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A COMBINED SENSITIVITY ANALYSIS OF SEVEN POTENTIAL EVAPOTRANSPIRATION MODELS

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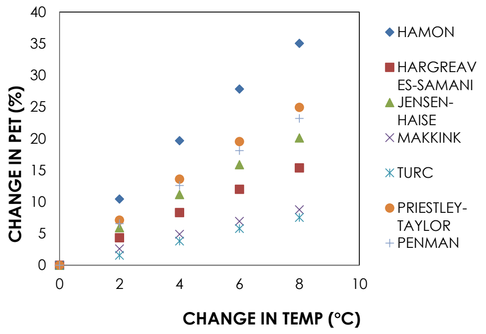
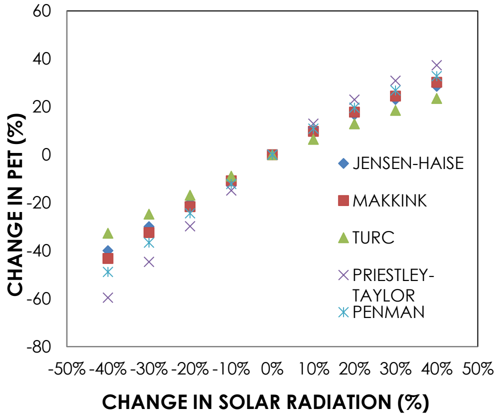
Graphical abstract





Abstract

Graphical and partial derivatives approaches were used to analyse the sensitivity of variables for the seven potential evapotranspiration models (PET). The models, which have different data requirements and structures, are Hamon, Hargreaves-Samani, Jensen-Haise, Makkink, Turc, Priestley-Taylor, and Penman. Julian date based mean imputation was used to fill the missing data. Tukey's outlier detection method was employed before estimating the PET. Partial derivative approach was conducted by combining the absolute values of the error term through a root mean square and changing to the finite difference form. According to partial derivatives analysis, Hamon is the most sensitive model followed by Penman, Priestley-Taylor, Hargreaves-Samani, Jensen-Haise, Turc, and Makkink models. Temperature is more sensitive meteorological input in Jensen-Haise and Makkink models while solar radiation is more sensitive ones in Turc and Priestley-Taylor models. Wind speed and relative humidity are the most and less sensitive ones in Penman model. Graphical analysis showed that Hamon was the most sensitive PET model with respect to the temperature while Priestley-Taylor was the one with respect to the solar radiation. Turc is the less sensitive PET model with respect to temperature and solar radiation. Overall, graphical method gives clearly comparison for sensitivity of PET. However, it does not indicate its sensitivity values compared to partial derivative approach.

Keywords: Potential evapotranspiration model, sensitivity analysis, graphical approach, partial derivatives, outlier detection

1.0 BACKGROUND

Evapotranspiration is a primary component in terrestrial water budgets [1, 2, 3, 4]. It is significantly influenced by climate and is an important part of regional hydrology [5, 6). A good estimate of evapotranspiration is very important for determining sustainable water use, and there are many methods available for calculating potential evapotranspiration (PET). There are approximately fifty methods or models to calculate PET, and different methods often give very different estimates because of the varying assumptions and input data involved [7, 8, 9]. Simple methods may require only one data parameter such as mean temperature, while complex methods require many climate variables such as maximum temperature, minimum temperature, solar radiation, and characteristics of vegetation [4, 10].

Evapotranspiration tends to be a site-specific characteristic, so estimations cannot be directly applied to places with different climates [11]. Hamon, Penman, Makkink, Turc and Priestley-Taylor are among the most widely used models for estimating PET in tropical and subtropical regions [9]. For Mediterranean climates, the Valiantzas and Copaise equations performed well [12]. Hargreaves-Samani has been suggested for both semiarid and arid regions [13], while Blaney-Criddle can also be used in arid climates [4]. In humid regions, the Priestley-Taylor has generally shown acceptable estimates [14]. Turc and adjusted Hargreaves have been reported to be suitable for humid conditions [3, 15].

