ABSTRACT

An accurate estimation of crop evapotranspiration (ET_c) is of paramount importance for many studies such as hydrologic water balance, irrigation system design and management, crop yield simulation, and water resources planning and management. The reference evapotranspiration (ET_0) is determined for a standard reference surface (grass or alfalfa) and is multiplied with an empirical crop coefficient (K_c) to obtain ET_c. The accuracy of ET_c estimation therefore depends upon the derivation of proper K_c as well as ET_0 computation.

Numerous ET_0 methods based on different approaches have been reported exhaustively in the literature. These methods range in sophistication from simple empirical temperature, radiation or pan evaporation based to complex resistance based methods. Before applying these methods to a region to provide reliable ET_0 estimation, they have to be properly evaluated and calibrated based on the locally collected lysimeter measured ET_0 data accompanied by meteorological data. However, in the absence of lysimeter data, the physically based Penman-Monteith (PM) method, recommended by the Food and Agriculture Organization of the United Nations (FAO 56), which yields consistently accurate ET_0 estimates across a wide range of climatic conditions, is generally adopted as the standard method for evaluation and calibration of ET_0 estimation methods.

ET_0 estimation methods other than the Penman-Monteith method continue to remain in practice because of simpler data requirements. The choice of the method, however, depends mainly on its suitability for the region, on the availability of

climatic data, reliability and limitations of the method. In the present study, FAO 24 Blaney-Criddle, Jensen-Haise and FAO 56 Hargreaves (temperature based), Priestley-Taylor, FAO 24 Radiation and Makkink (radiation based), FAO 24 Modified Penman (physically based), and FAO 56 Pan evaporation and Christiansen (pan evaporation based) methods were selected to evaluate their applicability with respect to FAO 56 Penman-Monteith method for daily, weekly and monthly time steps in Tirupati, Nellore, Rajahmundry, Anakapalli and Rajendranagar regions of Andhra Pradesh.

The climatic data along with lysimeter measured ET_c data for different crops for the period 1992-2001 at Tirupati, 1983-2003 at Nellore, 1990-2001 at Rajahmundry, 1980-2001 at Anakapalli and 1978-1993 at Rajendranagar meteorological centers of Andhra Pradesh were collected from IMD, Pune and used in the analysis. A part of the data was used for the development of models and rest of the data for validating the models developed. The performance of the models was evaluated by commonly used numerical and graphical performance indicators. The numerical performance indicators include the coefficient of determination (R^2), root mean square error (RMSE) and efficiency coefficient (EC). The performance of the models was also verified graphically through scatter and comparison plots.

The ET_0 estimation methods selected for the present study were evaluated to identify the methods that yield results closer to the Penman-Monteith method. The ET_0 estimates of these methods deviated significantly from those of FAO 56 PM method in all the regions on all time steps. However, the Blaney-Criddle (temperature based) method, Modified Penman (physically based) method and Christiansen (pan

evaporation based) method performed marginally better than the other methods though deviated considerably from the PM method.

The study also developed relationships between the PM method and other ET_0 estimation methods. These relationships provide an easy to use approach to obtain ET_0 estimates using the methods for which meteorological data are available and then to get results comparable with PM method. The relationships relating the PM method with, Blaney-Criddle method in all regions except at Rajendranagar, Priestley-Taylor and Radiation methods at Anakapalli region, Modified Penman method at all regions and Christiansen method at Nellore, Rajahmundry and Anakapalli regions improved the performance of the methods yielding results comparable with PM method. The methods, in general, showed an improved performance for weekly and monthly time steps.

Most of the ET_0 estimation methods are empirical and generally applicable for the regions for which they were developed. In order to make them applicable to other regions, in the present study, the selected ET_0 estimation methods were recalibrated with respect to the Penman-Monteith method and their performance was evaluated. The recalibrated Blaney-Criddle (temperature based), Radiation (radiation based) and Modified Penman (physically based) methods performed satisfactorily by improving their performance over the inter-relationships in terms of evaluation criteria irrespective of the time step and the region. Further, the Christiansen (pan evaporation based) method improved its performance only marginally.

Simple regression techniques also provide adequate estimation of ET_0. The implementation of regression methods considering all the predictor variables may, however, sometimes lead to overfit and consequent reduction in the predictive capability. Therefore, the linear regression models for ET_0 estimation were developed in the present study by following eliminating superfluous predictor variables based on multiple and partial correlation analysis. It was observed that the temperature, wind velocity and sunshine hours mostly influenced ET_0 on all time steps in the regions of the study area. The effect of relative humidity on ET_0 was found to be relatively less compared to the above climatic parameters. The linear regression models developed in terms of these predictor variables performed better than recalibrated ET_0 estimation methods in the reasonable ET_0 estimation.

Many of the ET_0 estimation methods do not effectively represent the complete nonlinear dynamics inherent in the ET_0 process. Artificial Neural Networks (ANNs), which are capable of representing complex and nonlinear process effectively, are used in recent times as a successful soft computing tool in ET_0 modelling. The present study examined several aspects associated with the use of ANN structure including the type of input data, number of hidden layers and nodes in each hidden layer to be included in the network in the ET_0 estimation. The ANN(4,3,1) models for Tirupati and Nellore regions and ANN(4,4,1) models for Rajahmundry, Anakapalli and Rajendranagar regions were found to yield satisfactory results and showed marginally an improved performance over linear regression models on all time steps. However, the ANN models outperformed linear regression models on daily time steps in the regions of the study area.

Precise information on K_c values for estimating ET_c for regional scale irrigation planning is a major impediment in many regions. The K_c values suggested by earlier investigators based on lysimeter measured ET_c data have to be locally calibrated to account for the differences in crop canopy under given climatic conditions. In the present study, K_c values were derived for different crops and compared with those recommended in FAO 56. The K_c curve, fitted to follow the trend similar to that of FAO 56 curve significantly deviated for most of the crops in the regions at different stages of crop growth, barring a few exceptions. A third order polynomial K_c models for different crops in the regions selected for the present study were therefore developed for use in the ET_0 estimation for daily, weekly and monthly time steps. It has been observed that ET_c values computed based on K_c values estimated using these models are comparable with those of lysimeter measured ET_c.