Methods for estimation of missing meteodata required by scheduling irrigation models

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Abstract

Irrigation scheduling models require a full set of meteorological data to determine the time to irrigate and amount of irrigation water for agricultural crops. Determination of evapotranspiration is part of these models and they require the availability of real current data. Frequently, some of the indicators are missing from the meteodata required by the irrigation models. Then the task of their estimation appears. Various cheap stationary or mobile weather stations and instruments are available in the market, but they are able to provide just some of the necessary data. If any of the required weather data are missing or cannot be calculated, it is strongly recommended that the user estimate the missing data. Procedures to estimate missing air temperature, humidity, radiation, wind speed and precipitation data are given in the article with some examples.

Keywords: irrigation scheduling; evapotranspiration; meteodata; missing data

INTRODUCTION

Definitions

Irrigation scheduling was defined by Jensen (1981) as *"a planning and decision-making activity that the farm manager or operator of an irrigated farm is involved in before and during most of the growing season for each crop that is grown"*. This basic definition remains the typical view of irrigation scheduling today.

Evaporation from terrestrial surfaces is primarily meteorologically determined when water is not limited and this led to the hypothetical concept of "potential" rates of evaporation estimated from weather data. Penman (1948) formulated the basic physics of evaporation using two terms, an energy term related to radiation and an aerodynamic term related to the vapour pressure deficit of the air and wind speed. Plant transpiration is the process of water movement through a plant and its evaporation from aerial parts, such as leaves, stems and flowers. Evapotranspiration (ET) is the sum of evaporation and plant transpiration from the Earth's land and ocean surface to the atmosphere (Jensen, 1967). *Reference evapotranspiration (ET_o)* is defined as "*the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sec m^{-1} and an albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, well-watered, and completely shading the ground*" (Allen et al., 1988). Some authors (Lopez-Moreno et al., 2009) suggest that it is preferable to estimate ET_o by means of the Penman-Monteith equation even though some of the required parameters must be indirectly estimated. This conclusion is supported by the better results obtained with Penman-Monteith than with the Hargreaves equation.

Irrigation scheduling

Estimates of alfalfa reference *(ET_o)*, that were used in the first computerized irrigation scheduling program (Jensen, 1969) were calculated using the Penman method with alfalfa wind speed coefficients developed at Kimberly, ID (Jensen et al., 1970). After that time during the period of more than 45 years several models (Water Balance Method, Soil Moisture Measuring, Computer Models) have been developed in different countries.

First model for prognosis and management of the irrigation regime in Bulgaria was developed in 1977 at the N. Poushkarov Institute of Soil Science (Krafti et al., 1980). At present a more sophisticated model exists now in the form of Decision support system for irrigated crops growers (Sadovski & Christov, 2018).

All modern models for irrigation scheduling are based on the use of real current meteorological data. The set of such data include: mean, minimal and maximal air temperature (°C), solar radiation (MJ m^{-2} d^{-1}) or duration of sunshine (h), air humidity (%), wind speed (m/sec) and precipitation (mm). These data are taken from the near meteorological stations, stationary or mobile meteorological devices (weather stations) or from web based meteorological services.

Frequently, some of the indicators are missing from the meteodata required by the irrigation models. Then the task of their estimation appears. This is the subject of this article.

If some of the required weather data are missing or cannot be calculated, it is strongly recommended that the user estimate the missing climatic data with one of the following procedures and use the FAO Penman-Monteith method for the calculation of ET_o (Allen et al., 1988). The use of an alternative ET_o calculation procedure, requiring only limited meteorological parameters, is less recommended. Procedures to estimate missing air temperature, relative humidity, solar radiation, wind speed and precipitation data are suggested and given in the next section.

MATERIALS AND METHODS

Instruments

Materials for this study are company data for various cheap stationary and mobile weather stations and instruments. Here follows their brief description.

*La Crosse Technology V21-WTH Professional Wi-Fi Weather and Wind Station***.**

Measurements: Indoor air temperature range between 32°F and 122°F, while the outdoor ranges from -40°F to 140°F; Records air humidity between 10% and 99% and wind speeds up to 111 MPH.

