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Forecast of short-term daily reference evapotranspiration under limited meteorological variables using a hybrid bi-directional long short-term memory model (Bi-LSTM)

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Abstract

As the standard method to compute reference evapotranspiration (ET_0), Penman-Monteith (PM) method requires eight meteorological input variables, which makes it difficult to apply in data scarce regions. To overcome this problem, a hybrid bi-directional long short-term memory (Bi-LSTM) model was developed to forecast short-term (1–7-day lead time) daily ET_0. The model was trained, validated and tested using three meteorological variables for the period of 2006–2018 at selected three meteorological stations located in the semi-arid region of central Ningxia, China. The performance of the hybrid Bi-LSTM model to forecast short-term daily ET_0 was evaluated against daily ET_0 calculated by the Penman-Monteith method using the statistical metrics namely, mean absolute error (MAE), root mean square error (RMSE), Pearson's correlation coefficient (R) and Nash-Sutcliffe efficiency (NSE). The results showed that the hybrid Bi-LSTM model with a combination of three meteorological inputs (maximum temperature, minimum temperature and sunshine duration) provides the best forecast performance for short-term daily ET_0 at the selected meteorological stations. When averaged across stations, the statistical performance at different forecast lead time were as follows; 1-day lead time: RMSE = 0.159 mm day^{-1}, MAE = 0.039 mm day^{-1}, R = 0.992, NSE = 0.988; 4-day lead time: RMSE = 0.247 mm day^{-1}, MAE = 0.075 mm day^{-1}, R = 0.972, NSE = 0.985 and 7-day lead time: RMSE = 0.323 mm day^{-1}, MAE = 0.089 mm day^{-1}, R = 0.943, NSE = 0.982. Moreover, the hybrid Bi-LSTM model consistently improved the forecast performance of short-term daily ET_0 compared to the adjusted Hargreaves-Samani (HS) method and the general Bi-LSTM model. The hybrid Bi-LSTM model developed in this study is currently integrated into the modern intelligent irrigation system of 30 ha of *Lycium barbarum* plantation in central Ningxia in China, a region with limited meteorological data. It is recommended however that the hybrid Bi-LSTM should be evaluated across a wide range of climatic conditions in different regions of the world.

Introduction

Reference evapotranspiration (ET_0) is an essential meteorological variable to compute crop water requirements and soil water balances (Abdullah et al., 2015; Djaman and Irmak, 2013). Therefore, reasonable estimate and forecast of ET_0 have become crucially important in agricultural water management, especially in irrigated agriculture for real-time irrigation scheduling and water-saving technologies (Hobbins et al., 2016; Shiri, 2017).

Globally, the Penman-Monteith FAO-56 method is used as the standard method to estimate the ET_0 (Allen et al., 1998). Moreover, this method has been served as a criterion for comparing the forecasted values of other models (Pereira et al., 2015; Sentelhas et al., 2010; Shiri, 2017). However, calculation of ET_0 using Penman-Monteith method is not feasible enough at field scale as it requires large amount of meteorological variables that are not easy and convenient to measure in individual farms (Almorox et al., 2015; Todorovic et al., 2013; Valiantzas, 2015). Meanwhile, Hargreaves-Samani (HS) method (Hargreaves and Samani, 1985) has been proposed as an alternative to Penman-Monteith method to estimate ET_0 with limited set of variables (Xu and Singh, 2002; Almorox et al., 2018; Zanetti et al., 2019). However, the HS method has been shown to