

A preliminary study of potential evapotranspiration by Penman's method

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ABSTRACT. Potential evapotranspiration was calculated by Penman's equation under different meteorological conditions obtained at diverse climatic stations, classified according to Thornthwaite. The relative importance of the aerodynamic and energy terms in the equation at different climatic stations was also discussed. Comparison of potential evapotranspiration values from Penman's as well as from Pan data also has been made and the correction factors over the entire climatic spectrum have been worked out and discussed.

1. Introduction

Of the many processes of hydrologic and agricultural significance, the mechanism of the return of moisture to the atmosphere from natural surfaces known as evapotranspiration is not well understood even today, because of the difficulties in quantitative assessment of evaporation from land surfaces. This is mainly due to the fact that water on evaporation rapidly mixes with the other gases of the atmosphere and is transported over long distances and to great heights.

Potential evapotranspiration (abbreviated as P. E.) is the amount of water loss taking place from an extensive water surface or a green crop completely shading the ground and never short of water (Thornthwaite 1948). In the present paper it is proposed to compute monthly P. E. values by Penman's method (1948) for various stations situated in diverse climatic regions classified according to Thornthwaite's classification (Subrahmanyam 1956), and assess the relative importance of the two terms (aerodynamic and energy) in the equation. Also it is intended to compare the P.E. values by Penman's formula with Class 'A' Pan evaporation (converted into P. E.) to find out the correction factors under diverse climatic conditions.

2. Method

Penman's formula used for calculations of evaporation is —

$$E = \left[\frac{\Delta}{\gamma} \left\{ (1-r)R_A \left(u + b \frac{n}{N} \right) - \sigma T^4 (0.56 - 0.092 \sqrt{e_d}) \left(0.10 + 0.90 \frac{n}{N} \right) \right\} + 0.35(e_a - e_d) \left(1 + \frac{u}{100} \right) \right] / \left(\frac{\Delta}{\gamma} + 1 \right)$$

where,

E —The potential evaporation in mm/day with surface reflectivity, r , of 5%, corresponding to open water;

R_A —Incident radiation outside the atmosphere on a horizontal surface expressed in mm of evaporable water per day;

n —The duration of sunshine during the interval of the estimate;

N —The maximum duration during the same time;

σ —The Stefan—Boltzman constant;

T —The temperature in degrees absolute;

e_d —The vapour pressure in mm of Hg;

e_a —The saturation vapour pressure in mm of Hg;

u —The daily wind travel at 2 m above the ground in statute miles;

γ —The psychrometric constant;

Δ —The rate of change with temperature of the S.V.P.;

Δ/γ is therefore dimensionless since both are in mb/°C.

The first part of the numerator, the energy budget (within middle brackets) estimates net radiation by subtracting the amount of energy reflected back into space from the incoming global radiation. The second part, the aerodynamic term (Brutsaert 1965) estimates the advected drying power of the air in terms of its saturation deficit, and of its movement. The relative importance of the two terms is adjusted by the ratio which increases with temperature.

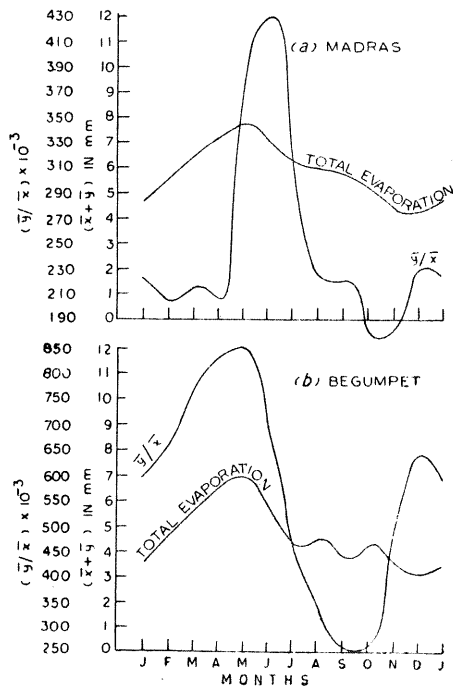


Fig. 1. (a & b). March of evaporation and ratio of aerodynamic to energy terms

3. Data used

The stations chosen for the present study and their climatic category as per Thornthwaite's classification (Subrahmanyam 1956) are given below :