Inovalley SM79 Meteorological station installation external sensor.

Measurements: Outdoor sensor measures the air humidity and temperature of the soil and plants. External sensor measures outdoor air temperature and air pressure. Any information that is relevant is clearly displayed on the large, legible display so you can only get a glimpse of what to do outside the weather. The Inovalley weather station can be enriched with additional outdoor sensors.

*AcuRite 01089M Rain Gauge with Thermometer & Humidity***.**

Measurements: LCD screen shows rainfall totals plus current indoor and outdoor air temperature and air humidity. Indicates barometric pressure and displays rainfall records for the previous day, current week, month and year. Also shows daily maximal and minimal air temperature and humidity.

AcuRite Pro Color Weather Station with Wind Speed.

Measurements: Color display shows indoor/outdoor air temperature and air humidity, wind speed, dew point temperature, atmospheric pressure. Wind information includes current wind speed, average wind speed and peak wind speed-readings.

Agrila Intelligent Agriculture System.

Measurements: Outdoor air temperature, air humidity, sunshine duration, wind speed, precipitation amount, soil temperature and soil moisture.

As can be seen from the examples provided, there are virtually no weather stations or instruments, which are able to provide a complete set of meteorological data. On the other hand, it is impossible to rely on existing networks of stationary meteorological stations to provide farmers with timely accurate data to be valid for the specific fields on which irrigated crops are grown. The problem is in their remoteness from the irrigated fields. This requires the use of different methods for estimation of the missing meteodata.

Calculation procedures with missing data

Here is a formula that can be universally applied (Hozo et al., 2005) for calculating various meteorological indices that are measured overnight with an interval of one hour or 30 minutes:

$$X_{mean} = \frac{a+2m+b}{4}, \qquad (1)$$

where X_{mean} is the mean of the variable using the values of the median (m), low and high end of the range (a and b, respectively). Also we have X_{min} = a, X_{max} = b.

The formula (1) is a best estimator for the mean when dealing with a small sample size $n < 60$. As soon as sample size exceeds 60, the median itself is the best estimator.

Air temperature

For standardization if daily maximum (T_{max}) and minimum temperatures (T_{min}) are measured, T_{mean} for 24-hour periods is defined by the next formula rather than as the average of hourly temperature measurements:

$$T_{mean} = \frac{T_{\max} - T_{\min}}{2}, \qquad (2)$$

The temperature is given in degrees Celsius (°C) or Fahrenheit (°F).

Relative humidity

In case when relative humidity data are available measured overnight with 1 hour or 30 minutes intervals, the same formula (1) may be applied.

Where humidity data are lacking or are of questionable quality, an estimate of relative humidity (RH %), can be obtained by assuming that dew point temperature (T_{dew}) is near the daily minimum temperature (T_{min}). However, it is standard practice in 24-hour calculations of ETo to use T_{dew} measured or calculated during early morning. This second method is to merely set:

$$T_{dew} = T_{min} - K_o \qquad (3)$$

in the calculation for ETo where K_o = 0°C for humid and sub humid climates and K_o = 2°C for arid and semiarid climates.

The relative humidity can be estimated by the following more precise formula:

$$RH = \exp(\frac{a.b(T_{dew} - T_{mean)})}{T_{dew}.T_{mean} + b(T_{dew} + T_{mean} + b)}), \qquad (4)$$

where the constants are a = 17.27 and b = 237.7.

However, there is a very simple formula that is found (Lawrence, 2005) to be quite useful for approximating the conversion for moist air (RH > 50%).

$$RH = 100 - 5(T - T_{dew}). \qquad (5)$$

Solar radiation

The first method relies on the fact that for the same month and often for the same day, the variables affecting incoming solar radiation (R_s), and sunshine duration (n), are similar throughout a given region. This implies that: (1) the size of the region is small; (2) the air masses governing rainfall and cloudiness are nearly identical within parts of the region; and (3) the physiographic of the region is almost homogenous. Differences in relief should be negligible as they strongly influence the movement of air masses. Under such conditions, radiation data observed at nearby stations can be used (Allen et al., 1988).

