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RESEARCH PAPER

Validation of New Version of Hargreaves–Samani Model for Calculating Solar Radiation from Temperature and Humidity Data

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ABSTRACT

The performance of Valiantzas' new version of Hargreaves–Samani model for calculating solar radiation from temperature and humidity data was validated in a semi-arid region of India. The validation was done by using the meteorological data (2005-14) obtained from a weather station at Agricultural Engineering College and Research Institute, Kumulur, Lalgudi Taluk of Tiruchirapalli district, located in Tamil Nadu, India. The indexes used for comparison are co-efficient of determination (R^2), Standard Error Estimate (SEE) and long-term average ratio (rt). It was found that the mean solar radiation estimated from Valiantzas' new version and Hargreaves–Samani model were higher compared to the measured solar radiation. The comparison showed a good performance (SEE = 4.412 MJ m^{-2} day^{-1} and $R^2 = 0.543$) of the proposed new version of solar radiation equation. Hence, researchers can use this model on the basis of available data to getter better results for agricultural water management studies.

HIGHLIGHTS

- **Model Validation:** The new version of the Hargreaves-Samani model using temperature and humidity data showed good performance in estimating solar radiation under semi-arid conditions in Tamil Nadu.
- **Accurate ET Estimates:** Substituting solar radiation values from Valiantzas' model into FAO56-PM provided reliable reference evapotranspiration estimates with high correlation ($R^2 \approx 0.959$).
- **Practical Application:** The model is especially useful in regions with limited or unreliable solar radiation data, supporting precision agriculture and water management studies.

Keywords: Evapotranspiration, FAO56 Penman-Monteith, Solar radiation, Temperature, Relative humidity, Hargreaves-Samani Model, Valiantzas' Model

Precise estimation of reference evapotranspiration is to be done for planning and supply of optimal quantity of irrigation water. Among the available physical and empirical models of reference evapotranspiration (ET_0), FAO56 Penman-Monteith (FAO56-PM) (Allen *et al.* 1998) method is a globally recommended method for estimation of ET_0.

But the complication faced in FAO56-PM method is, the inputs appear explicitly in the calculation. The FAO56-PM method requires maximum and minimum air temperatures (T_{max} and T_{min}), solar radiation (R_S), maximum and minimum relative humidity (RH_{max} and RH_{min}), wind speed (u) as well as latitude and altitude of site. However, all of these

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input variables may not be available for a given location, especially in developing countries.

Another serious problem of the full-set data requirements of FAO56-PM is the high cost of typical sensors required for ET_0 automated stations (Valiantzas 2012, 2013d; Exner-Kittridge, 2012). In the last years automatic weather stations with electronic sensors have been widely used. However, the cost of typical sensors for measuring full data T, RH, RS, and u may be a serious problem especially in developing countries. In many stations, the data sets are incomplete and/or do not respect appropriate quality requirements.

To address this complexity in calculation of reference evapotranspiration without compromising the accuracy, Valiantzas (2006, 2013a,b) developed algebraic formulae by simplifying Penman's equation,for calculating directly ET_0 from a complete set of routinely measured meteorological variables. To address the issue of non-availability of data or limited data of routinely measured meteorological variables, Valiantzas (2006, 2013a,b,c,d, 2014a,b, 2015, 2017, 2018a,b) proposed further simplifications of FAO56-PM method under limited data conditions that has accuracy equal to FAO56-PM method.

Solar radiation is not routinely measured at many weather stations, or its measurements are not always reliable, and therefore it may need to be estimated. Hargreaves and Samani (1982) proposed an empirical model for estimation of solar radiation which require only maximum and minimum daily air temperature (routinely measured). This model can be used in stations where solar radiation is not routinely measured or where measurements are not always reliable or when device under repair. Hargreaves and Samani (1982) also has various modifications as in Samani (2000) and Samani *et al.* (2011).