Some studies in Malaysia have attempted to predict evapotranspiration in irrigated agricultural areas. A study in the Muda area estimated potential evaporation using Penman, and PET using Penman-Monteith, and compared the estimations with pan evaporation data [16]. Another study at Seberang Perak paddy estate used eight methods (Penman, Penman-Monteith, pan evaporation, Kimberly-Penman, Priestley-Taylor, Hargreaves, Hargreaves-Samani, and Blaney-Criddle) to estimate evapotranspiration of irrigated rice to be used in a water balance equation to improve water management in rice cultivation [11]. The results showed that the lowest estimate was from the Penman-Monteith method, but there were no significant differences between the Penman-Monteith, Blaney-Criddle, and pan evaporation methods. At Besut Irrigation Scheme in Terengganu, the reference evapotranspiration was estimated using the Penman-Monteith equation [17, 18], and [19] also used the Penman-Monteith equation to calculate reference evapotranspiration in the Tanjung Karang paddy fields. The Food and Agriculture Organization Penman-Monteith (FAO-PM) was used for reference evapotranspiration in the rice irrigation management information system (RIMIS) program at Tanjung Karang and was found to be suitable there [20]. Another study in the Muda agricultural area compared five different methods with pan evaporation data, and Penman-Monteith was found to be the best model, followed by FAO-Penman-Monteith, Blaney-Criddle, and modified Penman and Christiansen [5]. Later, the Makkink method was found to give the best PET estimates among radiation based methods [21].

Several studies have investigated sensitivity analysis of PET, typically using derivative-based methods, with widely varying results due to differences in climate, PET models used, and meteorological and/or physical inputs evaluated [22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32]. However, only a few studies are available analyzing the sensitivity of evapotranspiration models by taking into account the effect of climate change on evapotranspiration. [10] investigated the sensitivity of eight different PET estimates to climate change using five different climate stations in US and assuming an increase in temperature from 2◦C to 6◦C and a change in other climatic variables of ±10% to 30%. They found that the different models differed in their sensitivity to meteorological inputs.

The aim of the present study is to evaluate the individual sensitivity of meteorological inputs of PET models in conjunction with the sensitivity of PET models to observed climate change at urban tropical area.

2.0 THE MODELS

In this study, we compared temperature based methods (Hamon and Hargreaves-Samani), radiation based methods (Turc, Makkink, and Jensen-Haise), and combination methods (Penman and Priestley-Taylor). As shown in Table 1, the Hamon method is the simplest among the seven methods used in this study, and only requires daily mean temperature data. The Hargreaves-Samani method is also a simple method, using daily minimum (min), maximum (max) and mean temperatures, and extraterrestrial radiation instead of solar radiation. All radiation based methods in this study used both daily temperature and solar radiation parameters. For the Turc method, daily mean relative humidity was also considered in selecting the appropriate equation for the method. The combination methods can be considered complex methods because they required more variables such as temperature, net radiation and relative humidity. The Penman method, which included a wind parameter, was the most complex method in the comparison. Both combination methods required daily climatic inputs. The formulas used to estimate PET by each method are detailed in Table 2.

3.0 METHODS AND MATERIALS

3.1 Study Site

The Penchala catchment (Figure 1) is in an urban area that crosses two districts boundaries: Kuala Lumpur and Petaling Jaya. The area of the catchment is 14 km2. The head of the Penchala River is found on Bukit Kiara Hill, which is located near Taman Tun Dr. Ismail and meets Sungai Klang in the Bandar Sunway area.

3.2 Data

The daily pan evaporation data and meteorological data were taken from Petaling Jaya station (Station Number 48648) at 03° 06'N and 101° 39'E at a height of 45.7m above mean sea level. The meteorological data included maximum temperature, minimum temperature, mean temperature, relative humidity, wind speed, rainfall and solar radiation.

Table 1 Variables of meteorological data required by the PET methods [8, 10, 33]

Method	Temperature	Radiation	Humidity	Wind	Others
Hargreaves-Samani	Daily Mean, Min, Max	Extraterrestrial			
Hamon	Daily Mean				- Daytime length - Calibration coefficient = 1.2
Turc	Daily Mean	Solar	Mean Daily		
Makkink	Daily Mean	Solar			- Elevation = 45.7m
Jensen-Haise	Daily Mean, Min, Max	Solar			- Elevation = 45.7m
Priestley-Taylor	Daily Mean	Net Radiation derived from Solar Radiation	Mean Daily		- Calibration constant = 1.26 - Elevation = 45.7m - Albedo = 0.23 - Emissivity = 0.98 - Specific heat of moist air at constant pressure = 0.001013 MJ/kg/°C - Stefan-Boltzmann constant = 5.6697E-08 Wm^{-2}K^{-4}
Penman	Daily Mean	Net Radiation derived from Solar Radiation	Mean Daily	Mean Wind	- Elevation = 45.7m - Albedo = 0.23 - Emissivity = 0.98 - Specific heat of moist air at constant pressure = 0.001013 MJ/kg/°C - Stefan-Boltzmann constant = 5.6697E-08 Wm^{-2}K^{-4}