Station	Climatic type	Denoted as
Jodhpur	Arid	A.
Hyderabad	Semi Arid	S.A.
Visakhapatnam	Do.	S.A.
Poona	Do.	S.A.
New Delhi	Do.	S.A.
Madras	Dry Sub Humid	D.S.H.
Nagpur	Do.	D.S.H.
Calcutta	Moist Sub Humid	M.S.H.
Gauhati	Humid	H.
Shillong	Per Humid	P.H.

In the present study data for the 3 years, 1964-1966 was used as obtained from the records of the India Meteorological Department.

r is a constant in the formula and is taken to be 0.05 since the surface reflectivity of open water is considered to be 5 per cent. The constants a and b in the equation vary from station to station and the values as derived by Gangopadhyaya, George and Datar (1970) are employed in the present study. The values of R_1 in the equation are to be converted to mm/day. For this, the values given in Smithsonian Tables for

specific dates throughout the year are plotted on a graph and from the graph the mean monthly values are extracted by equal triangulation method. These are expressed in cal/cm²/min which are converted into the above units by dividing with the latent heat of vapourization.

n , the number of actual sunshine hours for the ten stations are collected from the meteorological records, and N , the possible hours of sunshine duration are taken from the Smithsonian Tables.

The values of σT^4 obtained from the Smithsonian Tables for the corresponding mean monthly temperatures culled from the climatological tables are converted into mm of evaporable water per day by dividing with the latent heat of evaporation.

Actual vapour pressure e_d is obtained by the conventional method using dry and wet bulb temperatures taken from climatological records. Where wet bulb temperature is not available, the mean monthly values of R. H. are collected and from the R. H. and dry bulb temperature, the wet bulb is extracted and the rest is done as usual. e_a , the S. V. P. is obtained from the Smithsonian Tables corresponding to the temperature values. Both e_a and e_d are expressed in mm of Hg, utilising respective altitude tables.

The wind measurement needed here is daily wind run in miles at 2 m a.g.l. Records of it were few and hence these values were obtained by reducing to 2 m height, the P. T. anemograph values by using the logarithmic wind law ;

$$\frac{u_1}{u_2} = \left(\frac{Z_1}{Z_2} \right)^{0.3} \quad (\text{Kohler } et \text{ al. } 1959)$$

In two cases, Shillong and Gauhati, where the P. T. anemograph was not installed the readings of the cup anemometer were taken and reduced to 2 m a. g. l. The values thus obtained are later converted to miles/day.

The values of the constant Δ/γ are taken from Thornthwaite's (1967) paper for temperatures 16°C, values are obtained from extrapolated graph. The evaporation values thus obtained are multiplied by a factor of 0.7 to convert them into potential evapotranspiration (Penman 1963).

Investigations in U. S. S. R. indicate that evaporation obtained from a 20 m² tank can often be taken as equivalent to potential evapotranspiration (Konstantinov 1963). Studies conducted with different types of evaporimeters in India show that 20 m² tank evaporation

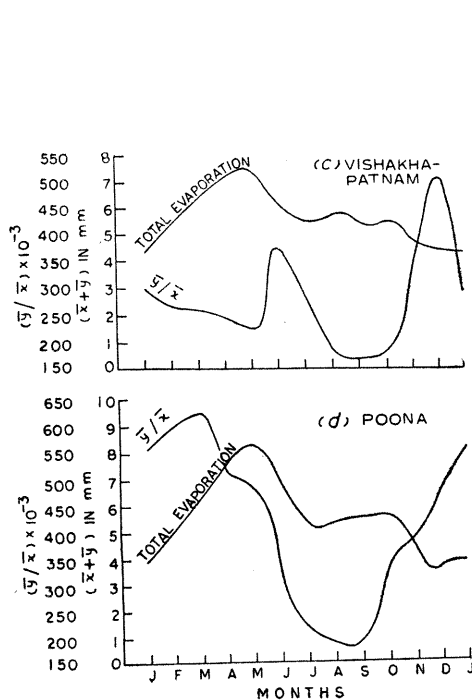


Fig. 1 (c & d)