Second method uses the difference between the maximum and minimum air temperature (T_{max} - T_{min}) as an indicator of the fraction of extra-terrestrial radiation that reaches the earth's surface. The Hargreaves' radiation formula, adjusted and validated at several weather stations in a variety of climate conditions, is:

$$R_s = k_{Rs}\sqrt{(T_{\max} - T_{\min})}R_a, \qquad (6)$$

where R_a extraterrestrial radiation [MJ m^{-2} d^{-1}], T_{ax} maximum air temperature [°C], T_{min} minimum air temperature [°C], K_{Rs} adjustment coefficient (0.16 - 0.19) [°C$^{-0.5}$]. For 'interior' locations, where land mass dominates and air masses are not strongly influenced by a large water body, $K_{Rs} \cong 0.16$; for 'coastal' locations, situated on or adjacent to the coast of a large land mass and where air masses are influenced by a nearby water body, $K_{Rs} \cong 0.19$.

If the solar radiation, R_s, is not measured, it can be calculated with the Angstrom formula, which relates solar radiation to extra-terrestrial radiation and relative sunshine duration:

$$R_s = (a_s + b_s \frac{n}{N})R_a \qquad (7)$$

where n is the duration of sunshine, N is the duration of the day that is calculated for the selected location. The constants are a_s = 0.25 and b_s = 0.5 respectively. R_a is the maximum solar radiation at atmospheric transparency, equal to one, and is calculated from geographic latitude of the point and declination of the Sun (Sadovski, 2018).

Wind speed

Importing wind speed data from a nearby station, as for radiation data, relies on the fact that the airflow above a homogeneous region may have relatively large variations through the course of a day but small variations when referring to the total for the day.

Using data of wind speed that are measured overnight with 30 minutes or 1-hour intervals, the formula (1) again may be applied.

Precipitation

The most difficult and tricky task is to estimate missing precipitation data as the rain is an extremely local phenomenon.

The missing data can be estimated by using the data of the neighbouring stations (Jamal, 2017).

First method: The missing precipitation P_x can be determined using simple arithmetic average, if the normal annual precipitation at various stations are within 10% of the normal precipitation at station, x, as follows:

$$P_x = \frac{1}{n}\sum_{i=1}^{n} P_i, \qquad (8)$$

where n is number of the neighbouring stations and P_i are corresponding measured precipitations. It is worth noting that the distance from the various stations to the station x with the same relief should not exceed certain limit (for example 10 km).

Second method: The inverse distance method has been advocated to be the most accurate method as compare to the method discussed above (Chatterjee & Singh, 2014). Amount of precipitation to be estimated at a location is a function of measurements at the surrounding stations and distance from each station from the location x. Rainfall P_x at station x is given by:

$$P_x = \frac{\sum_{i=1}^{n}\left(\frac{P_i}{d_i^b}\right)}{\sum_{i=1}^{n}\left(\frac{1}{d_i^b}\right)}, \qquad (9)$$

where n is number of the neighbouring stations, P_i are corresponding measured precipitations, d_i are distances to station x and b is selected power (b = 2 is commonly used).

Atmospheric pressure

A simplification of the ideal gas law, assuming 20°C for a standard atmosphere, can be employed to calculate atmospheric pressure (P):

$$P = 101.325\left(1 - \frac{0.0065z}{288.15}\right)^{5.256}, \qquad (10)$$

where P atmospheric pressure (kPa), z elevation above sea level (m).

RESULTS AND DISCUSSION

An illustration of the present methods for estimation of missing meteodata is made with actual meteorological data for Panicheri, the municipality of Hisarya, Bulgaria (Meteoblue, 2018) for the period 4-9 November 2018.