Table 2 Formula of methods used to estimate PET in the present study

Method	Formula Applied
Hamon [34]	$PET = 0.1651 \times Ld \times RHOSAT \times KPEC$
Hargreaves-Samani [35]	$\lambda PET = 0.0023 \times R_a \times TD^{0.5} \times (T + 17.8)$
Turc [36]	$PET = 0.013\left(\frac{T}{T+15}\right)(R_s + 50)$
Makkink [37]	$PET = 0.61\left(\frac{\Delta}{\Delta+\gamma}\right)\frac{R_s}{58.5} - 0.12$
Jensen-Haise [25]	$PET = (0.014Ta - 0.37)(0.00063Qt)$
Priestley-Taylor [38]	$\lambda PET = \alpha \frac{\Delta}{\Delta+\gamma}(R_n - G)$
Penman [39]	$PET = \frac{\Delta}{\Delta+\gamma}\left(\frac{R_n - G}{\lambda}\right) + \frac{\gamma}{\Delta+\gamma} fe(u_2)(e_s - e_a)$

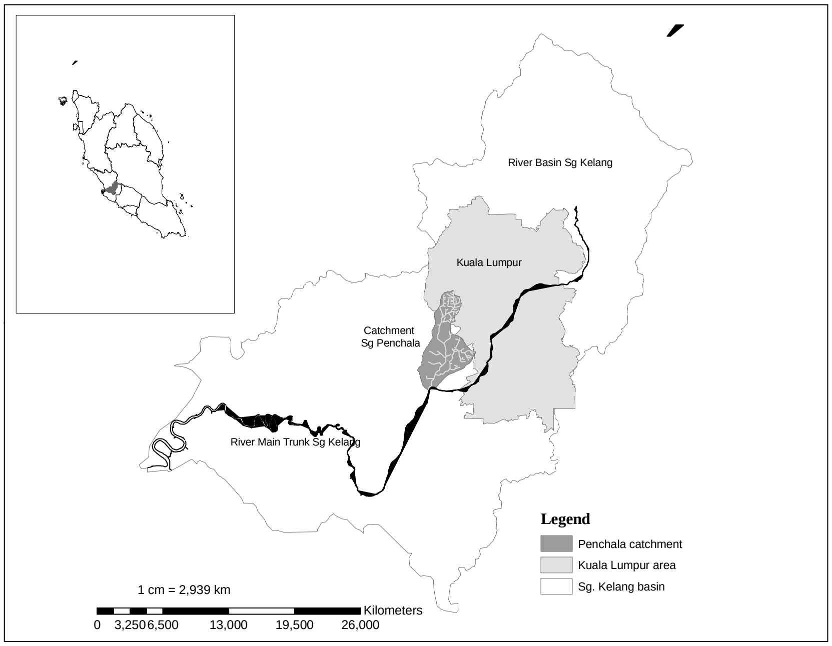


Figure 1 Location map of Penchala catchment

Prior to PET calculation, Julian date based mean imputation was applied to fill the missing data [40]. Tukey's outlier filter was employed to detect the outlier data, which is a value in a quartile range 1.5 below the lower quartile or 1.5 above the quartile [41]. Five years of daily meteorological data from 1994 to 1998 were used for the PET estimation. The daily pan evaporation data were used as reference values to compare with the PET estimates. According to [39], pan evaporation is considered as apparent potential evaporation. Pan evaporation data were multiplied by the pan coefficient, kp = 0.75, to get the potential evapotranspiration values.

3.3 Partial Derivative Method

The sum of the absolute values of the error terms gives the maximum possible value of the error. Combining these terms by a root-mean-square and changing to the finite different form [42] of the equation in the Table 2, gives

$$\delta PET = \sqrt{\left(\frac{\partial PET}{\partial T}\Delta T\right)^2} \qquad (1)$$

where $\frac{\partial PET}{\partial T}$ is the partial derivative of PET with respect to temperature in Hamon, and Hargreaves-Samani models. ΔT is set to 0.05.

$$\delta PET = \sqrt{\left(\frac{\partial PET}{\partial T}\Delta T\right)^2 + \left(\frac{\partial PET}{\partial Rs}\Delta Rs\right)^2} \qquad (2)$$

where $\frac{\partial PET}{\partial T}$ and $\frac{\partial PET}{\partial Rs}$ are the partial derivative of PET with respect to temperature and solar radiation in Jensen-Haise, Makkink, Turc, and Priestley & Taylor models. ΔT and ΔRs are set to 0.05 and 0.005, respectively.

$$\delta PET = \sqrt{\left(\frac{\partial PET}{\partial T}\Delta T\right)^2 + \left(\frac{\partial PET}{\partial Rs}\Delta Rs\right)^2 + \left(\frac{\partial PET}{\partial RH}\Delta RH\right)^2 + \left(\frac{\partial PET}{\partial Up}\Delta Up\right)^2} \qquad (3)$$

where $\frac{\partial PET}{\partial T_{mean}}$, $\frac{\partial PET}{\partial T_{mean}}$, $\frac{\partial PET}{\partial RH}$, and $\frac{\partial PET}{\partial Up}$ are the partial derivative of PET with respect to temperature, solar radiation, humidity and wind speed in Penman model. ΔT is set to 0.05 meanwhile ΔRs, ΔRH and ΔUp are set to 0.005.