Valiantzas (2017)proposed a new version of Hargreaves-Samani model for places where good quality RH measurements are available for predicting solar radiation based on temperature and relative humidity. The additional cost of RH sensors compared to the cost of R_s and u sensors is extremely low (Exner-Kittridge and Rains, 2010). Several studies have provided valuable information on the accuracy of the Valiantzas' reference evapotranspiration equations at different countries like Iran (Valipour, 2014); Mediterranean Climate (Kisi, 2014); Pilbara region of Western Australia (Ahooghalandari *et al.* 2016), Senegal (Djaman *et al.* 2015); Burkina Faso (Djaman *et al.* 2016).

Therefore the need of the hour is to estimate evapotranspiration accurately under limited data condition with good accuracy similar to FAO56-PM method. Hence this study aimed to evaluate the new version of solar radiation (R_S) formula that includes temperature and relative humidity (RH) data proposed by Valiantzas (2017) for places where good quality RH measurements are available. A comparison was made between the ET_o estimated from FAO56-PM method by substituting the R_s values obtained from Hargreaves–Samani model and Valiantzas Model. The evaluation was done on daily time steps under a semi-arid region in India for the first time.

MATERIALS AND METHODS

Study area

Meteorological data required for estimating reference evapotranspiration using FAO56-PM method were collected from the weather station located at the Agricultural Engineering College and Research Institute, Kumulur for a period of ten years (2005 to 2014). Kumulur is a village in Lalgudi Taluk of Tiruchirapalli district, located in Tamil Nadu, India. It is a semi-arid region, located at 10.93°N Latitude; 79.82°E Longitude and 70m Elevation above MSL (Arunadevi *et al.* 2017). The long-term average relative humidity is 51% and long-term average wind speed is 1.9 m/s.

Estimation of Solar Radiation

Hargreaves-Samani R_S formula based on T ($HS\ R_s\ [T]$)

Hargreaves and Samani (1982) recommended a simple equation to estimate solar radiation:

$$R_S = 0.16 * R_A \left(T_{\max} - T_{\min}\right)^{0.5} \quad \ldots(1)$$

where R_A = extraterrestrial radiation; T_{max} = maximum temperature; and T_{min} = minimum temperature.

Valiantzas R_S formula based on T and RH (Val R_s [T & RH])

Hargreaves and Allen (2003) reported that Hargreaves proposed a formula for estimating solar radiation from RH data alone in 1977. Accordingly, R_s is given by;

$$R_s \propto \left(1 - RH/100\right)^x \quad \ldots(2)$$

where x is an empirical exponent. By combining Eq. (1) & Eq. (2), R_s is considered as function of temperature and RH. Valiantzas (2017) identified the regression coefficients by following a calibration procedure and used global climatic data set including monthly data, the FAO-CLIMWAT (Smith 1993) from thirteen countries that essentially cover the typical range. Finally, Valiantzas (2017) proposed the following simple purely empirical and mathematical form of equation in which R_s is estimated from the T and RH data. The new version of Hargreaves–Samani Model requiring temperature and RH data:

$$R_s = 0.338 * R_A * \left(T_{\max} - T_{\min}\right)^{0.3} * \left(1 - \frac{RH}{100}\right)^{0.2} \quad \ldots(3)$$

In Eq. (3) the value of 1.001 was used instead of 1 because of the singularity appearing when RH/100 = 1.

Estimation of Reference Evapotranspiration

The FAO56-PM equation for estimating the daily grass-reference evapotranspiration is given by;

$$ET_0 = \frac{0.408 * \Delta(R_n - G) + \gamma \frac{900}{[T + 273]} * u * \left(e_a - e_d\right)}{\Delta + \gamma\left(1 + 0.34 * u\right)} \quad \ldots(4)$$

Where ET_0 reference evapotranspiration [mm day^{-1}], R_n net radiation at the crop surface [MJ m^{-2} day^{-1}], G soil heat flux density [MJ m^{-2} day^{-1}], T mean daily air temperature [°C], u wind speed at 2 m height [m s^{-1}], e_s saturation vapour pressure [kPa], e_a actual vapour pressure [kPa], $e_s - e_a$ saturation vapour pressure deficit [kPa], Δ slope ofvapour pressure curve [kPa °C^{-1}], γ psychrometric constant [kPa °C^{-1}].

