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Deployment of artificial neural network for short-term forecasting of evapotranspiration using public weather forecast restricted messages

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ABSTRACT

Near-future irrigation demand forecasting is important information for anticipating decisions on crop irrigation scheduling and planning water allocation in large irrigation command areas of Texas. The key determinant that is required for estimating irrigation demand in advance is toward the evapotranspiration forecast. Normally, in rich data environment, current reference evapotranspiration (ETo) is estimated by the well-known FAO56 PM method which requires bunch of observed climatic data. In poor data environment for either current or future estimation, this well-known method application is restricted. Indeed, the correctness of ETo forecast remains a challenging computational task, since inaccurate weather variables can alter the forecast accuracy. Therefore, this study aims to employ artificial neural network (ANN) methodology for forecasting near future ETo values by using restricted climate information messages retrieved from public weather forecast source. Four ANNs learning algorithms including the Generalized Feedforward (GFF), Linear Regression (LR), Multilayer Perceptron (MLP) and Probabilistic Neural Network (PNN) are applied with three sets of inputs combination composed of minimum (Tmin) and maximum (Tmax) daily air temperatures, extraterrestrial radiation (Ra) and net solar radiation (Rs) to forecast ETo in Dallas. The coefficient of correlation (CC), mean square error (MSE), normalized mean square error (NMSE), mean absolute error (MAE) and mean square error skill score (MSESS) were used for the models evaluation. Statistically, in comparison with FAO56 PM, the performances of ANNs models using only Tmax and Tmin predictors were inferior to those of Tmax, Tmin and Ra. With Tmax, Tmin and Rs input-sets, MLP yielded the highest accuracies (CC = 0.926; MSE = 0.770 mm/day, NMSE = 0.143 mm/day; MAE = 0.708 mm/day). Tmax is an important ETo forecast predictor, and the performance improvement relies mostly on Rs accuracy. With precise weather forecast information, ANN made ETo forecast possible (Average CC = 0.860, MSESS = 0.738). These results can assist irrigation districts to accommodate in advance their crop water demand to near-future irrigation requirement.

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1. Introduction

Irrigation water-use efficiency improvement is amongst the key strategies that can substantially save more water, and then re-allocate it to other users in Texas. The water resources in the State of Texas are shared by many users and for multiple uses. Based on existing literatures, the major water problems and challenges that Texas is facing today are the provision of sufficient water supply for various users including irrigators and the maximization of water-use efficiency in a timely manner at irrigation district level.

However, an effective water supply at irrigation field can be achieved by providing to the individual end-user or district a near-future irrigation demand forecasting tool. So, water users and planners can anticipate their irrigation water delivery and allocation plan based on the public weather forecast information release. Irrigation demand forecast tool has not yet been deployed in the irrigation districts of the State of Texas. Many other sophisticated applications devices are currently being used in the State for irrigation field data measurement in which include current soil water balance information, an essential component of irrigation scheduling and water management. These applications, even with their very wide spectrum of data requirement, are used for current irrigation estimates.

Moreover, reference evapotranspiration forecast for short-term near-future as opposed to current estimates, is central to

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support timely irrigation decision in advance. This is an extremely important step forward, because by having reliable ETo forecast values, growers can accommodate in advance their crop water demand to near-future irrigation requirement in order to anticipate the scheduling and irrigation practices at a defined weekly time intervals. In fact, the concept of reference evapotranspiration has been widely applied in crop water demand determination (Allen et al., 1998; Doorenbos and Pruitt, 1977; Hargreaves, 1994). According to Sentelhas et al. (2010), ETo is an important parameter for irrigation planning and management. Basically, evapotranspiration is a nonlinear energy balance complex process that can be indirectly obtained toward FAO56 Penman–Monteith (PM), which requires enormous data. Some meteorological factors forecast have poor precisions that limit the ETo forecasting accuracies with the standardized PM method (Li and Cui, 1996). In some cases, a low forecast precision in the weather forecast datasets may alter ETo forecast accuracy. Perera et al. (2014) have also indicated that the uncertainty in ETo forecast will decline with the increase of the performance of the weather forecast data, or with the removal of the systematic errors from the forecast weather variables. Other recent studies like of those Luo et al. (2015) found that a low precision in weather forecast variables led to a great forecast error, and they reported that with the increase in weather forecast accuracy, the model performance can be improved. One of the main routine tasks is to develop a near future ETo model forcing with restricted weather forecast parameters, i.e., a model capable to forecast reliable ETo values by using only daily air temperatures data released from public weather forecast open source. As the accuracy of the ETo rely fundamentally on the climatic data reliability, achieving a proper crop irrigation demand prediction will also depend on reliable public weather forecast information.

