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WEEKLY PAN EVAPORATION ESTIMATION BY STEPHENS-STEWART AND GRIFFITH MODELS

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ABSTRACT : Stephens-Stewart model (SSM), and Griffith's model (GM) were used to estimate the weekly pan evaporation (EPW) at Pantnagar, located at the foothills of Himalayas in the Uttarakhand state of India. Weekly meteorological data of maximum and minimum air temperatures, relative humidity in the morning (7 AM) and afternoon (2 PM), wind speed, sunshine hours and pan evaporation from January 2004 to December 2007 were used. The best combination of input variables models were decided using the Gamma Test (GT). The estimated values of EPW by the Stephens-Stewart and Griffith's model were compared with observed values of EPW based on statistical indices such as root mean squared error (RMSE), coefficient of efficiency (CE) and correlation coefficient (r).

Keywords: *Gamma test, weekly pan evaporation, Stephens-Stewart model, Griffith's model.*

Evaporation is a nonlinear dynamic process of hydrology cycle, which depends on various meteorological factors occurring in nature. Therefore, accurate estimation of evaporation (Ep), particularly in the arid and semiarid regions, is essentially required for integrated water resources management and modelling studies related to hydrologic water balance, agronomy, forestry, horticulture, irrigation system design and management, river flow forecasting, lake-ecosystems, etc. (Lenters *et al.,* 9; Dinpashoh, 3; Sabziparvar *et al.,* 16).

A number of attempts have been made by the researchers to estimate the evaporation from climatic variables (Penman, 11; Stephens and Stewart, 17; Griffiths, 6; Priestley and Taylor, 13; Jensen *et al.,* 7; Gavin and Agnew, 5). Chu *et al.* (2) used wind tunnel experiments to investigate the wind effects on the evaporation rate of the Class A evaporation pan and found that the evaporation rate increased with the wind speed, and the wind speed exceeding 6.0 m/s could blow water over the edges of the pan. Yuhe and Guangsheng (18) discovered the strongest correlation between annual relative humidity and pan evaporation in the Liaohe Delta during the period of 1961 to 2005.

Based on the above reviews, this study was conducted to analyse the performances of Stephens-Stewart model, and Griffith's model to estimate the weekly pan evaporation using various input variable combinations of meteorological data for study location.

MATERIALS AND METHODS

1. Study area and data acquisition

The study was conducted at Pantnagar, located at the latitude of 29° 3' N and longitude of 79° 31' E in Uttarakhand state of India (Fig. 1). The area lies in the *Tarai* belt located in the foothills of the Himalayas at an elevation of 243.8 m above mean sea level. It has a sub-humid and sub-tropical climate with summer season from February to May, rainy season from June to September, and winter season from October to January. The mean annual rainfall in the study area is about 1400 mm. The weekly weather data including maximum and minimum air temperature (T_{max} and T_{min}), relative humidity (RH_1 and RH_2), wind speed (W_S), sunshine hours (S_H), and open pan evaporation (E_P) were collected from the observatory at Crop Research Centre (CRC) of G. B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India. Relative humidity (RH_1) was recorded in the morning at 7 AM and (PM_2) was recorded in the afternoon at 2 PM (Indian Standard Time). The data set consisted of four years of weekly records from January, 2004 to December, 2007. The statistical parameters of the meteorological data are given in Table 1, and cross-correlation between the data sets are represented in Table 2.

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Table 1: The statistical analysis of the climatic data for training, testing and all data sets at Pantnagar.

Statistical parameters	Climatic variables with unit						
	T_{max} (°C)	T_{min} (°C)	RH_1 (%)	RH_2 (%)	W_S (km/h)	S_H (H)	E_{PW} (mm)
Training (156 data form 2004-2006)							
Minimum	14.60	3.70	51.00	15.00	1.00	1.00	0.80
Maximum	41.60	27.90	97.00	78.00	19.8	11.30	17.2
Mean	29.69	17.15	84.44	50.59	5.23	7.21	4.46
SD	5.89	7.10	10.67	16.12	3.39	2.21	2.82
Kurtosis	-0.32	-1.45	1.39	-0.71	3.17	-0.28	2.58
C_s	-0.37	-0.21	-1.50	-0.41	1.59	-0.49	1.35
Testing (52 data from 2007)							
Minimum	17.30	2.60	53.00	8.00	1.70	1.00	1.30
Maximum	40.50	25.50	95.00	84.00	7.70	11.00	10.90
Mean	29.04	16.88	83.58	51.73	4.66	6.40	3.92
SD	5.28	7.11	9.77	18.16	1.80	2.27	2.35
Kurtosis	-0.003	-1.22	3.22	-0.49	1.28	-0.15	1.17
C_s	-0.17	-0.33	-1.94	-0.28	0.02	-0.18	1.32
All data set (208 from 2004-2007)							
Minimum	14.6	2.6	51.00	8.00	1.00	1.00	0.80
Maximum	41.6	27.9	97.00	84.00	19.8	11.3	17.2
Mean	29.53	17.08	84.23	50.88	5.09	7.00	4.32
SD	5.73	7.09	10.44	16.62	3.08	2.25	2.72
Kurtosis	-0.29	-1.39	1.68	-0.63	4.13	-0.33	2.52
C_s	-0.32	-0.24	-1.57	-0.36	1.68	-0.40	1.37