Comparisons of methods

A comparison was made between the measured solar radiation and solar radiation obtained by HS R_s [T] model and Val R_s [T & RH] model separately. In addition, comparison was made between the reference evapotranspiration estimated from FAO56-PM equation by substituting measured R_s values and solar radiation obtained by HS R_s [T] model and Val R_s [T & RH] model separately.

In this study, the comparison were done by using simple error analysis and linear regression.

$$Y = S.X \quad \ldots(5)$$

where S is the regression coefficient (slope of the line), Y is the reference measured values of R_S, and X = corresponding estimates of R_S by the comparison formula. The indexes used in error analysis is standard error estimate (SEE) and long term average ratio (rt).

$$SEE = \sqrt{\frac{\sum_1^n \left(Y_i - X_i\right)^2}{n-1}} \quad \ldots(6)$$

$$rt = \frac{X_{av}}{Y_{av}} \quad \ldots(7)$$

where, Y_i = reference measured values, at i^{th} data point; X_i = corresponding estimates by the comparison formula; n = total number of observations; X_{av} and Y_{av} are the long term average values of tested models and reference values respectively.

RESULTS AND DISCUSSION

The solar radiation measured at the weather station located in the study area was found to vary from 9.591 to 22.73MJ m^{-2} day^{-1}. The variation of daily mean of measured solar radiation for the study area is shown in Fig. 1. The mean solar radiation of the study area is around 17.01 MJ m^{-2} day^{-1} with the standard deviation of 2.65 MJ m^{-2} day^{-1} (Table 1). The mean solar radiation from measured by using Eq. 1 (HS R_s [T]) and 3 (Val R_s [T & RH]) is around 18.41 and 20.99 MJ m^{-2} day^{-1}. It was found that the mean solar radiation estimated from both the models were higher compared to the measure solar radiation.

Table 1: Summary Statistics of Solar Radiation

Variable	Minimum ($MJ\ m^{-2}\ day^{-1}$)	Maximum ($MJ\ m^{-2}\ day^{-1}$)	Mean ($MJ\ m^{-2}\ day^{-1}$)	Std. deviation ($MJ\ m^{-2}\ day^{-1}$)
Measured R_s	9.59	22.73	17.01	2.65
HS R_s [*T*]	12.44	22.46	18.41	2.32
Val R_s [*T* & *RH*]	14.87	24.80	20.99	2.55

Table 2: Summary Statistics of Reference Evapotranspiration

Variable	Minimum ($mm\ day^{-1}$)	Maximum ($mm\ day^{-1}$)	Mean ($mm\ day^{-1}$)	Std. deviation ($mm\ day^{-1}$)
FAO56-PM ET_0	2.830	6.810	4.778	0.998
ET_0 using *HS* R_s [*T*]	3.035	7.112	4.970	1.076
ET_0 using Val R_s [*T* & *RH*]	3.316	7.557	5.322	1.148

