Catena 145 (2016) 204–213

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Application of adaptive neuro-fuzzy technique to determine the most relevant variables for daily soil temperature prediction at different depths

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RETRACTED

A R T I C L E   I N F O

Article history:
Received 26 August 2015
Received in revised form 1 May 2016
Accepted 6 June 2016
Available online 15 June 2016

Keywords:
Soil temperature
ANFIS
Variable selection
Prediction

A B S T R A C T

Having knowledge on soil temperature [illegible] [illegible] [illegible]rtant meteoro[illegible]ogical parameter, is of indispensable significance for various scientific researches. [illegible] this st[illegible] [illegible]daptive neuro-fuzzy inference system (ANFIS) is applied for determining the most relevant parameters for pr[illegible]on of daily soil temperature at six depths of 5, 10, 20, 30, 50 and 100 cm. The simulati[illegible] [illegible]rried out for a[illegible] [illegible]nian city located in the southern coastal part of the country. The process conduct[illegible] [illegible]ased on ANFIS methodology includes several ways to recognize the parameters providing high prediction pr[illegible]ion. For this ai[illegible] eight parameters of minimum, maximum and average air temperatures (T_{min}, T_{max} and $T_{av[illegible]}$ [illegible]elative humid[illegible] (R_h), water vapor pressure (V_P), atmospheric pressure (P), sunshine hours (n) and horizont[illegible] [illegible]bal solar ra[illegible]tion (H) are considered. A comprehensive variable selection is performed to introduce the bes[illegible] [illegible] [illegible]orst [illegible]ts and combinations of inputs. According to the results, at all examined depths T[illegible] [illegible]s the most sign[illegible] [illegible]arameter, while R_h is the least relevant element. Also, at all depths, the air temperature[illegible] [illegible] T_{max} and T_{avg} present superiority over other inputs to offer precise predictions. It is found that the [illegible]mal co[illegible] [illegible]f two inputs is different for some depths; nevertheless, for all depths, T_{avg} plays a role as an i[illegible] Th[illegible] [illegible]ults specify that the use of more than two inputs may not be advisable; thus, considering the most re[illegible] [illegible]ombination of two parameters would be more suitable to achieve higher accuracy and [illegible] [illegible]mplexity[illegible] [illegible]e study results demonstrate the importance of proper selection of input parameters to [illegible]r acc[illegible]e predic[illegible] at different depths.

1. Introduction

Soil temperature is a signi[illegible]ant element [illegible] gives information that is particularly required [illegible] an input for variou[illegible] [illegible]cientific researches (Jackson et al., 2008). Ge[illegible]lly, si[illegible] the ground has a slow rate of heat transportation and a h[illegible] heat [illegible]age cap[illegible]city, its temperature variations show slow trends. [illegible] [illegible] the lo[illegible] [illegible]ermal conductivity of the ground, the soil i[illegible] [illegible]le to re[illegible] hea[illegible] [illegible] the atmosphere during the cooling period [illegible] [illegible]ast, thr[illegible] [illegible]t the heating periods or during the summer [illegible]son, th[illegible] soil absorb[illegible] heat from the atmosphere, which can be uti[illegible] effici[illegible] [illegible]inter season. This cycle, which happens betwe[illegible] [illegible] and atmosphere throughout the year, demonstrates that the [illegible] is a good source of thermal energy potential (Bilgili, 2010; Tala[illegible] [illegible]14). In the colder period, the soil is warmer than the ambient air and vice versa in the warmer period. Therefore, soil temperature is regarded as an important meteorological parameter for a variety of applications including the ground source heat pump, solar energy applications such as passive heating for buildings as well as computation of the heat losses from the buildings (Mihalakakou, 2002; Bilgili, 2010).

Furthermore, accessibility to the soil temperature data at different depths is profitable for the purposes of ecological applications and agricultural management (Kätterer and Andrén, 2009).

