | 1980-1994 | 1995-2001 |
| | Sugarcane | CO419, CO7602 | Mar-Feb | 320 | | | |
| Rajendranagar | Castor | ARUNA | Jun-Nov | 135 | 1978-1993 | 1978-1988 | 1989-1993 |
| | Maize | B21,CM202, CM119, CM104, GANGA5 | July-Oct | 100 | | | |

## 1.3 THESIS ORGANISATION

The thesis consists of six chapters and the chapter-wise content is summarized below.

The first chapter introduces the importance and necessity of evapotranspiration estimation along with the scope of the present study.

A critical review of literature relevant to the present study is reported in the second chapter. It describes various reference evapotranspiration ($ET_0$) estimation methods and, simple regression and artificial neural network modelling techniques. It also presents briefly the past study related to the scope of the present investigation.

The evaluation of $ET_0$ estimation methods for daily, weekly and monthly time steps with respect to the FAO 56 Penman-Monteith method for the Tirupati, Nellore, Rajahmundry, Anakapalli and Rajendranagar regions of Andhra Pradesh is presented in the third chapter. It also presents the development of relationships between PM method and other methods and also, derives recalibrated equations to make them applicable in the regions of the study area.

The fourth chapter presents the identification of climatic parameters influencing $ET_0$ in the regions and development of simple linear regression $ET_0$ models in terms of these parameters. It also presents the development of optimal artificial neural network $ET_0$ models and compares their performance with that of simple linear regression models.

The fifth chapter deals with the derivation of crop coefficients for different crops in the selected regions and compares them with those recommended in FAO 56. It also presents the development of $K_c$ models and compares $ET_c$ computed using $K_c$ values estimated from these models with that of lysimeter measured $ET_c$.

The summary and conclusions of the present study along with the scope for future work are presented in the sixth chapter.