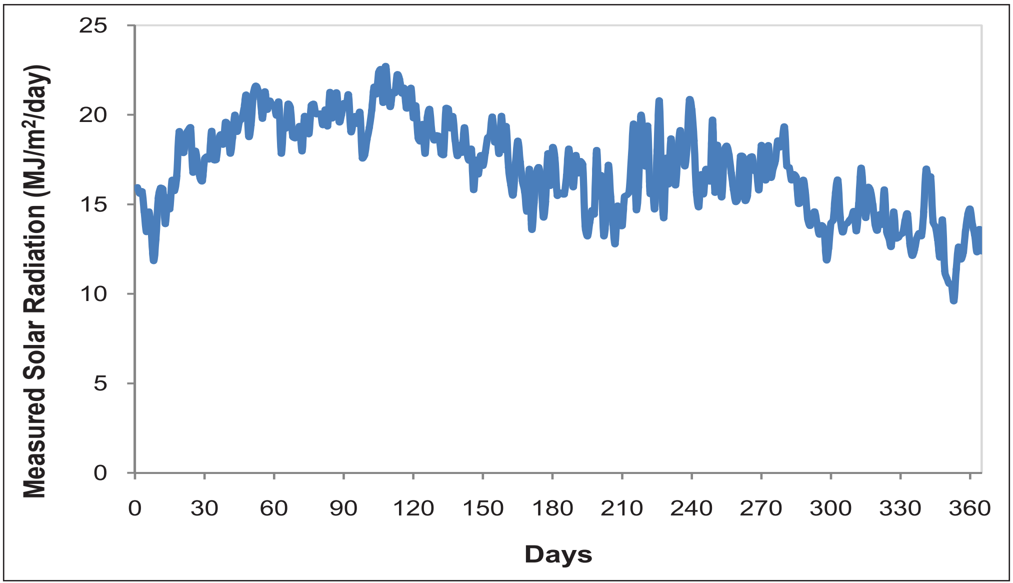
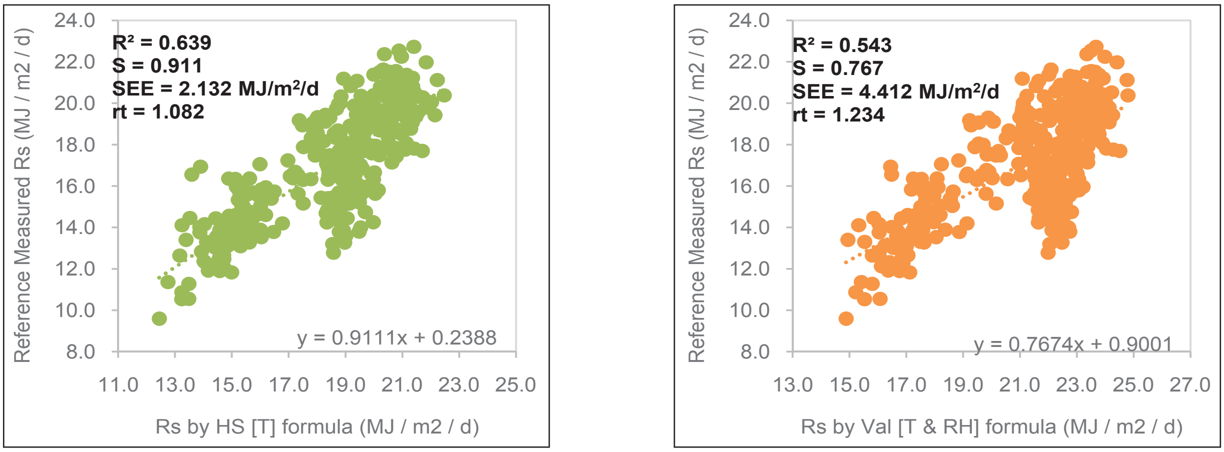


Fig. 1: Measured Average Solar Radiation for Kumulur Station

The results of simple linear regression analysis for Eq. 1 (*HS* R_s [*T*]) and Measured R_S and for Eq. 3 (Val R_s [*T* & *RH*]) and Measured R_S for the study area is presented in Fig. 2a and 2b respectively along with R^2 value, slope (*S*), standard error estimate (*SEE*) and long-term average ratio (*rt*). The regression equation obtained from the analysis is also presented in the figures.

The R^2, SEE and *rt* values for *HS* R_s [*T*] model was 0.639,2.132 MJ m^{-2} day^{-1}, 1.082 respectively (Fig. 2a). The Valiantzas' model requiring temperature and relative humidity performed excellently at this station. The SEE of Val R_s [*T* & *RH*] model is 4.412 MJ m^{-2} day^{-1} (Fig. 2b) and also it closure to maximum value of SEE (4.010 MJ m^{-2} day^{-1}) reported by Valiantzas (2017) for the station located at Hastings, California which has an arid climate. The R^2 value for Val R_s [*T* & *RH*] model is 0.543. Both models produced approximately the same bias (*rt*).