Soil temperature can affect various stages of plant root activities, including the absorption and translocation of water, seed germination, seedling emergence, and plant growth. Soil temperature can be utilized to identify the type and rate of physical, chemical, biological and microbiological interactions in the soil (Ghuman and Lal, 1989; Tenge et al., 1998; Zhang et al., 2001; Hu et al., 2002). It plays a remarkable role in analyzing the eco-environmental conditions and climate change of the region (Wu et al., 2013). The information from soil temperature is also considered particularly important for hydrological, meteorological and atmospheric modeling.

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http://dx.doi.org/10.1016/j.catena.2016.06.008
0341-8162/

Nevertheless, long-term and reliable measured soil temperature data at the ground surface and different depths are scarcely available for many locations. This shortage of information limits the locations for aforementioned studies using soil temperature data. Therefore, developing theoretical approaches for prediction of soil temperature at different depths using other available data, such as meteorological parameters, would be of indispensable significance (Mihalakakou, 2002; Paul et al., 2004).

In recent years, the artificial intelligence techniques have received favorable attention to develop general models in various scientific fields such as in business (Zhang and Wu, 2009), personalized and cognitive educational context (De Melo et al., 2014; Moridis and Economides, 2009; Lamb et al., 2012) and medical diagnosis (Jiang et al., 2010), solar radiation prediction (Shamshirband et al., 2016) , wind energy calculations (Medjber et al., 2016) and etc.

Over the previous years, artificial intelligence techniques have been also used in many investigations to predict soil temperature at different depths.

Bilgili (2010) utilized linear and non-linear regression, as well as artificial neural network (ANN) techniques to predict monthly soil temperature at five different depths, based upon several meteorological parameters for Adana, Turkey. They found that the soil temperature can be predicted favorably using the parameters of atmospheric temperature, atmospheric pressure and global solar radiation. Also, ANN is more efficient than the regression methods. Ozturk et al. (2011) developed feed-forward ANN models to estimate soil temperature at five depths of 5, 10, 20, 50 and 100 cm in 66 locations of Turkey. They utilized different geographical and meteorological parameters as inputs. They found that the developed models are capable of estimating soil temperature with good accuracy. Tabari et al. (2011) applied a multilayer perceptron (MLP) ANN model and a multivariate linear regression (MLR) method for estimation of daily soil temperature at six different depths in an arid region of Iran. The attained results showed that ANN provides superiority over the MLR method. Also, the average ambient temperature and relative humidity are the most significant parameters to estimate soil temperature at all depths. Bilgili et al. (2013) applied multiple nonlinear regression analysis and the ANN approach to predict monthly soil temperature at five depths for different locations of Turkey using only the soil temperature data of neighboring stations. Their findings showed that the ANN model offers precise prediction of soil temperature. Moreover, it is possible to predict soil temperature [illegible]on data of neighboring stations with high precision. [illegible] et al. (2013) developed an ANN-based model to predict monthly mean soil temperature at 10 cm depth for a large area with complex terrain. They compared the capability of the ANN with multiple linear regression and found that ANN offers much higher performance for prediction of soil temperature. Talaee (2014) estimated the daily soil temperature at six different depths based on the coactive neuro-fuzzy inference system (CANFIS) for two arid and semiarid Iranian stations. For this aim, six parameters were selected as input components of the CANFIS model. The results indicated the adequacy of the CANFIS for soil temperature estimation. Nahvi et al. (2016) developed an extreme learning machine (ELM) model and a hybrid self-adaptive evolutionary (SaE)-ELM model, called SaE-ELM, to predict daily soil temperature at 6 different depths from 5 cm to 100 cm for two Iranian stations with different climate conditions. They used air temperatures as the final inputs for the ELM and SaE-ELM models because of their high correlations with soil temperature. By conducting validations against other models, they showed that both ELM and SaE-ELM models provide high precision for predicting soil temperature at all depths, but a slightly more accuracy can be achieved for the coupled SaE-ELM model. Tabari et al. (2014) employed the ANN technique to forecast short-term soil temperature for one day ahead at six different depths at two humid and arid stations of Iran. They also considered six input combinations, using only soil temperature and average air temperature. The results demonstrated the favorable capability of ANN for forecasting short-term soil temperature. Also, it was found that the precision of ANN models becomes stronger with increasing the depths of the soil.