Furthermore, the sensitivity of meteorological variable inputs were employed by using the percentage error value of each variable as determined by the equations (4) – (7):

$$\text{Percent of Error for T} = \left(\frac{\frac{\partial PET}{\partial T}\Delta T}{PET}\right) \times 100\% \qquad (4)$$

$$\text{Percent of Error for Rs} = \left(\frac{\frac{\partial PET}{\partial Rs}\Delta Rs}{PET}\right) \times 100\% \qquad (5)$$

$$\text{Percent of Error for RH} = \left(\frac{\frac{\partial PET}{\partial RH} \Delta RH}{PET} \right) \times 100\% \quad (6)$$

$$\text{Percent of Error for Up} = \left(\frac{\frac{\partial PET}{\partial Up} \Delta Up}{PET} \right) \times 100\% \quad (7)$$

3.4 Graphical method

Graphical method was used to analyse the sensitivity of PET models by changing one variable while the other variables remain unchanged. Table 3 showes changes of meteorological data used in the present and previous study [10].

Table 3 Change of meteorological input data

Variables	Present study	Previous study [1]
Temperature	0 up to 8°C	0 up to 6°C
Solar Radiation	-40% up to +40%	-30% up to +30%
Humidity	-8% up to +8%	-30% up to +30%
Wind	-80% up to 80%	-30% up to +30%

1. [10]

4.0 RESULTS AND DISCUSSION

4.1 PET Estimation

Evaluating model performance by visually comparing predicted and observed data is an important first step [43]. Figure 2 shows the monthly mean estimated evapotranspiration using the Turc, Makkink, Jensen-Haise, Priestley-Taylor, Hargreaves-Samani, Hamon, and Penman methods compared against the pan evaporation data. From this, the Makkink and Priestley-Taylor methods appeared to give estimates closest to the pan evaporation values.

4.2 Partial Derivatives Based Sensitivity Analysis

Table 4 shows the mean values of the δPET for each PET model. Notice that Hamon, Penman, Priestly-Taylor, Samani-Hargreaves, Jensen-Haise, Turc, and Makkink models appeared to give the highest up to lowest values of the δPET. The higher the value of δPET, the more sensitive the PET model [25]. Hamon model shows the highest value of δPET. Therefore, Hamon model is the most sensitive PET models among others. On the contrary, Makkink is the less sensitive PET model among others.

Table 5 shows percentage of error of temperature in Hamon and Hargreaves-Samani models. Notice that the value of Hamon model is higher than Hargreaves-Samani model. Therefore, temperature is more sensitive meteorological input data in Hamon model.

Table 6 shows percentage of error of temperature and solar radiation in Makkink, Turc, Jensen-Haise, and Priestley-Taylor models. Notice that those values of temperature are higher in Jensen-Haise and Makkink models. On the contrary, those values of solar radiation are higher in Turc and Priestley-Taylor models. Thus, temperature are more sensitive meteorological input data in Makkink and Jensen-Haise models meanwhile solar radiation are more sensitive meteorological input data in Turc and Priestley-Taylor models.

Table 7 shows percentage of error of temperature, solar radiation, relative humidity, and wind speed in Penman model**.** Notice that wind speed, temperature, solar radiation, and relative humidity appeared to give the highest up to the lowest value of percentage of error. Thus, wind speed is the most sensitive meteorological input data in Penman model followed by temperature, solar radiation, and relative humidity.

Table 4 Partial derivatives of PET models

Models	δPET	
	Average	Standard deviation
Hamon	0.0146	0.0008
Hargreaves-Samani	0.0020	0.0002
Jensen-Haise	0.0017	0.0004
Makkink	0.0008	0.0002
Turc	0.0012	0.0002
Priestley-Taylor	0.0025	0.0003
Penman	0.0068	0.0002

Table 5 Percentage of error of temperature in Hamon and Hargreaves-Samani models

Model	Percentage of error temperature
Hamon	0.276
Hargreaves-Samani	0.045

Table 6 Percentage of error of temperature and solar radiation in four different PET models

Model	Percentage of error	
	temperature	solar radiation
Makkink	0.0661	0.0033
Turc	0.0643	3.5100
Jensen-Haise	0.0469	0.00001
Priestley-Taylor	0.3930	0.4190