The reference evapotranspiration estimated from FAO56-PM method for the study area was found to vary from 2.83 to 6.81 mm day^{-1}. The variation of reference evapotranspiration using FAO56-PM method is shown in Fig. 3. The mean reference evapotranspiration estimated from FAO56-PM equation by substituting measured R_s values is lesser compared to the ET_0 obtained by using solar radiation obtained by *HS* R_s [*T*] model and Val R_s [*T* & *RH*].



(a) (b)

Fig. 2a-2b: Comparison of daily Solar Radiation estimated by Hargreaves–Samani Model and Valiantzas' Model versus Measured Solar Radiation

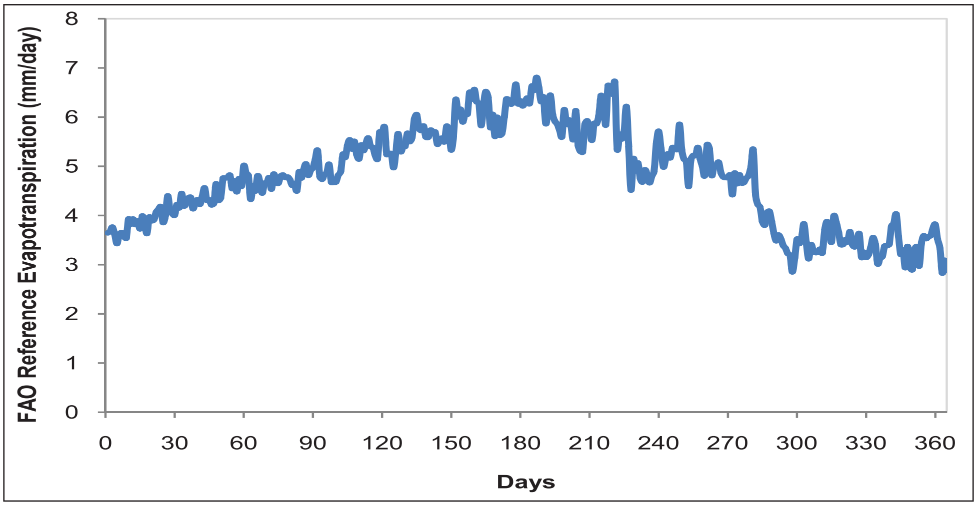
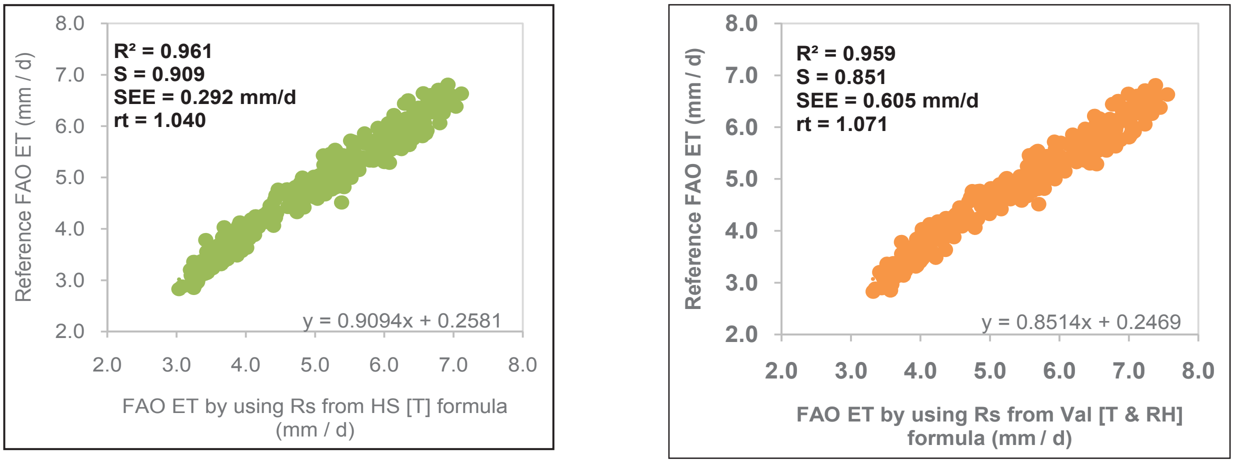