Table 2: Cross-correlation between the climatic data sets at Pantnagar.

	T_{max}	T_{min}	RH_1	RH_2	S_H	W_S	E_{PW}
T_{max}	1.0						
T_{min}	0.778	1.0					
RH_1	-0.741	-0.343	1.0				
RH_2	-0.340	0.276	0.691	1.0			
S_H	0.523	0.0491	-0.562	-0.703	1.0		
W_S	0.461	0.554	-0.359	0.014	0.056	1.0	
E_{PW}	0.856	0.589	-0.872	-0.486	0.479	0.574	1.0

Fig. 1: The location map of the study area.

2. Stephens-Stewart model

Stephens and Stewart (17) gave an equation for evaporation estimation which require only solar radiation and mean air temperature data. The model is:

$$E_p = R_s (a + b T_m) \quad \ldots(1)$$

where, a and b are the fitting constant, RS is daily solar or shortwave radiation (MJ m^2 day^{-1}). If solar radiation, RS, is not measured, it can be calculated with Angstrom formula.

3. Griffith model

Griffiths (6) stated the equation for evaporation based on the mean air temperature and wind speed.

According to this assumption, the following relationship can be written as:

$$E_p = \theta + \alpha_1 T_m + \alpha_2 W_s \quad \ldots(2)$$

where, θ, α_1 and α_2 are the coefficients of linear multiple regression, T_m is mean air temperature (°C).

4. Performance evaluation criteria

The performance of the developed models was evaluated based on various statistical indices, viz. root mean squared error (RMSE), coefficient of efficiency (CE) and correlation coefficient (r). The RMSE evaluates the difference between observed and predicted values of E_p. To assess the goodness of fit between observed and predicted values of E_p, the CE was suggested by Nash and Sutcliffe (10). The value of r measures the degree to which two variables are linearly related. These statistical indices are written as:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(E_{POWi} - E_{PPWi})^2} \quad \ldots(3)$$

$$CE = \left[1 - \frac{\sum_{i=1}^{N}(E_{POWi} - E_{PPWi})^2}{\sum_{i=1}^{N}(E_{POi} - \overline{E_{PO}})^2}\right] \quad \ldots(4)$$

$$r = \frac{\sum_{i=1}^{N}(E_{POWi} - \overline{E_{POW}})(E_{PPWi} - \overline{E_{PPW}})}{\sqrt{\sum_{i=1}^{N}(E_{POWi} - \overline{E_{POW}})^2 \sum_{i=1}^{N}(E_{PPWi} - \overline{E_{PPW}})^2}} \quad \ldots(5)$$

where, E_{POWi} and E_{PPwi} are the observed and predicted E_{PW} values for i^{th} dataset; N is the total number of observations; and $\overline{E_{POW}}$ and $\overline{E_{PPW}}$ are the mean of observed and predicted E_{PW} values, respectively. The models having higher value of r and CE, and lower values of RMSE were adjudged relatively better model for pan evaporation estimation.

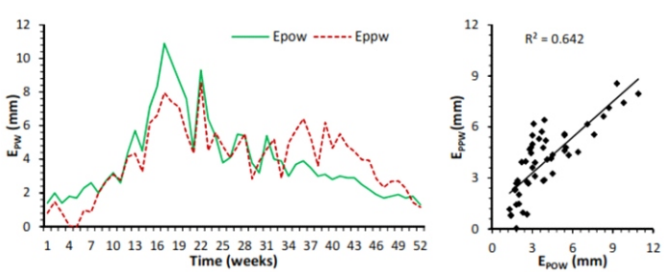

Fig. 2: Observed (E_{POW}) versus predicted (E_{PPW}) values of weekly pan evaporation and their corresponding scatter plot of SSM model during testing phase.

