Testing and Modification of Penman's Evaporation Model for Estimating Class A Pan Evaporation for Udaipur Region, India*

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Abstract (English): Evaporation from the surface of the earth to the atmosphere concerns workers from a wide range of disciplines. Although much theoretical study and experimental work have been done in this direction, there is still much scope in this field. None of the methods to determine the rate of evaporation have yet produced a complete answer that meets the need of engineers and others requiring quantitative results. This paper summarises the test results of evaporation rate obtained by using the original evaporation model developed by Penman and also the results obtained by the modified model. It was found that the results obtained by use of the modified model were very close to the observed values of the evaporation measured by USWB Class A Pan.

Results indicated that variations between the estimated and observed rates of evaporation were -7.55%, -26.81%, -5.29% and -13.45% for Rabi, Summer, Kharif and yearly estimates respectively while using the original model. After modification, the variations between the estimated and observed rate of evaporation were found to be +2.96%, -9.89%, +5.64% and -0.86% respectively for the above mentioned periods. The test results showed that the modified model could be used with a higher degree of confidence in Udaipur region of India.

Résumé (French): L evaporation a partir de la surface du sol dans l atmosphere interesse des chercheurs de plusieurs disciplines. On a bien e labore beaucoup de travaux theorigues et experimentaux mais il est necessaire d'ecrire 'davantage dans ce domaine. Aucune des methodes qui determinent le degre d' evaporation ne repondent completement aux demandes et besoins des ingeniers et autres qui exigent des resultats quantitaties. Cet article rassemble les resultats du degre d evaporation obtanus par l'utilisation du modele original d' evaporation developpe par monsieur Penman et aussi ceux obtenus par la validite et la modification du modele original. Nous avons etabl, que les resultats obtenus par l'utilisation du modele modifie ont ete tres proches des valeurs actuelles d'evaporation mesurees a l'aide de l'evaporimeter standard USWB Class A cuve.

Les resultats indiquent que les differences entre le degre d'evaporation estime et le degre d'evaporatin observe ont ete, de -7.55%; -26.81%; -5.29% et -13.45% pour la saison "Rabi"; la saison d'ete la saison "Kharif" et pour tout l'annce estimees respectivement pendant l'utilisation du modele original. Cependant, apres le temps d'utilisation du modele modifie nous avons obtenu les variations par rapport aux periodes de l'annee : +2.96%; -9.89%; +5.64% et -0.86%. En outre, la valeur du degre d'evaporation pour la saison Rabi de L'annee 1993, estimee a l'aide du modele modifie, se trouvait etre proche de celle observee. Les resultats de notre test ont montre que le modele modifie pourrait etre utilise avec la haute probabilite statistique.

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Introduction

Evaporation of water plays an important part in most human activity designed to satisfy basic needs. The rate of evaporation from the open water surfaces can be measured by evaporimeters or open pans. However, pan evaporation data are not always available for a particular region. Under such conditions prediction equations are often used for the purpose. Whatever be the approach of estimation of evaporation, efficient design and operation of irrigation and related projects depend on an awareness of the quantity of water that is lost through the process of evaporation (Blaney and Criddle 1958). Many models to estimate the rate of evaporation have been developed by various workers and scientists in various parts of the world. However, quite often the same are used in areas with climatic characteristics different from the areas in which the models were originally developed. This necessitates adequate testing of the models regarding their validity to be used under another climatic condition, In Udaipur region of India too where such models were in use were not adequately tested and validated. It was therefore, felt necessary to determine the comparative reliability of five most commonly used models so as to make them useful for future predictions. This paper however, summarises test results of only Penman's model, which is widely used for estimating evaporation rate due to its inherent capacity to account for radiation and aerodynamic aspects. This is because evaporation is a direct function of radiation and drying capacity of air (Al-Nakshabandi et al. 1974). The Penman model was thus tested and validated with the help of a twenty years data-base (1973-1992). The validated model was then use to re-estimate the evaporation for the seasons under consideration and for the whole year alike. Further, the model was used to predict the rate of evaporation for the Rabi season of the crop year 1992-93. It was found that the modified model predicted value was very close to the observed value of evaporation. The main objective of this paper is therefore, to present the test results obtained by use of the original Penman model and the modified Penman model and to discuss possibilities of improvement in this direction.