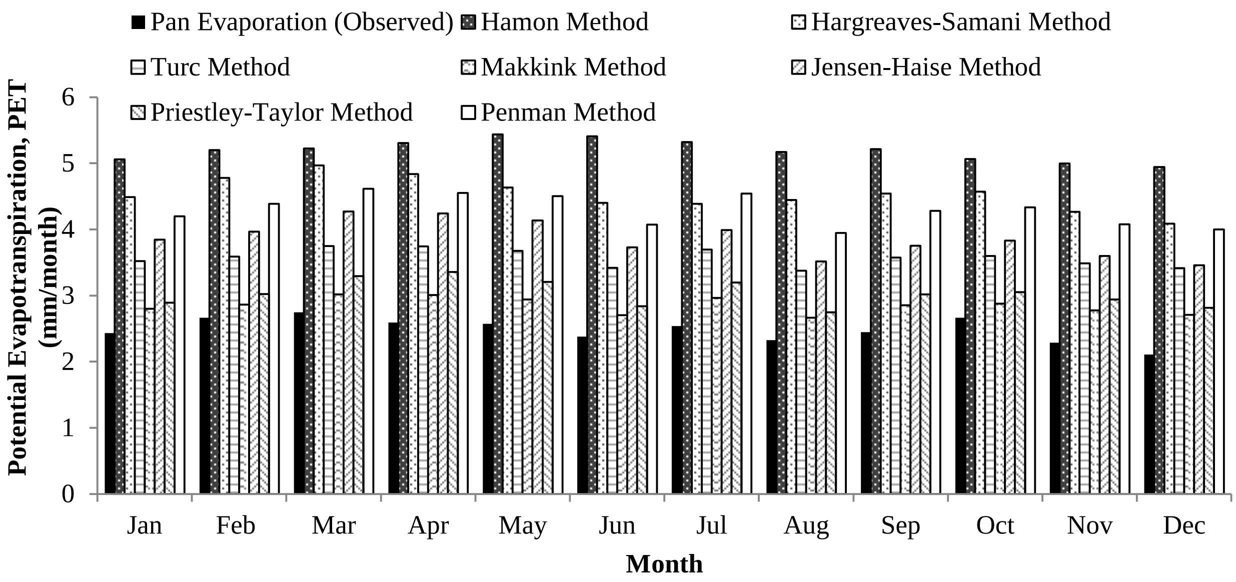


Figure 2 Comparison between monthly mean observed data (pan evaporation) and estimated PET models

Table 7 Percentage of error of temperature, solar radiation, relative humidity, and wind speed in Penman model

Model	Percentage of error of variables			
	temperature	solar radiation	relative humidity	wind speed
Penman	8.61e-2	4.43e-3	5.05e-5	2.49e-1

4.2 Graphical Method Based Sensitivity Analysis

Figure 3 shows the percentage of changes in PET in response to changes of temperature for all PET models.

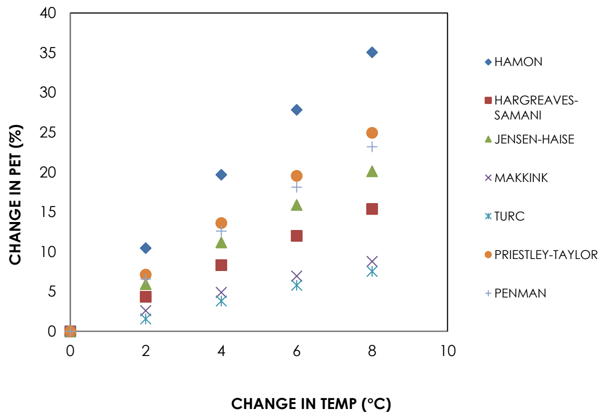


Figure 3 Percentage of changes in Potential Evapotranspiration (PET) in response to changes of temperature

Notice that Hamon is the most sensitive model in response to temperature change followed by Priestley-Taylor, Penman, Jensen-Haise, Hargreaves-Samani, Makkink, and Turc models. Similarly, result of of partial derivatives support the graphical one. As the models which require temperature data as the only meteorological input data, those models are the most sensitive response to the temperature [10].

Jensen-Haise, Makkink, Turc, Priestley Taylor, and Penman models use solar radiation (Rs) as a meteorological input to estimate PET. Figure 5 shows the response of these five models to a ±40% of changes in solar radiation. Priestley Taylor is the most sensitive models among others which is followed by Penman, Makkink, Jensen-Haise, and Turc models. Previous study also showed that Priestley Taylor and Jensen-Haise are the most sensitive response to solar radiation change [10].

Penman model requires all meteorological input data to compute the PET. We have discussed earlier that wind speed, temperature, solar radiation, and relative humidity appeared to give the highest up to the lowest value of percentage of error. According to Figure 4, it appears that relative humidity contribute a negative correlation to PET. The higher changes in relative humidity, the lower changes PET. One possible reason is in the higher relative humidity, there is limited vapor pressure that govern a transport of air into the atmosphere. On the contrary, the wind speed contributes a positive correlation.