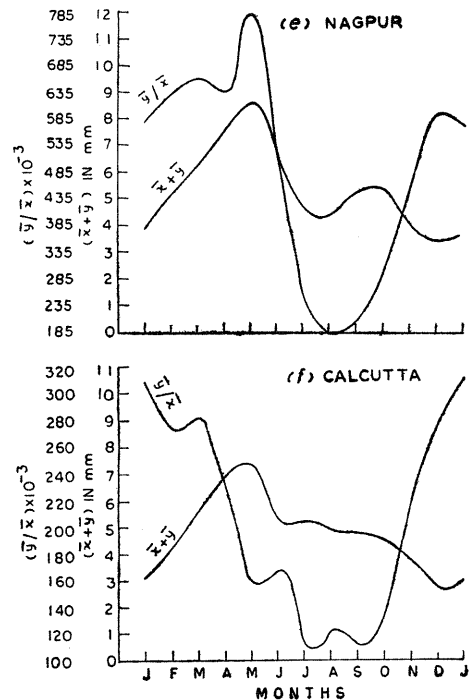


Fig. 1 (e & f)

March of evaporation and ratio of aerodynamic to energy terms

can be calculated from a knowledge of Pan evaporation data (Final report—PL 480 project, Gangopadhyaya 1969). This has been taken advantage of in the present investigation and the values of evaporation of non-rainy days only from Class 'A' Pan covered with wire mesh are multiplied by a factor of 0.8 for February and March, 0.75 for April and May and 0.9 for June and 1.0 for the rest of the period to obtain potential evapotranspiration.

4. Results and discussions

The ratio of aerodynamic to energy terms and total evaporation from Penman's equation are represented graphically in Fig. 1. Generally it can be seen that evaporation gradually increases from January and attains a peak value in summer and decreases later during monsoon season. After the withdrawal of the monsoon, evaporation shows a slight rise due to clearing of skies and then decreases gradually due to low air temperatures. The figures also show that the march of the ratio of aerodynamic to energy terms and total evaporation are not identical but more or less out of phase. In many cases it is seen that the two peaks are clearly separated and the high evaporation rates despite low ratios is probably

due to higher contribution by the energy term in relation to aerodynamic term.

In order to compare the evaporation values obtained by Penman's formula with that of readily available Pan evaporation data both the values are converted into potential evapotranspiration and plotted in Fig. 2. The unit slope line drawn prominently shows that in either arid (Jodhpur) or semi-arid (Poona, Visakhapatnam, Hyderabad and New Delhi) potential evapotranspiration as deduced from Pan is higher than that calculated by Penman, presumably due to 'Oasis' effect (Penman 1956). As one moves into the moist climatic zones, the proximity between the two values also is gradually reached which can be clearly seen from the march of the graphs of Madras (dry sub-humid), Calcutta (moist sub-humid), Gauhati (humid) and Shillong (per humid). The correction factors (difference between potential evapotranspiration deduced from Penman equation and Pan evaporation) for different stations were averaged and plotted against the climatic zones in order to understand the variation with climate and shown in Fig. 3. Generally it can be seen that in all months the correction factors are maximum in the arid/semi-arid regions

