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Assessing reference evapotranspiration by the Hargreaves method in north-eastern Italy

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ABSTRACT

The Food and Agriculture Organization of the United Nations proposed the (FAO)-56 Penman–Monteith equation (FAO-56 PM) as the standard method for estimating reference evapotranspiration (ET_0). This equation requires weather data which are not available in most stations or present wide gaps and/or inaccuracies in their measurement. To solve this problem, the Hargreaves equation (HARG) is recognized by FAO and is often used. This equation is based on average, minimum and maximum air temperature and extraterrestrial radiation. It tends to overestimate ET_0 in humid conditions and requires a local calibration. This paper examines the possibility for calibrating the HARG equation in Veneto region (north-eastern Italy) according to different criteria. For this study, full weather data sets of daily values collected along the period 1994–2006 from 35 agro-meteorological stations located in the Veneto plain were used. Ten stations were selected for calibration of the adjusted HARG equations, in order to represent the different areas of the plain, while the other 25 were used for validation.

The median daily FAO-56 PM ET_0 was 1.93 mm and the original HARG overestimated this value by 18.9%. Adopting a common calibrated value of 0.0020 instead of 0.0023 as a constant value (H_A) in the HARG formula, the overestimation was reduced to 2.6%. Other calibrations, as specific for each site or deriving H_A from a relationship between $T/\Delta T$, did not produce further estimation improvement.

1. Introduction

Reference evapotranspiration (ET_0) is one of the most useful indicators required for efficient irrigation management. Its accurate estimate is essential for water resources management, irrigation scheduling, crop production and environmental assessment (Sharma, 1985; Jensen et al., 1990). Many methods for estimating reference evapotranspiration have been proposed but most of them are only valid under specific climatic and agronomic conditions and cannot be applied under conditions that are different from those under which they were originally developed (Allen et al., 1998). The Food and Agriculture Organization of the United Nations FAO-56 Penman–Monteith combination equation (FAO-56 PM) has gained acceptance as a standard method for estimating reference evapotranspiration (Allen et al., 1998). According to the FAO-56 PM approach, the reference evapotranspiration expresses the evaporative demand of the atmosphere independent of crop type, crop development and management practices. In fact, it is referred to "a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m^{-1} and an albedo of 0.23″, which closely resembles an extensive surface of green grass of uniform height, actively growing, completely shading the ground and with adequate water. The only factors affecting ET_0 are weather variables and consequently, ET_0 is a climatic variable and can be computed from meteorological data (Sentelhas et al., 2010).

The Penman–Monteith equation ranked as the best equation for estimating daily and monthly ET_0 in all climates because it can be used globally without any local calibration because it incorporates both physiological and aerodynamic parameters and has been validated in different environments using accurate lysimeter measures.

The FAO56-PM equation is a physically based approach—and the calculation procedure requires numerous reliable weather measurements of air temperature, relative humidity, solar radiation and wind speed.

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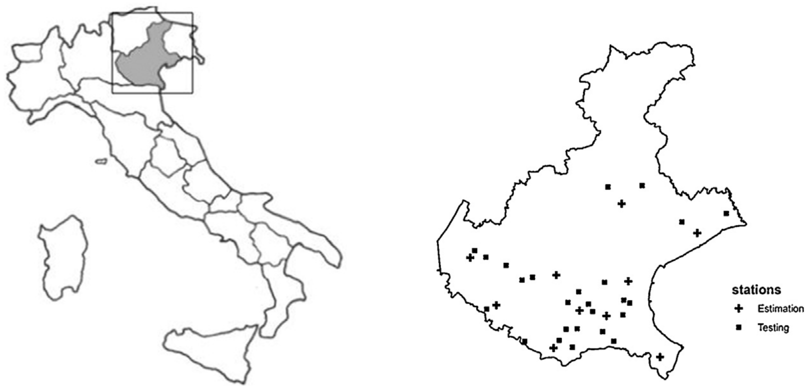

Fig. 1. Spatial distribution of 35 agro-meteorological stations used in the analysis.