Fig. 2: FAO Reference Evapotranspiration for Kumulur Station



(a) (b)

Fig. 3a-3b: Comparison of daily FAO ET_o estimated by substituting Measured and Solar Radiation obtained from Hargreaves–Samani Model and Valiantzas' Model

The R^2 value obtained while comparing reference evapotranspiration estimated from FAO56-PM equation by substituting measured R_s and Val R_s [*T* & *RH*] values was around 0.959 with lower SEE (0.605 mm day^{-1}) which indicates that using R_s values obtained from Valiantzas (2017) model gives a very good estimate of reference evapotranspiration similar to FAO56-PM method. Valiantzas (2017) also reported that it yields better results than the Hargreaves–Samani and the new formula at six and four stations, respectively.

SUMMARY AND CONCLUSION

The comparison showed a good performance of the new version of Hargreaves–Samani model for calculating solar radiation from temperature and humidity data. It is also suggested that validation of this new version of Hargreaves-Samani equation may be done in different climatic zones of India, which will be useful for the researchers to easily calculate reference evapotranspiration during limited availability of data without compromising the accuracy. To conclude, it will be useful for precision agriculture and water management studies.

REFERENCES

Ahooghalandari, M., Khiadani, M. and Jahromi, M.E. 2016. "Calibration of Valiantzas' reference evapotranspiration equations for the Pilbara region, Western Australia." *Theor. Appl. Climatol*., pp. 1–12.

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. 1998. "Crop evapo-transpiration: Guidelines for computing crop water requirements." FAO, Rome.

Arunadevi, K., Ramachandran, J., Vignesh, S., Visuvanathakumar, S. and Anupriyanka, S. 2017. Comparison of Reference Evapotranspiration in semi arid region. *International Journal of Agriculture Sciences*, **9**(52): 4886-4888.

Djaman, K. *et al.* 2015. "Evaluation of sixteen reference evapotranspiration methods under Sahelian conditions in the Senegal River Valley." *J. Hydrol.: Reg. Stud.*, **3**: 139–159.

Djaman, K., Irmak, S., Kabenge, I. and Futakuchi, K. (2016). "Evaluation of the FAO-56 Penman-Monteith model with limited data and the Valiantzas' models for estimating reference evapotranspiration in the Sahelian conditions." *Journal of Irrigation and Drainage Engineering***.** 10.1061/(ASCE)IR.1943-4774.0001070, 04016044.

Exner-Kittridge, M.G. and Rains, M.C. 2010. "Case study on the accuracy and cost/effectiveness in simulating reference evapotranspiration in West-Central Florida." *J. Hydrol. Eng.*, 10.1061/(ASCE)HE.1943-5584.0000239, 696–703.

Exner-Kittridge, M.G. 2012. "Closure of 'Case study on the accuracy and cost/effectiveness in simulating reference evapotranspiration in West-Central Florida' by Exner-Kittridge, M.G, Rains. M.C." *J. Hydrol. Eng.*, 10.1061/(ASCE)HE.1943-5584.0000430, 225–226.

Hargreaves, G.H. and Allen, R.G. 2003. "History and evaluation of Hargreaves evapotranspiration equation." *J. Irrig. Drain. Eng.*, **129**:1(53): 53–63.

Hargreaves, G.H. and Samani, Z.A. 1982. "Estimating potential evapotranspiration." *J. Irrig. Drain. Div.*, **108**(3): 225–230.

