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EVALUATION OF REFERENCE EVAPOTRANSPIRATION ESTIMATION METHODS AND DEVELOPMENT OF CROP COEFFICIENT MODELS

Prof. K. V. SivaKumar Babu
Assistant Professor, Department of Civil Engineering,
UshaRama College of Engineering and Technology,
Vijayawada, Krishna [dt], A.P. India

Prof. G. Bogayya Naidu
Assistant Professor,
Department of Civil Engineering, V. R. Siddartha Engineering College
Vijayawada, Krishna [dt], A.P. India

Prof. V. Srinivasulu
Professor, Department of Civil Engineering,
JNTUK-Kakinada, Andhra Pradesh, India

ABSTRACT

This study is an attempt to find best alternative method to estimate reference evapotranspiration (ETo) for the Nagarjuna Sagar Reservoir Project [NSRP], command area located at Andhra Pradesh, India. When input climatic parameters are insufficient to apply standard Food and Agriculture Organization (FAO) of the United Nations Penman–Monteith (P–M) method. To identify the best alternative climatic based method that yield results closest to the P–M method, performances of four climate based methods namely Blaney–Criddle, Radiation, Modified Penman and Pan evaporation were compared with the FAO-56 Penman–Monteith method. Performances were evaluated using the statistical indices. The statistical indices used in the analysis were the standard error of estimate (SEE), raw standard error of estimate (RSEE) and the model efficiency. Study was extended to identify the ability of Artificial Neural Networks (ANNs) for estimation of ETo in comparison to climatic based methods. The networks, using varied input combinations of climatic variables have been trained using the back propagation with variable learning rate training algorithm. ANN models were performed better than the climatic based methods in all performance indices.

The analyses of results of ANN model suggest that the ETo can be estimated from maximum and minimum temperature using ANN approach in NSRP area.

Key words: Reference Evapotranspiration, Artificial Neural Networks, Regression

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1. INTRODUCTION

An accurate estimation of evapotranspiration 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. It may not 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 expensive setup and maintenance limit its application. In practice, the reference evapotranspiration (ET_0) is therefore first determined for a standard reference surface (grass/alfalfa) and is then multiplied by an empirical crop-coefficient (K_c) to obtain crop evapotranspiration (ET_c). The accuracy of ET_c estimation depends upon the derivation of the proper crop coefficient as well as the ET_0 computation.

A number of ET_0 models based on different approaches have been reported exhaustively in the literature. These models vary from simple empirical relationships to complex methods. However, before these methods are applied to a region to provide the ET_0 estimation, they have to be evaluated and calibrated based on the locally collected reference crop evapotranspiration data through lysimeter accompanied by meteorological data. In the absence of lysimeter data, the modified Penman-Monteith Method (PMM), recommended by the United Nations Food and Agriculture Organization (FAO-56) is generally adopted for evaluation and calibration of several ET_0 estimation methods.

There has been growing evidence that the more physically based FAO-56 Penman-Monteith method yields consistently more accurate ET_0 estimates across a wide range of climatic conditions and is therefore being proposed in recent times as the most competent method for ET_0 computation. However, the other methods continue to remain in practice either because of traditional use or simpler data requirements. The choice of the method, therefore, depends mainly on its suitability for the region and, on the availability of climatic data, its reliability and limitations. However, the method selected for use shall not only produce good result with a minimum of climatic data but also represent the one which has been calibrated and applied over a wide range of climatic conditions. In the present study, the performance of several ET_0 methods is evaluated in different regions of Andhra Pradesh with a view to quantify differences in ET_0 estimates as influenced by climatic conditions and, also to identify methods that yield best results closer to the PMM method. Among the ET_0 methods evaluated, the Blaney-Criddle, Modified Penman and Christiansen methods agree reasonably well with the FAO-56 PM method irrespective of the region and time step. The study also developed inter-relationships between the methods and PMM. These relationships provide an easy to use approach

to obtain ET_0 estimates by the methods for which meteorological data are available and then to get accurate results in terms of the desired method.