Frequently all these information are not available (especially in developing countries) because there are a limited number of meteorological stations adequately equipped (Allen et al., 1998), or present wide gaps and/or inaccuracies in their measurement. For these reasons, this method is restricted by the lack of input variables. Concerned about that, Allen et al. (1998) suggested to use the Hargreaves equation for estimating ET_0 when sufficient climatic parameters are not available to solve the FAO-56 PM equation. The Hargreaves equation (Hargreaves and Samani, 1985) is based only on average, minimum and maximum air temperature and extraterrestrial radiation and has been widely used for its simplicity and potentiality to calibrate its parameters to improve the estimations. Many studies showed that the Hargreaves equation provides reliable estimates of reference evapotranspiration for five days or longer time steps (Hargreaves, 1989; Jensen et al., 1997; Droogers and Allen, 2002; Hargreaves and Allen, 2003; Murugappan et al., 2011). However, there is a need for ET_0 estimation for a shorter period even in absence of accurate data (Shuttleworth, 1993).

Discrepancies between FAO-56 PM and Hargreaves ET_0 estimates are found in different regions of the world. In example, Hargreaves overestimates ET_0 under cold-humid conditions, with daily FAO-56 PM ET_0 ranging around 2–3 mm (Jensen et al., 1990; Amatya et al., 1995; Itenfisu et al., 2003; Temesgen et al., 2005; Trajkovic, 2007) and underestimates in hot and humid locations, where maximum daily ET_0 reaches 10.8 mm d^{-1} (Sivaprakasam et al., 2011). Spatial variability is also found with Hargreaves overestimations in inland stations and underestimations in coastal stations (Gavilan et al., 2006; Bautista et al., 2009). In the cited studies, local calibrations lead to improvement of Hargreaves estimates, confirming the necessity to improve the accuracy of the Hargreaves equation (Jensen et al., 1997; Droogers and Allen, 2002). In most cases regional calibrations have been proposed, but only fewer attempts have been made to improve the equation through the use of meteorological parameters (Vanderlinden et al., 2004).

The primary objective of this work was to develop a regional calibration for the Hargreaves equation useful for plain areas of north-eastern Italy.

2. Material and methods

2.1. Area description

The study was conducted in the plain territory of Veneto region, NE Italy. The area climate is sub-humid, typical of the Po valley, with mean annual rainfall ranging from 800 to 1000 mm fairly uniformly distributed throughout the year. Winter is the relatively less rainy season, the maximum monthly rainfall is observed in June (just over 100 mm) and the second most rainy month is October.

The monthly cumulated values of total incoming radiation display a not perfectly symmetrical bell-shaped pattern with respect to the month with the maximum (July), when the available energy is slightly above 720 MJ m^{-2}, on average, corresponding to 9.5 mm of evaporable water per day.

The yearly average temperature ranges from 10 to 14.4 °C; January is the coolest month, with average temperature ranging from −1 to 3.9 °C in different locations. The average temperature is higher than 20 °C for 1–3 months and the difference of temperature between hottest and coolest month exceeds 19 °C.

On average, the relative humidity varies relatively little during the year, the maximum values being around 90% in winter and 75% in summer.

2.2. Weather data source

The meteorological data sets used for this study correspond to the period from 1994 to 2006 and were provided by the Meteorological Service—Environmental Prevention and Protection Agency of the Veneto Region (A.R.P.A.V.), Teolo (PD), Italy.

This network is composed of 60 automatic agro-meteorological stations, but only 35 of these were used in the present study because only this subset of stations had a prolonged and continuous meteo data set. Among them, 10 were selected for calibration of the adjusted Hargreaves equations, in order to represent different areas of the plain, while the other 25 were used for validation (Table 1, Fig. 1). The stations used for calibration and validation were spatially distributed so that they covered the same territory.

These locations were chosen because they cover a wide and homogeneous area of Veneto plain and are situated at a wide range of elevations, from −3 meters above sea level (m a.s.l.) (Padron Porto Tolle) to 296 meters above sea level (m a.s.l.) (Marano di Valpollicella). Each agro-meteorological station is equipped with sensors to measure air temperature and relative humidity, soil temperature, atmospheric pressure, leaf wetness, rainfall, wind speed and direction, solar radiation and pan evaporation.

The variables useful for the calculation of FAO-56 PM ET_0 considered in this study were as follows:

- air temperature at 2 m above ground level measured with a semiconductor thermometer (linearized NTC thermistor), one instantaneous value acquired every 15 min;
- air relative humidity at 2 m above ground level measured with electrical capacitive hygrometer, one instantaneous value acquired every 15 min;