Materials and Methods

The study was conducted at the College of Technology and Agricultural Engineering, Udaipur. The data required for the study were collected from the Agricultural Meteorological Station located at the Demonstration Farm of the college with good fetch in all directions. It is however, advisable to collect data from a network of stations for better accuracy and representation. The area falls under the sub-humid region of the agro-climatic zone IV-A of the state of Rajasthan in India and is situated between 24 35 N latitude and 73 42 E longitude at an altitude of about 582.17 m above mean sea level. The average rainfall in the region is about 662.0 mm and more than 80.0% of this amount is received during the Kharif season alone due to the influence of South-West monsoon. Mean values of different meteorological parameters determined on the basis of past twenty years data (1973-1992) on seasonal as well as on annual basis are presented in Table 1

Table1. Seasonal and annual mean values of different meteorological parameters (1973-1992)

Parameters Period	Temperature (°C)	Relative humidity (%)	Sunshine (hrs/day)	Wind velocity (km/hr)	Evaporation (mm/day)
Rabi season	17.91	54.79	9.41	3.66	3.71
Summer season	27.90	34.23	10.31	7.07	10.11
Kharif season	27.12	66.46	6.87	6.25	5.67
Whole year	23.50	55.40	8.60	5.40	5.80

The soils of the area fall under the class sandy-clay-loam with a bulk density in the range of 1.57gm/cc to 1.62 gm/cc at depths 0-30 cm and 30-60 respectively. Infiltration rate was found to be about 2.2 cm/hr while the field capacity was found to be 21.0% on dry weight basis. Electrical conductivity was found to be 0.18 m mhos/cm at 25 C and soil pH was found to be 8.7.

Regression Analysis

Since a physical basis was needed for predicting evaporation in the region, multiple linear regression analysis was carried out and suitable regression models were developed both for seasonal prediction and yearly prediction with evaporation as the predicted variable and temperature, relative humidity, sunshine and wind velocity as predictor variables. For this purpose, the whole year was divided into three seasons prevailing in the region on the basis of standard weeks as given below.

Rabi season	42^{nd} week (mid October)	to	11^{th} week (mid March)
Summer season	11^{th} week (mid March)	to	22^{nd} week (May end)
Kharif season	22^{nd} week (May end)	to	42^{nd} week (mid October)

Regression analysis was carried out to develop seasonal and yearly prediction equations. Regression coefficients, standard errors and constant values were determined and underlying regression models developed for each case. Computed 't' values were compared with standard 't' values to examine significance.

The Penman Model

This model, developed by Penman in 1948 combines the energy budget and mass transfer models. The method combines fundamental physical principles and empirical concepts based on meteorological observations and hence is quite reliable. The model was developed for humid area not far from the ocean and essentially covered with growing vegetation. For free water surface evaporation, the model may be mathematically represented as follows:

$$\mathbf{E} = [\Delta /(\Delta+\gamma)]\, \mathbf{Rn} + [\gamma/(\Delta+\gamma)]\, \mathbf{Ea}$$ where,

E = Open water surface evaporation, mm/day

Δ = Slope of saturated vapour pressure curve of air at mean air temperature, mm Hg/ ^{o}C

γ = Psychrometer constant, mm Hg/ ^{o}C

$\Delta/(\Delta+\gamma)$ = **$[1-\{\gamma/(\Delta+\gamma)\}]$.** This varies with air temperature and elevation of the region

$\mathbf{R_n}$ = Daily net radiation at earth surface, mm/day

= $(1-\alpha)(0.18+0.55n/N)R_a - \sigma T_a^4(0.56-0.092\sqrt{e_d})(0.1+0.9n/N)$

α = Short wave reflectance (Albedo) = 0.05 for open water surface

n = Actual duration of bright sunshine, hrs/day

N = Maximum possible duration of bright sunshine, hrs/day

$\mathbf{R_a}$ = Mean extraterrestrial radiation, mm/day

σ = Stephen-Boltzman constant = 2.0510^{-9} mm/day

$\mathbf{T_a}$ = Mean air temperature, ^{o}K = (273+ ^{o}C)

$\mathbf{E_d}$ = Saturated vapour pressure at mean dew point temperature (actual vapour pressure in the air), mm Hg