Kisi O. 2014. Comparison of different empirical methods for estimating daily reference evapotranspiration in Mediterranean climate. *Journal of Irrigation and Drainage Engineering*, 10.1061/(ASCE)IR.1943-4774.0000664

Samani, Z. 2000. "Estimating solar radiation and evapotranspiration using minimum climatological data." *J. Irrig. Drain. Eng.*, 10.1061/(ASCE)0733-9437(2000)126:4(265), 265–267.

Samani, Z., Hargreaves, G., Tran, V. and Bawazir, S. 2011. "Estimating solar radiation from temperature with spatial and temporal calibration." *J. Irrig. Drain. Eng.*, 10.1061/(ASCE)IR.1943-4774.0000342,692–696.

Valiantzas, J.D. 2012. "Discussion of 'Case study on the accuracy and cost/effectiveness in simulating reference evapotranspiration in West-Central Florida' by Exner-Kittridge, M.G., Rains. M.C." *J. Hydrol. Eng.*, 10.1061/(ASCE)HE.1943-5584.0000394, 224–225.

Valiantzas, J.D. 2006. Simplified versions for the Penman evaporation equation using routine weather data. *Journal of Hydrology***,** **331**(3-4): 690–702.

Valiantzas, J.D. 2013a. Simplified reference evapotranspiration formula using an empirical impact factor for Penman's aerodynamic term. *Journal of Hydrol. Eng.*, **18**(1): 108–114.

Valiantzas, J.D. 2013b. Simple ET_0 forms of Penman's equation without wind and/or humidity data I theoretical development. *Journal of Irrigation and Drainage Engineering*, ASCE **139**(1): 1–8.

Valiantzas, J.D. 2013c. Simple ET_0 forms of Penman's equation without wind and/or humidity data II: comparisons with reduced set-FAO and other methodologies. *Journal of Irrigation and Drainage Engineering*, **139**(1): 9–19.

Valiantzas, J.D. 2013d. Simplified forms for the standardized FAO-56 Penman–Monteith reference evapotranspiration using limited weather data. *Journal of Hydrology*, **505**: 13–23.

Valiantzas, J.D. 2014a. Closure to "Simple ET_0 forms of Penman's equation without wind and/or humidity data. I: theoretical development" by John D. Valiantzas. *Journal of Irrigation and Drainage Engineering***,** **140**(7).

Valiantzas, J.D. 2014b. Discussion of "comparison of different empirical methods for estimating daily reference evapotranspiration in mediterranean climate" by Ozgur Kisi. *Journal of Irrigation and Drainage Engineering*, **141**(4).

Valiantzas, J.D. 2015. Simplified limited data Penman's ET_0 formulas adapted for humid locations. *Journal of Hydrology*, **524**: 701–707.

Valiantzas, J.D. 2017. Modification of the Hargreaves–Samani model for estimating solar radiation from temperature and humidity data. *Journal of Irrigation and Drainage Engineering*, **144**(1): 06017014.

Valiantzas, J.D. 2018a. Discussion of "Evaluation of Valiantzas' Simplified Forms of the FAO-56 Penman-Monteith Reference Evapotranspiration Model in a Humid Climate" by Koffi Djaman, Daran Rudnick, Valere C. Mel, Denis Mutiibwa, Lamine Diop, Mamadou Sall, Isa Kabenge, Ansoumana Bodian, Hossein Tabari, and Suat Irmak. *Journal of Irrigation and Drainage Engineering*, **144**(7): 07018026.

Valiantzas, J.D. 2018b. Temperature-and humidity-based simplified Penman's ET0 formulae. Comparisons with temperature-based Hargreaves-Samani and other methodologies. *Agricultural Water Management*, **208**: 326-334.

Valipour, M. 2014. Investigation of Valiantzas' evapotranspiration equation in Iran. *Theor. Appl. Climatol.*, 10.1007/s00704-014-1240-x