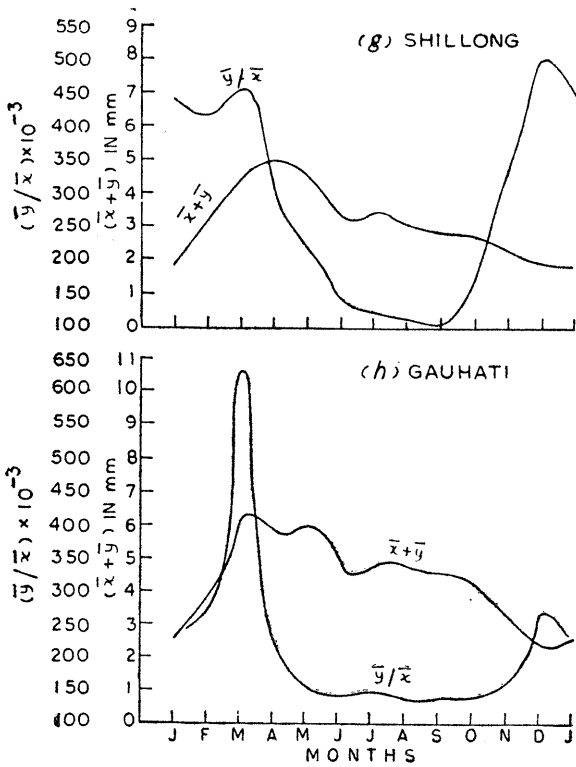


Fig. 1 g & h)

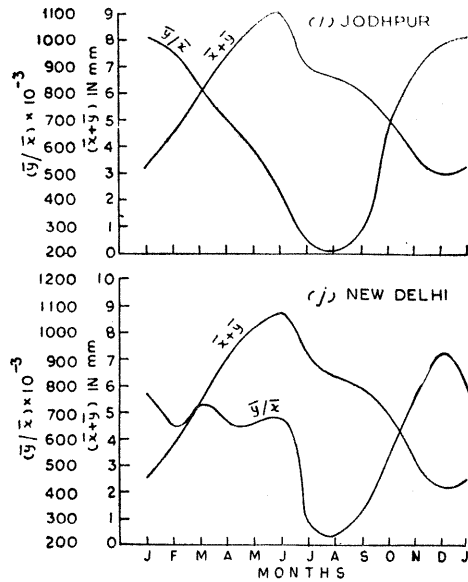


Fig. 4 (i & j)