$\mathbf{E_a}$ = Drying power of air, mm/day = $0.35(e_s - e_d)(1.0+W_2/160)$

$\mathbf{e_s}$ = Saturated vapour pressure at mean air temperature, mm Hg

$\mathbf{W_2}$ = Mean wind velocity at 2.0m above ground, km/day

Results and Discussion

Test results of regression analysis

For the purpose of the present study multiple linear regression analysis was carried out to establish relationship between the predicted variable evaporation and the predictor variables, temperature, relative humidity, sunshine and wind velocity at 95.0% level of confidence. Multiple linear regression models were only developed for the purpose of the study, since the use of complex logarithmic, quadratic and cubic regression models did not significantly improve the estimation of evaporation as calculated from a linear regression (Baier et al. 1965). The test results are presented in Table 2 to Table 5.

Table 2. Meteorological parameters influencing evaporation and their statistical values (Rabi season)

Predictor variable, Xi	Regression coefficient, Bi	Standard error	t-value
Temperature(T), °C	0.09	0.02	3.95
Relative humidity(H), %	-0.08	0.02	-4.27
Sunshine(S), hrs/day	0.67	0.22	3.10
Wind velocity at 3.0m(W), km/hr	0.26	0.13	2.05
Constant (C)	-0.44	3.02	-0.14

Coefficient of correlation, R(Adj.) = 0.9873	Coefficient of determination, R^2(Adj) = 0.9747
Standard error = 0.18 mm/day	Predicted variable : Evaporation(E), mm/day

Prediction model (Rabi season), E = C + f(B,X) = -0.44 + 0.09(T) - 0.08(H) + 0.67(S) + 0.26(W)

Table 3. Meteorological parameters influencing evaporation and their statistical values (Sum. season)

Predictor variable, Xi	Regression coefficient, Bi	Standard error	t-value
Temperature(T), °C	0.43	0.06	7.51
Relative humidity(H), %	-0.10	0.02	-5.57
Sunshine(S), hrs/day	-0.45	0.28	-1.63
Wind velocity at 3.0m(W), km/hr	0.49	0.16	3.03
Constant (C)	2.88	2.86	1.01

Coefficient of correlation, R(Adj.) = 0.9972	Coefficient of determination, R^2(Adj.) = 0.9942
Standard error = 0.16 mm/day	Predicted variable : Evaporation(E), mm/day

Prediction model (Summer season), E = C + f(B,X) = 2.88 + 0.43(T) - 0.10(H) - 0.45(S) + 0.49(W)

Table 4. Meteorological parameters influencing evaporation and their statistical values (Kharif season)

Predictor variable, Xi	Regression coefficient, Bi	Standard error	t-value
Temperature(T), °C	0.56	0.09	6.54
Relative humidity(H), %	-0.13	0.03	-5.40
Sunshine(S), hrs/day	-0.07	0.13	-0.55
	0.15	0.11	1.32
Constant (C)	-1.12	3.25	-0.34

Coefficient of correlation, R(Adj.) = 0.9906	Coefficient of determination, R^2(Adj.) = 0.9812
Standard error = 0.36 mm/day	Predicted variable : Evaporation(E), mm/day

Prediction model (Kharif season), E = C+f(B,X) = -1.12 + 0.56(T) - 0.13(H) - 0.07(S) + 0.15(W)

Table 5. Meteorological parameters influencing evaporation and their statistical values (Whole year)

Predictor variable, Xi	Regression coefficient, Bi	Standard error	t-value
Temperature(T), °C	0.19	0.04	4.78
Relative humidity(H), %	-0.03	0.02	-1.56
Sunshine(S), hrs/day	0.63	0.14	4.66
Wind velocity at 3.0m(W), km/hr	0.87	0.12	7.25
Constant (C)	-7.18	2.42	-2.97

Coefficient of correlation, R(Adj.) = 0.9934	Coefficient of determination, R^2(Adj.) = 0.9869
Standard error = 0.36 mm/day	Predicted variable : Evaporation(E), mm/.day

Prediction model (Whole year), E = C + f(B,X) = -7.18 + 0.19(T) - 0.03(H) + 0.63(S) + 0.87(W)

It is evident from the above analysis that there exists a strong relationship between the selected meteorological parameters and evaporation as indicated by the coefficients of correlation and determination. The standard errors obtained indicate that the results predicted by the regression models would contain error ranging from 0.16 mm/day to 0.36 mm/day.