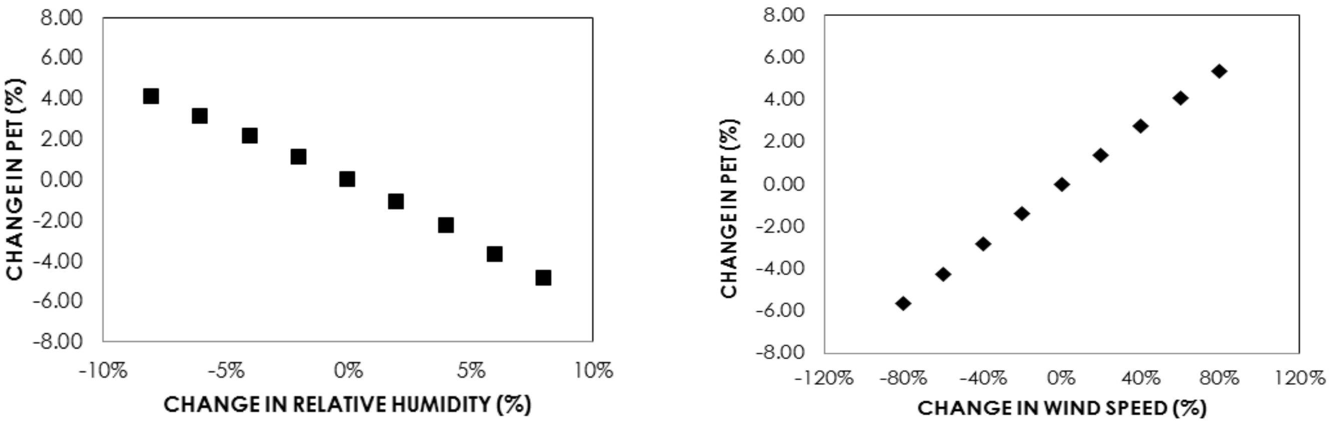


Figure 4 Percentage of changes in Potential Evapotranspiration (PET) in response to changes of relative humidity (left) and wind speed (right)

Notice that a high wind speed will be an additional energy to transport the water vapor into the atmosphere. When wind blows it will sweep away the air-borne water particles from the air above the body of water.

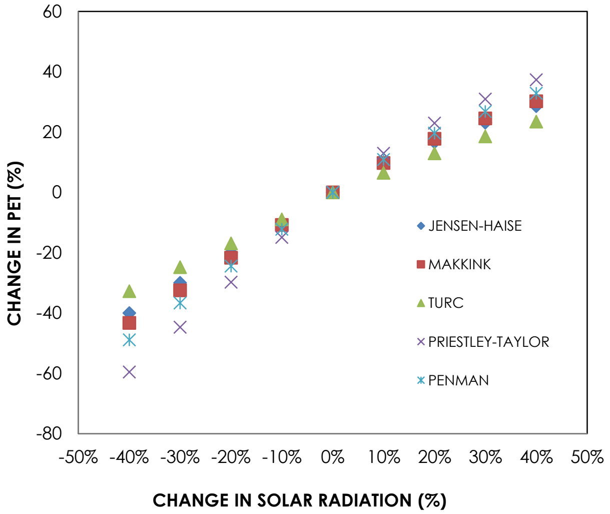


Figure 5 Percentage of changes in Potential Evapotranspiration (PET) in response to changes of solar radiation

5.0 CONCLUSION

Partial derivatives give exact value of sensitivity of the model and sensitivity of each variables of PET model. Hamon is the most sensitive model followed by Penman, Priestley-Taylor, Hargreaves-Samani, Jensen-Haise, Turc, and Makkink models. Temperature is more sensitive meteorological input in Jensen-Haise and Makkink models while solar radiation is more sensitive ones in Turc and Priestley-Taylor models. Wind speed and relative humidity are the most and less sensitive ones in Penman model.

Graphical method shows the clearly comparison of sensitivity of variables among all seven models. In this study, Hamon was the most sensitive PET model with respect to the temperature while Priestley-Taylor was the one with respect to the solar radiation. Turc is the less sensitive PET model with respect to temperature and solar radiation.

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References

[1] El-Baroudy, I., Elshorbagy, A., Carey, S., *et al.* 2010. Comparison of Three Data-driven Techniques in Modelling The Evapotranspiration Process. *Journal of Hydroinformatics*. 12: 365-379.

[2] Ladlani, I., Houichi, L., Djemili, L., *et al.* 2012. Modeling Daily Reference Evapotranspiration (ET0) in the North of Algeria Using Generalized Regression Neural Networks (GRNN) and Radial Basis Function Neural Networks (RBFNN): A Comparative Study. *Meteorology and Atmospheric Physics*. 118: 163-178.