Mostly, in data restriction situation, temperature-based estimates were often used particularly to perform ETo estimation. When the data availability is not a constraint in an environment like in United States; there are still challenges with ETo forecast, as for the one hand it requires a good computing capability, and for the other hand the forecasts accuracy depends on the good quality of the weather forecast data precision retrieved from public source. In order to ensure reliability in the ETo forecast, it is desirable to use the most accurate weather forecast data which are often referred to temperature data. Such choice is very relevant and represents a decisive step when constructing ETo forecast model. And also because unreliable weather forecast message may produce unreliable irrigation water demands for crops. Reporting of data containing biases causes substantial impedance to ET and in the establishment of irrigation water requirements, and translates into substantial economic losses caused by misinformed water management (Allen et al., 2011). Amongst the weather forecast information, temperatures data are one of the most reliable forecasted variables, and widely available. For instance a variable like wind velocity forecast contains a source of error (Luo et al., 2014). Hence, by using reliable public weather forecasted variables may probably reduce the source of error in the ETo forecasting.

Lately, the procedures for short-term ETo forecast were empirically derived from simpler models, commonly from the temperature-based equations. Knowing that the ETo is a nonlinear physical-based complex process, it makes the simpler equations to often fail in capturing the relationship between atmospheric, soil and crops parameters. Furthermore in the past, the procedure of ETo forecast relied only on calibrating the simpler equations. However, since the explanatory powerfulness of any given simpler equations vary with climatic condition, these types of equations led to misestimating ETo beyond the environment of their originated local ambit. This may lead to an overestimation or underestimation of the irrigation depth and miss planning of the schedule that

can exponentially increase the water pumping cost and lead to an excessive use of the limited water resources.

Recently, the daily forecast of reference ETo was conducted in Australia using numerical weather prediction outputs (Perera et al., 2014). Undeniably, in the field of agriculture water resources engineering, artificial neural network (ANN) modeling has proven outstanding performances in solving complex nonlinear problems from the atmospheric and crop water demand relation. The artificial neural networks are known as nonlinear intelligent platforms that adapt the neural weight to solve the nonlinear problem because of their generalized and probabilistic estimation properties. In the past, as in the recent years, artificial neural networks methodologies have been used in ETo modeling which were well documented by the works of Kişi and Ozturk (2007), Landeras et al. (2008), Khoob (2008a,b), Wang et al. (2007, 2010) and Falamarzi et al. (2014). Traore et al. (2008, 2010a, 2014) have also used ANNs to perform ETo modeling for current estimates of crop water needs in Sudano-Sahelian zone. Sudheer et al. (2003) employed the radial basis function neural network to assess the daily ET for rice crop, and Traore et al. (2010b) have deployed the network for similar ET related studies in West Africa. These outstanding results showed that the ANN has a great capability in modeling current ETo nonlinear complex problem. Holding to this great capability for current estimation, the model may also perform better for near future ETo forecasting.

There are not many works done using ANNs for near future ETo forecasting in Texas, but worldwide except those of Landeras et al. (2009) in Spain, Chauhan and Shrivastava (2009) in India, Torres et al. (2011), Ballesteros et al. (2012) and Trajkovic et al. (2003, 2005) in Serbia and Montenegro in Europe. Tian and Martinez (2012a) used retrospective forecast analogs in the Southeastern United States. Palmer et al. (2012) have also used national weather service data to forecast ETo in United States. It was noted that in China the use of least-squares support vector machine model to forecast ETo (Guo et al., 2011). Therefore, in the present study, the artificial neural network performance test is a point of interest for a near-future ETo computation. The main objective of this present study is to employ different neural network algorithms to forecast near-future ETo for a station located in Dallas by using minimum and maximum daily air temperatures variables retrieved from public weather forecast source, as well as radiation parameters.

The study used four different neural network algorithms which are the Generalized Feedforward (GFF), Linear Regression (LR), Multilayer Perceptron (MLP) and the Probabilistic Neural Network (PNN). Scientists have routinely used various parameters mostly required in ETo forecast such as "cloud cover, maximum and minimum temperatures, mean dew point temperature, and mean wind speed scale, relative humidity, solar radiation, etc". But the drawback is that some of these variables have low forecast precision. Studies like those of Luo et al. (2014) have used only temperature data. Since this present study is attempting to forecast ETo by using only the most reliable weather forecast variables, therefore only the daily temperature data and radiation are considered as the network predictors with the goal of minimizing biases and ensuring the forecast reliability.

2. Materials and method

2.1. Study area and data collection

The study area is in Dallas, where the weather station is located at Texas A&M AgriLife Research and Extension Center (96°46′E, 33°00′N). Dallas is located in northern Texas, United States. It has a humid subtropical climate, with annual average temperature of 19.5 °C, annual precipitation of 954 mm. Table 1 highlights