Test results of Penman's model

Estimated values of each of the components of the model and the resulting rates of evaporation on seasonal and yearly basis are presented in Table 6

Table 6 Evaporation estimated by Penman's model

Components → Period ↓	(1-α)	(n/N)	(0.18+0.55 n/N)	Extraterrestrial Radiation, Ra (mm/day)	Ta^4 (mm/day)
1	2	3	4	5	6
Rabi season	0.95	0.84	0.64	11.30	14.32
Summer season	0.95	0.81	0.63	15.72	16.40
Kharif season	0.95	0.54	0.48	14.98	16.23
Whole year	0.95	0.71	0.57	13.67	15.46

Saturated vapour pressure at dew point temperature, e_d (mm Hg)	(0.56-0.092$\sqrt{e_d}$)	(0.1+0.9n/N)	Net Radiation, R_a (mm/day)	Δ/(Δ+γ)	ΔRn/(Δ+γ)
7	8	9	10	11	12
8.43	0.29	0.86	3.30	0.67	2.21
9.65	0.27	0.83	5.73	0.77	4.41
17.85	0.17	0.59	5.20	0.78	4.06
12.01	0.24	0.74	4.66	0.73	3.40

Wind velocity at 2.0 m, W_2 (km/day)	Wind function, f(w) =0.35(1.0+W_2/160)	Saturated vapour pressure at mean air temperature, e_s (mm Hg)	Vapour pressure deficit, (e_s-e_d) (mm Hg)	Drying capacity of air, Ea (mm/day)
13	14	15	16	17
82.01	0.53	15.38	6.95	3.68
158.11	0.77	28.20	18.55	12.99
140.00	0.66	26.85	9.00	5.94
120.96	0.62	21.68	9.67	6.00

$[\gamma/(\Delta+\gamma)]$	$[\gamma E_a/(\Delta+\gamma)]$	Estimated evaporation, E (mm/day)	Observed pan evaporation, Ep (mm/day)	Variation (%)
18	19	20	21	22
0.33	1.22	3.43	3.71	-7.55
0.23	2.99	7.40	10.11	-26.81
0.22	1.31	5.37	5.67	-5.29
0.27	1.62	5.02	5.80	-13.45

It is evident from Table 6 that the rate of evaporation estimated with the help of the combination model lags behind the observed pan evaporation rate for all the seasons and over the year alike. These variations clearly indicated that the modification of the model was necessary to make it valid to be used in Udaipur region. Now, looking into the original basis of the model in light of Penman's concept we find that the model contains considerable empiricism in terms of estimate of net radiation, omission of soil heat flux, nature of the wind function and in the use of daily or other average values for air temperature, relative humidity and wind function where, in principle instantaneous values are required. To start with the radiation term, if observations of net radiation are made directly over the water surface of interest, the term presents no problem. Though Penman's derivation takes into account the effect of any difference between air and water temperature in evaporation and advective heat transfer, his method of computing net radiation assumes that the emitted radiation for the water body is a function of the air temperature incorporating significant error in the estimate. For the purpose of the present study therefore, a widely used approximated expression for the net radiation term was used that incorporates the difference between incident and reflected radiation. Studies by Permele and Mcguinness (1974) indicated that the expression could be used with a fair degree of accuracy provided other observations are made accurately in evaluating the term. Penman (1956) while making a survey of evaporation based on the fundamental works observed that the energy-balance method approaches the ideal in theory, but in practice there are great difficulties in measuring some of the terms other than evaporation and for the sensible heat transfer to the air it is necessary to fall back on aerodynamic ideas. Kohler (1967) presented a modified method over the original Penman model from network observations in air temperature, dew point, wind velocity and net radiation and expressed that the accuracy of Penman method depended on the applicable mass transfer wind function.

Validation of the model

For validation of the model, emphasis was laid on the aerodynamic term rather than on the radiation term. As far as the aerodynamic term is concerned, the empirical constants in the term were determined based on observations of evaporation from a sunken pan, 76.20 cm in diameter rather than from a standard United States Weather Bureau Class A pan, 122.0 cm in diameter. This in turn means that the same wind function can not be used under all conditions. Singh et al. (1981) emphasised the importance of using a wind function applicable to the surface under consideration and suggested the use of a wind function that is based on local observed data on wind run. The aerodynamic term however, is not only dependent on the empirical constants but also on the pan factor. Hence, it was felt necessary to modify the pan factor too to represent the standard United States Weather Bureau Class A pan used for the purpose of the study. It may be recalled here that pan factor of 0.35 was suggested by Penman based on his observation of evaporation from a sunken pan. Thus, keeping in view the importance of the pan factor, and a locally developed wind function, a regression analysis was further carried out to determine the exact value of the pan factor and the values of the empirical constants associated with the wind function. The analysis gave rise to the following modified values of the pan factor and the empirical constants.