Using 24 hourly data for mean air temperature (°C), relative humidity (%) and wind speed (m/sec) with help of formula (1) estimations of their average daily values are made and the results of observed and calculated data together with the corresponding error are presented in Table 1. It can be seen that the error of air temperature is small, the error of relative humidity

Table 1. Comparison of observed and estimated data for air temperature, relative humidity and wind speed from Panicheri

Date	Air Temperature (°C)			Relative Humidity (%)			Wind Speed (m/sec)		
	Obs.	Calc.	Error (%)	Obs.	Calc.	Error (%)	Obs.	Calc.	Error (%)
04/11/2018	11.96	11.82	1.17	69.20	65.75	5.00	1.51	1.78	-17.88
05/11/2018	12.22	12.57	-2.84	64.10	62.75	2.14	1.30	1.27	2.50
06/11/2018	12.99	13.33	-2.62	67.70	68.00	-0.49	1.56	1.63	-4.65
07/11/2018	12.66	12.87	-1.62	72.90	72.00	1.26	1.83	1.84	-0.41
08/11/2018	11.80	11.67	1.14	70.60	69.50	1.53	1.07	1.22	-14.25
09/11/2018	11.77	11.88	-0.93	65.30	66.75	-2.30	1.40	1.52	-8.57

does not exceed 5% and only the error of wind speed is a bit larger.

In a recent study, 7 temperature-based solar radiation models were adopted to improve the Makkink model (M1–M7) for ET_0 estimation in Northwest China based on the least square method using the meteorological variables during 1990-2010 obtained from 12 stations (Zhang et al., 2018). The applicability of the improved Makkink (MKi) models, original Makkink model, Jensen-Haise model and Irmak model on different time scales were evaluated using meteorological data during 2011-2016. The M5 was the improved Makkink model using the El-Sebaii radiation model (El-Sebaii et al., 2009). The El-Sebaii model estimated solar radiation R_s based on the air temperature and relative humidity data:

$$R_s = (a + b.T + c.RH).R_a, \qquad (11)$$

where RH is the relative humidity (%), R_a is extra-terrestrial radiation, *a*, *b* and *c* are empirical coefficients.

The M5 which only requires air temperature and relative humidity as input data is highly recommended to estimate ET_0 on both daily and monthly scale. This means that it is not necessary to calculate the missing data for the other meteorological variables.

The estimation of hourly solar radiation data was carried out in a study based on two methods (Dimas et al., 2011). First method is by using decision matrix from measured RH and ambient temperature data. The second method is by using RH clearness index, clearness index-beam atmospheric transmission and beam atmospheric transmission-RH correlation. Obviously, the first method is more suitable for application with easily accessible data.

Fixed functional set genetic algorithm method (FFSGAM) is used to develop optimal functional formulations for estimating missing precipitation data (Teegavarapu et al., 2009). Results using multiple performance indices suggest that the performance of FFSGAM in estimating missing precipitation data is better than a conventional inverse distance weighting method. The method also provided better results when limited number of stations was used. The ability of the method to select functional forms that include elementary functions for both distance and correlation coefficient between stations helps in improving the accuracy of the estimation method.

Many researchers discuss the applicability of the so-called method of self-organizing models or Group method of data handling -GMDH (Acock & Pachepsky, 2000). Performance of the GMDH method has been compared with “climatology” and persistence estimates. Here climatology is defined to mean that estimates of a weather variable for a particular day of a particular year were obtained as average values for the same day across all years in the database except for the year for which the estimate was sought. The persistence estimates of a weather variable were obtained as values of the same variable measured the day before the day for which the estimate was sought.

The performance of the GMDH model developed to predict a missing daily weather variable depended on the variable. Best results were obtained for maximum and minimum temperatures and for wind run. The lack of accuracy in precipitation estimates makes our GMDH networks not suitable to be used to make agricultural management decisions such as irrigation scheduling that are based on the amount of precipitation. The successful use of self-learning algorithms to predict precipitation has been reported for conditions in Germany (Dumais & Young, 1995).

CONCLUSIONS

In this paper, a new formula is suggested to estimate missing meteodata when meteorological indices are measured overnight with an interval of one hour or 30 minutes. Several formulas are given for calculation of air temperature, relative humidity, solar radiation, wind speed, precipitation and atmospheric pressure, which can be applied when stationary or mobile weather stations and instruments are used. The present study confirms the high potential of different models for use in reconstructing missing events, namely: decision matrices, fixed functional set genetic algorithms, method of self-organizing models (GMDH).

DISCLAIMER

The mention of trade names or commercial products is for the information of the reader and does not constitute an endorsement or recommendation for use by the author or his institution.

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