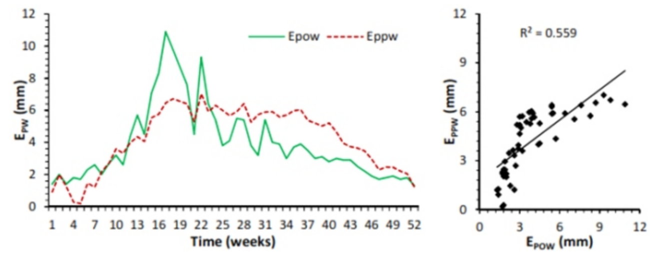

Fig. 3: Observed (E_{POW}) versus predicted (E_{PPW}) values of weekly pan evaporation, and their corresponding scatter plot of GM model during testing phase.

RESULTS AND DISCUSSION

1. Gamma test for selection of model input variables

The selection of model input variables is a very difficult task, especially for nonlinear models such as MLP and CANFIS models. In this study, a new technique, the Gamma test, is used to decide the model input variables (Koncar, 8; Agalbjorn *et al.,* 1) and Remesan *et. al.,* 14 & 15). The few applications of GT in the field of hydrology include water level and flow modeling (Durrant, 4); daily solar radiation prediction , daily pan evaporation estimation , Runoff prediction and daily suspended sediment load prediction .

The available meteorological data set was partitioned into two sets: (a) first set consisting of data from January 1, 2004 to December 31, 2006 (156 data), was used for training/calibration of the models; and (b) second set consisting of data from January 1 to December 31, 2007 (52 data), was used for testing/validation of models. Various combinations of input variables of meteorological data including maximum and minimum air temperature (T_{max} and T_{min}), relative humidity (RH_1 and RH_2), wind speed ((W_s), and sunshine hours (S_H) were used to estimate E_P at weekly time step as output for models at Pantnagar. The performance of the developed models during validation phase was judged on the basis of root mean squared error (RMSE), coefficient of efficiency (CE) and correlation coefficient (r).

2. Performance of Climate based models

The values of statistical indices for climate based model (Stephens-Stewart model and Griffith's model) are given in Table 3. The table indicates that the values of RMSE is 1.399 mm/week, CE as 0.637 and r as 0.801 for Stephens-Stewart model during the test period, whereas the values of RMSE is 1.582 mm/week, CE is 0.537and r is 0.747 for Griffith's model during the test period, which reveals that the Stephens-Stewart model performed better than the Griffith's model. The equations for Stephens-Stewart and Griffith's model with their intercept and regression coefficients are expressed as:

$$E_p = 0.379 - 0.1771 R_s + 0.0151 T_{mean} * R_s \quad ...(6)$$

$$E_p = -3.504 + 0.307\, T_{mean} + 0.146\, W_s \quad ...(7)$$

The predicted evaporation (E_{PPW}) and its comparison with observed evaporation(E_{POW}) for both Stephens-Stewart and Griffith's model during testing period are plotted in Fig. 2 and Fig. 3 respectively.

Table 3: RMSE, CE and r values for climate based models during testing period at Pantnagar.

Model Name	RMSE	CE	r
Stephens-Stewart model	1.399	0.637	0.801
Griffith's model	1.582	0.537	0.747

CONCLUSIONS

The objective of this study was to investigate the potential of Stephens-Stewart and Griffith's model in estimating the weekly pan evaporation at Pantnagar, Uttarakhand, India. In this study, a new technique, Gamma test was used to identify the best combination of input variables for Stephens-Stewart and Griffith's model before the start of the modelling. The Gamma test found out the best model out of five developed models with the input variables: maximum and minimum air temperature, relative humidity values in the morning and afternoon, wind speed and sunshine hours. The performance of Stephens-Stewart and Griffith's model were judged on the basis of root mean squared error (RMSE), coefficient of efficiency (CE) and correlation coefficient (r) during validation phase. The models with six input variables such as T_{max}, T_{min}, RH_1, RH_2, W_s and S_H gave better estimates for the Stephens-Stewart and Griffith's model in testing phase. Thus the Gamma test has the capability to select the best combination of input variables with minimum efforts and time which is very much useful for a researcher/scientist/modeller. The performance of Stephens-Stewart model was found better than Griffith model, therefore, Stephens-Stewart model with six input variables (T_{max}, T_{min}, RH_1, RH_2, W_s, S_H) may be used for estimation of weekly pan evaporation at Pantnagar.

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