Pan factor = **0.30**
Empirical constants = **1.00 and 0.0164**
Modified wind function, f(w) = **$0.30(1.0 + 0.0164W_2)(e_s-e_d)$**

All other terms in the model remain the same bearing the same units of measurement as earlier.

Testing the validity of the modified model

To check the suitability of the model, the model was used to re-estimate the rate of evaporation on seasonal and yearly basis. Test results are presented in Table 7

Table 7 Evaporation estimated by modified Penman model

Components → Period ↓	$(1-\alpha)$	(n/N)	(0.18+ 0.55 n/ N)	Extraterrestrial Radiation, Ra (mm/day)	σTa^4 (mm/day)
1	2	3	4	5	6
Rabi season	0.95	0.84	0.64	11.30	14.32
Summer season	0.95	0.81	0.63	15.72	16.40
Kharif season	0.95	0.54	0.48	14.98	16.23
Whole year	0.95	0.71	0.57	13.67	15.46

Saturated vapour pressure at dew point temperature, e_d (mm Hg)	$(0.56-0.092\sqrt{e_d})$	(0.1+0.9n/N)	Net Radiation, R_a (mm/day)	$\Delta/(\Delta+\gamma)$	$\Delta Rn/(\Delta+\gamma)$
7	8	9	10	11	12
8.43	0.29	0.86	3.30	0.67	2.21
9.65	0.27	0.83	5.73	0.77	4.41
17.85	0.17	0.59	5.20	0.78	4.06
12.01	0.24	0.74	4.66	0.73	3.40

Wind velocity at 2.0 m, W_2 (km/day)	Wind function, f(w) $=0.35(1.0+W_2/160)$	Saturated vapour pressure at mean air temperature, e_s (mm Hg)	Vapour pressure deficit, (e_s-e_d) (mm Hg)	Drying capacity of air, Ea (mm/day)
13	14	15	16	17
82.01	0.70	15.38	6.95	4.87
158.11	1.10	28.20	18.55	20.41
140.00	0.98	26.85	9.00	8.82
120.96	0.90	21.68	9.67	8.70

$[\gamma/(\Delta+\gamma)]$	$[\gamma E_a/(\Delta+\gamma)]$	Estimated evaporation, E (mm/day)	Observed pan evaporation, Ep (mm/day)	Variation (%)
18	19	20	21	22
0.33	1.61	3.82	3.71	+2.96
0.23	4.70	9.11	10.11	-9.89
0.22	1.94	5.99	5.67	+5.64
0.27	2.35	5.75	5.80	-0.86

It is evident from the results presented above that the modifications made in the model have greatly reduced the variations between the estimated rate of evaporation and the observed rate of evaporation. Variations have been found to be +2.96%, -9.89%, +5.64% and -0.86% as against -

7.55%, -26.81%, -5.29% and -13.45% for the periods mentioned earlier. These variations are well within the acceptable range. The results indicate that the variations in the previous case were due mainly to the use of an inappropriate wind function. It however, does not undermine the importance of the radiation term, since Jensen (1963) indicated that reasonably reliable estimates of evaporation could be made using solar radiation as the main parameter. It may be noted here that the development of a single wind function suitable for all seasons is not an easy task based only on wind velocity data (Bavel 1966). It is therefore, stressed that any further improvement in the wind function term must be made by taking into account the surface roughness factor, atmospheric stability and history which means a function of the roughness to the windward side. Slight modification may also be made by determining the value of the saturated vapour pressure at the temperature of the evaporating water surface. Further, accuracy of the radiation term can be improved if an incident all-wave radiometer is used to determine the difference between incident and reflected radiation. Since the reflectivity for short-wave radiation depends upon the sun altitude, the amount and type of clouds, the value of α= 0.05 may also need modification.