Many of the ET_0 estimation methods are empirical and therefore are applicable for the regions for which they have been developed. In order to make them suitable for the other regions, the ET_0 estimation methods have been recalibrated with respect to PMM and their performance has been verified. The recalibrated Blaney-Criddle, Radiation, Modified Penman and Christiansen methods performed satisfactorily in terms of evaluation criteria for different time steps.

Simple regression techniques may sometimes provide adequate estimation of ET_0. The implementation of regression methods considering all the predictor variables may, however, lead to overfit and consequent reduction in the predictive capability. The regression models for ET_0 have therefore been developed in the present study by following stepwise procedure eliminating superfluous predictor variables based on statistical criteria. The temperature, wind velocity, sunshine hours and relative humidity, in that order, influenced ET_0. The regression models have been developed in terms of these predictor variables. The simple regression models recommended may conveniently be applied to the regions selected for the present study in the satisfactory ET_0 estimation.

Most 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 and which may not be always possible with the application of the traditional statistical techniques, are used in recent times as a successful soft computing tool in ET_0 modeling. 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 examines several aspects associated with the use of ANN structure including the type of input data, number of nodes in the hidden layers to be included in the network in the ET_0 estimation. The ANN models developed show the improved performance over simple regression methods.

Precise information on crop coefficients for estimating ET_c for regional scale irrigation planning is a major impediment in many regions. The crop coefficients suggested by earlier investigators developed based on lysimeter data and different climatic conditions, have to be locally calibrated under given climatic conditions. In the present study K_c values were derived for different crops and, relationships were proposed to estimate ET_c with reasonable degree of accuracy. The estimated values of K_c differ considerably from those suggested by FAO-56.

In the present study, The Blaney Criddle, Jensen-Haise and Hargreaves (Temperature based), Priestley-Taylor, FAO radiation and Makkink (radiation based), Pan evaporation and Christiansen (Pan evaporation based) and modified Penman and Penman- Monteith (physically based) methods have been selected to evaluate their applicability to the Tirupati, Nellore, Rajahmundry, Anakapalli and Rajendranagar regions of Andhra Pradesh. The multiple linear correlation and regression analysis has been carried out to develop simple empirical models relating commonly measured meteorological parameters influencing ET0 in the regions selected for the present study. The ANN approach has also been applied to model the ET0 in these regions. The crop coefficients' determination has been formulated for different crops during crop periods in these regions. The meteorological data along with ETc 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 stations were collected from IMD, Pune and used in the analysis. The data have been divided into two sets i.e. training data set for model development and testing data set for verifying the model developed. The performance of the methods selected for the present investigation has been evaluated by commonly used numerical and graphical indicators. The numerical indicators include the coefficient of determination (R2), root mean square error (RMSE), and efficiency coefficient (EC). The performance of the models has been verified graphically through scatter and comparison plots. Comparisons were performed for daily, weekly and monthly computational time steps.

2. PLAN TO EXECUTION

This consists of six chapters and the chapter wise content is summarized below.

The first chapter introduces the importance and necessity of reference and crop 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 estimation methods, regression and artificial neural network modelling techniques. It also presents briefly the past study related to the scope of the present investigations.

The evaluation of reference evapotranspiration estimation methods at different time steps with respect to 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 inter-relationships among the methods and derives recalibrated equations to make them applicable to the study region.

In the fourth chapter, simple regression models developed based on the multiple correlation and regression analysis and artificial neural network models. It also compares the performance of Artificial Neural Network models with that of simple regression models. The Artificial Neural Network models showed marginally an improved performance over simple regression models.

The fifth chapter deals with the development of crop coefficients for different crops and regions for various references evapotranspiration estimation methods and also includes the crop coefficient relationships. The estimated crop coefficient values differ significantly from those suggested by FAO-56

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

It is hoped that this thesis helps to provide a greater insight into the evaluation of reference evapotranspiration estimation methods, development of regression and Artificial Neural Network models and derivation of crop coefficients and, the results of the present investigation would be more useful for the reference evapotranspiration and crop evapotranspiration estimation with reasonable degree of accuracy.

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