[3] Fisher, D. K., III HCP. 2013. Evaluation of Alternative Methods for Estimating Reference Evapotranspiration. *Agricultural Sciences*. 4: 51-60.

[4] Tabari, H., Hosseinzadeh Talaee, P., Some'e, B. S. 2013. Spatial Modelling of Reference Evapotranspiration Using Adjusted Blaney-Criddle Equation in an Arid Environment. *Hydrological Sciences Journal*. 58: 408-420.

[5] Ali, M. H., Shui, L. T. 2009. Potential Evapotranspiration Model for Muda Irrigation Project, Malaysia. *Water Resources Management*. 23: 57-69.

[6] Huo, Z., Dai, X., Feng, S., *et al*. 2013. Effect of Climate Change on Reference Evapotranspiration and Aridity Index in Arid Region Of China. *Journal of Hydrology*. 24-34.

[7] Grismer, M. E., Orang, M., Snyder, R., Matyac, R. 2002. Pan Evaporation to Reference Evapotranspiration Conversion Methods. *Journal of Irrigation and Drainage Engineering.* 128: 180-184.

[8] Lu, J., Sun, G., McNulty, S. G., Amatya, D. M. 2005. A Comparison of Six Potential Evapotranspiration Methods for Regional Use in the Southeastern United States. *JAWRA Journal of the American Water Resources Association*. 41: 621-633.

[9] Le, T. P. Q., Seidler, C., Kändler, M., Tran, T. B. N. 2012. Proposed Methods for Potential Evapotranspiration Calculation of the Red River Basin (North Vietnam). *Hydrological Processes*. 26: 2782-2790.

[10] McKenney, M. S., Rosenberg, N. J. 1993. Sensitivity of Some Potential Evapotranspiration Estimation Methods to Climate Change. *Agricultural and Forest Meteorology*. 64: 81-110.

[11] Lee, T. S., Najim, M. M., Aminul, M. H. 2004. Estimating evapotranspiration of irrigated rice at the West Coast of the Peninsular of Malaysia. *Journal of Applied Irrigation Science*. 39: 103-117.

[12] Kisi, O. 2013. Comparison of Different Empirical Methods for Estimating Daily Reference Evapotranspiration in Mediterranean Climate. *Journal of Irrigation and Drainage Engineering.* doi: 10.1061/(ASCE)IR.1943-4774.0000664.

[13] Heydari, M. M., Heydari, M. 2013. Calibration of Hargreaves–Samani Equation for Estimating Reference Evapotranspiration in Semiarid and Arid Regions. *Archives of Agronomy and Soil Science.* 1–19. doi: 10.1080/03650340.2013.808740

[14] Suleiman, A. A., Hoogenboom, G. 2007. Comparison of Priestley-Taylor and FAO-56 Penman-Monteith for Daily Reference Evapotranspiration Estimation in Georgia. *Journal of Irrigation and Drainage Engineering* 133: 175-182.

[15] Gocic, M. and Trajkovic, S. 2014. Analysis of Trends in Reference Evapotranspiration Data in a Humid Climate. *Hydrological Sciences Journal.* 59(1): 165-180.

[16] Ali, M. H., Shui, L. T., Yan, K. C., Eloubaidy, A. F. 2000. Modelling Evaporation and Evapotranspiration under Temperature Change in Malaysia. *Pertanika Journal of Science and Technology*. 8: 191-204.

[17] Lee, T. S., Haque, M. A., Najim, M. M. M. 2005. Scheduling the Cropping Calendar in Wet-Seeded Rice Schemes in Malaysia. *Agricultural Water Management.* 71: 71-84. doi: 10.1016/j.agwat.2004.06.007.

[18] Lee, T. S., Haque, M. A., Huang, Y. F. 2006. Modeling Water Balance Components in Rice Field Irrigation. The Institution of Engineers, Malaysia. 67: 22-25.

[19] Amin, M. S. M., Rowshon, M. K., Aimrun, W. 2011. Paddy Water Management for Precision Farming of Rice. In: Uhlig U (ed). Current Issues of Water Management. InTech. 107-142.

[20] Rowshon, M. K., Amin, M. S. M., Lee, T. S., Shariff, A. R. M. 2009. GIS-Integrated Rice Irrigation Management Information System for a River-Fed Scheme. *Water Resources Management.* 23: 2841-2866. doi: 10.1007/s11269-009-9412-7.

[21] Tukimat, N. N. A., Harun, S., Shahid, S. 2012. Comparison of Different Methods in Estimating Potential Evapotranspiration at Muda Irrigation Scheme of Malaysia. *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS).* 113: 77-85.