March of evaporation and ratio of aerodynamic to energy terms

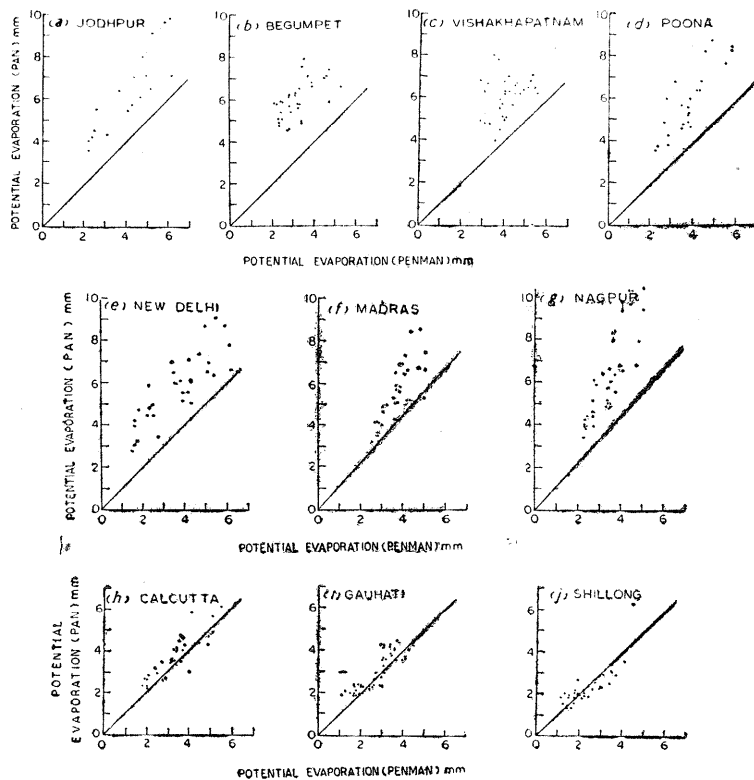


Fig. 2. Comparison of potential evapotranspiration by Pan and Penman methods

and gradually decrease towards per humid regions. Even in the arid/semi-arid zones the correction factors are maximum in the summer months and minimum in monsoon. After the withdrawal of the monsoon, these correction factors again show an increase. While the dry sub-humid zones have always a negative correction factor, with a minimum in the winter and a maximum in June the moist sub-humid regions have negative correction from June to January and then change sign and continue to be so till the onset of the monsoon. In the latter the correction factors always tend towards zero except in a month or two.

The humid region (Gauhati) also follows the same pattern of correction factor as that of moist sub-humid zone but the magnitude of the correction factors is less. In contrast to humid regions the magnitude and duration of correction factor is positive and large at per humid station (Shillong) and the negative factors although exist are few and tending to zero.

5. Conclusion

The present study is a preliminary attempt to estimate potential evapotranspiration by Penman's method under different meteorological conditions at diverse climatic stations classified according to Thornthwaite. Of the two terms in the equation the study shows that major contribution to evaporation comes from the energy term only. Comparison of potential evapotranspiration from Penman's equation and Pan data shows significant departures in the arid region of the climatic spectrum while at the other the departures tend towards a minimum. The variation of correction factors in different months at various climatic stations also shows that the correction factors are higher at arid/semi-arid and minimum at humid/per humid zones. Thus the study points out that the potential evapotranspiration values as estimated by Penman's method need modification for different climatic zones ; the quantitative estimation of which necessitates the extension

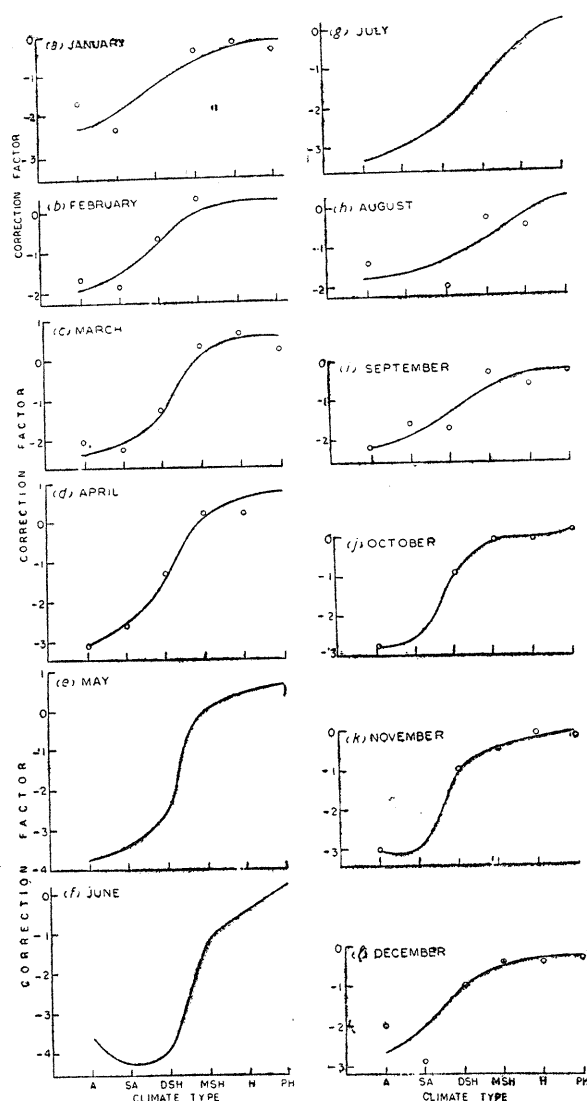


Fig. 3. Variation of correction factors in different months

of the present study to significant number of stations under each climatic category over a long period.

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