Basically, proper selections of more significant input parameters for soil temperature prediction to provide more precision and less complexity would be vital. In fact, the inclusion of many input variables can present many disadvantages. Some of the drawbacks would include the difficulty in explaining the model, inaccuracies caused by irrelevant parameters, complexity in the developed model due to a high number of required inputs and the time-consuming task of collecting more data.

Therefore, in this research, the adaptive neuro-fuzzy inference system (ANFIS) is applied to select the most important parameters influencing the daily soil temperature at different depths of 5, 10, 20, 30, 50 and 100 cm. ANFIS is a hybrid intelligent system that merges the technique of the learning power of the ANNs with the knowledge representation of fuzzy logic. The main advantages of the ANFIS model are computational efficiency and adaptability. The main aim of this study is to identify the most significant parameters for prediction of daily soil temperature in the port of Bandar Abbas located in the south coastal of Iran. The process, named variable selection, includes a number of ways to determine a subset of the [illegible] recorded parameters that show favorable capability for prediction. The ANFIS network is used to perform a variable [illegible] and thereafter, it is utilized to examine how eight parameters of minimum ambient temperature (T_{min}), maximum ambient temperature (T_{max}), average ambient temperature (T_{avg}), relative humidity (R_h), water vapor pressure (V_P), atmospheric pressure (P), sunshine hours [illegible] and global solar radiation on a horizontal surface (H) influence soil temperature (ST) in the nominated case study. In fact, according to the findings of the previous studies, it is presumed that soil temperature is typically influenced by these eight parameters.

2. Materials and methods

2.[illegible] [illegible]on of the study area

For this study, long-term measured data sets for the city of Bandar Abbas, the capital city of the Hormozgan province of Iran, were utilized. The province of Hormozgan, which covers an area of 68,000 km^2, is located in the south of Iran and north of the Persian Gulf and Oman Sea. It is located between 25° 24′ N and 28°57′ N and also between 53°41′ E and 59°15′ E. Bandar Abbas has a land area of around 100 km^2, which includes four regions and 70 districts. The Bandar Abbas population was reported as 520,000 in 2012 which is expected to increase to 820,000 in 2030. Bandar Abbas is the largest port of Iran, which enjoys a strategic position on the narrow Strait of Hormuz, and it is the site of the main base of the Iranian Navy. As a result, it is considered as a major strategic location in Iran. Bandar Abbas lies on flat ground with an average elevation of 9 m above sea level. The nearest elevated areas are Geno Mountain, 17 km to the north, and Pooladi Mountain, 16 km northwest of the city. Bandar Abbas is located at a geographical location of 27°13′N and 56°22′ E. Fig. 1 shows the geographical location of Bandar Abbas and the province of Hormozgan on the map of Iran. Fig. 1 also illustrates the topography map of Bandar Abbas and Hormozgan. During the past decades, the land use/cover in Bandar Abbas has changed significantly so that urban land has increased remarkably, while agricultural land and coastal zones have decreased. Table 1 provides all the changes in the distributions of land use/cover during the last decades (Dadras et al., 2013).

Long warm seasons and short cool seasons are the climatic characteristics of the region. Basically, the region is a desert area with an extremely low level of atmospheric precipitation. On the basis of Köppen classification, the climate condition of Bandar Abbas is categorized as BWh which relates to arid desert hot (Kottek et al., 2006). In the summer, the highest air temperature may reach to 49 °C while in the winter, the lowest can drop to 5 °C. Based on long-term measurements, the total annual rainfall is approximately 170 mm and the annual average relative humidity is 65%. Also, the ratio of mean