[22] Ambas, V. T., Baltas, E. 2012. Sensitivity Analysis of Different Evapotranspiration Methods Using a New Sensitivity Coefficient. *Global NEST J*. 14(3): 335-343.

[23] Bakhtiari, B., Liaghat, A. M. 2011. Seasonal Sensitivity Analysis for Climatic Variables of ASCE-Penman–Monteith Model in a Semi-Arid Climate. *J. Agric. Sci. Technol.* 13: 1135-1145.

[24] Beven, K. 1979. A Sensitivity Analysis of the Penman–Monteith Actual Evapotranspiration Estimates. *J. Hydrol.* 44(3-4): 169-190.

[25] Coleman, G., DeCoursey, D. G. 1976. Sensitivity and Model Variance Analysis Applied to Some Evaporation and Evapotranspiration Models. *Water Resour. Res*. 12(5): 873-879.

[26] Eslamian, S., Khordadi, M. J., Abedi-Koupai, J. 2011. Effects of Variations in Climatic Parameters on Evapotranspiration in the Arid and Semi-Arid Regions. *Global Planet. Change.* 78(3–4): 188-194.

[27] Gong, L., Xu, C.-Y., Chen, D., Halldin, S., Chen, Y. D. 2006. Sensitivity of the Penman–Monteith Reference Evapotranspiration to Key Climatic Variables in the Changjiang (Yangtze River) Basin. J. Hydrol. 329(3-4): 620-629.

[28] Hupet, F., Vanclooster, M. 2001. Effect of the Sampling Frequency of Meteorological Variables on the Estimation of the Reference Evapotranspiration. *J. Hydrol.* 243(3-4): 192-204.

[29] Irmak, S., Martin, D., Irmak, A., Howell, T. 2006. Sensitivity Analyses and Sensitivity Coefficients of Standardized Daily ASCE-Penman–Monteith Equation. *J. Irrig. Drain. Eng*. 132(6): 564-578.

[30] Ley, T. W., Hill, R. W., Jensen, D. T. 1994a. Errors in Penman–Wright Alfalfa Reference Evapotranspiration Estimates: I. Model Sensitivity Analysis. *Trans. ASABE.* 37(6): 1853-1861.

[31] Liang, L., Li, L., Zhang, L., Li, J., Li, B. 2008. Sensitivity of Penman–Monteith Reference Crop Evapotranspiration in Tao'er River Basin Of Northeastern China. *Chin. Geogr. Sci*. 18(4): 340-347.

[32] Rana, G., Katerji, N., 1998. A Measurement based Sensitivity Analysis of the Penman–Monteith Actual Evapotranspiration Model for Crops Of Different Height and in Contrasting Water Status. *Theor. Appl. Climatol.* 60(1): 141-149.

[33] Brutsaert, W. 1982. Energy Budget and Related Methods. Evaporation into the Atmosphere: Theory, History and Applications. D. Reidel Publishing Company. 215-217.

[34] Hamon, W. R. 1963. Computation of Direct Runoff Amounts From Storm Rainfall. *Int Assoc Sci Hydrol*. 63: 52-62.

[35] Hargreaves, G. H., Samani, Z. A. 1985. Reference Crop Evapotranspiration from Temperature. *Applied Engineering in Agriculture*. 1: 96-99.

[36] Turc, L. 1961. Evaluation des besoins en eau d'irrigation, {é}vapotranspiration potentielle. *Ann agron.* 12: 13-49.

[37] Makkink, G. F. 1957. Testing the Penman Formula by Means of Lysimeters. *J Inst Water Eng*. 11: 277-288.

[38] Priestley, C. H. B., Taylor, R. J. 1972. On the Assessment of Surface Heat Flux snd Evaporation Using Large-Scale Parameters. *Monthly Weather Review.* 100: 81-92.

[39] Brutsaert, W. 2005. *Hydrology: An Introduction.* Cambridge University Press. 130-131.

[40] Thirukumaran, S. & A, S. 2015. An Alternate Imputation Technique of a Mean Method for Missing Values and Comparative Study with Neighbor Methods. *International Journal of Applied Engineering Research*. 10**:** 9969-9982.

[41] Tukey, J. 1977. *Exploratory Data Analysis.* Addison-Wesley. 43-44.

[42] Jordan, K. A., R. O. Kuehl, J. I. Sewell. 1991. Planning the Experiment. In: Henry, Z. A., G. C. Zoerb, G. S. Birth (Editors). Instrumentation and Measurement for Environmental Sciences. 3rd Edition. American Society of Agricultural Engineering (ASAE), USA. 1-01–1-05.

[43] Legates, D. R., McCabe, G. J. 1999. Evaluating the Use of "Goodness-Of-Fit" Measures in Hydrologic and Hydroclimatic Model Validation. *Water Resources Research*. 35: 233-241.