Prediction of evaporation rate for Rabi season (1992-1993)

As discussed earlier, the Penman model was modified based on a data-base of twenty years. Though the model was properly validated, it was felt necessary to apply the same for future prediction and hence, the rate of evaporation for Rabi season of the crop-year 1992-93 was predicted with the help of the modified model. The same is presented in Table 8.

Table 8 Evaporation predicted by modified Penman model, Rabi season (1992-93)

Components → Period ↓	(1-α)	(n/N)	(0.18+ 0.55 n/ N)	Extraterrestrial Radiation, Ra (mm/day)	Ta^4 (mm/day)
1	2	3	4	5	6
Rabi season	0.95	0.80	0.62	11.30	14.29

Saturated vapour pressure at dew point temperature, e_d (mm Hg)	(0.56-0.092$\sqrt{e_d}$)	(0.1+0.9n/ N)	Net Radiation, R_a (mm/day)	$\Delta/(\Delta+\gamma)$	$\Delta Rn/(\Delta+\gamma)$
7	8	9	10	11	12
8.33	0.29	0.82	3.26	0.667	2.17

Wind velocity at 2.0 m, W_2 (km/day)	Wind function, f(w) =0.35(1.0+W_2/160)	Saturated vapour pressure at mean air temperature, e_s (mm Hg)	Vapour pressure deficit, (e_s-e_d) (mm Hg)	Drying capacity of air, Ea (mm/day)
13	14	15	16	17
63.61	0.61	15.25	6.92	4.22

[$\gamma/(\Delta+\gamma)$]	[$\gamma E_a/(\Delta+\gamma)$]	Estimated Evp., E (mm/day)	Observed Pan Evp., Ep (mm/day)	Variation (%)
18	19	20	21	22
0.333	1.41	3.58	3.42	+4.60

From the results presented above, it is evident that the modified model is able to predict the rate of evaporation with a fair degree of accuracy. The variation between the predicted and the observed rate of evaporation is about +4.6% indicating an overestimation of about 0.16 mm/day which is well within the acceptable range. It is obvious that the variation is due mainly to the vapour pressure deficit term and the accuracy of the radiation term to predict radiation over an area. The vapour pressure deficit term needs to be determined by finding the difference between the saturated vapour pressure at temperature of the evaporating surface and the saturated vapour pressure at mean dew point temperature. Further, while determining the value of the term 'σTa^4', absolute temperature (T_a) of the evaporating water surface should be considered instead of the mean absolute temperature of the air as has been considered for the purpose of the present study due to practical difficulties.

Estimation of evaporation by regression model

The rate of evaporation for the Rabi season of the crop-year 1992-93 was also calculated with the help of the regression model developed for the season and compared with the actual rate of evaporation as presented in Table 9

Table 9 Evaporation estimated by regression model for the Rabi season, 1992-93

Temperature (T) (^oC)	Relative humidity (H) (%)	Sunshine (S) (hrs/day)	Wind velocity at 3.0 m (km/hr)
1	2	3	4
17.70	54.65	9.40	2.84

Evaporation, E = -0.44 + 0.09(T) - 0.08(H) + 0.67(S) + 0.26(W)

= -0.44 + 0.09(17.70) - 0.08(54.65) + 0.67(9.40) + 0.26(2.84) = 3.82 mm/day

The regression model overestimates the rate of evaporation by 0.40mm/day. This is due to the error inherent in the model. This may be attributed to the fact that in developing the model only the above mentioned parameters were taken into consideration while, factors like topography, soil heat flux, water quality were not considered.

Conclusions

Based on the study and in light of the foregoing discussion the following specific conclusions are drawn.

1. Regression analysis carried out to study the relative effects of the meteorological parameters on evaporation reveals that among all the parameters, relative humidity has the maximum of retarding effect on evaporation, while temperature and wind velocity have been found to have positive effect on the rates of evaporation.

2. The regression models developed for the purpose of the study could be used as a physical basis only to compare model predicted results.

3. The modified Penman model can be used for predicting the rate of evaporation both for short-term as well as long-term purposes. However, proper care must be taken while evaluating the vapour pressure deficit term and the radiation term. This is especially true for designing supply systems for highly water sensitive crops grown in the region.

4. There is scope for the development of calculation procedures based on this study that would allow the practising engineers to calculate evaporation from turbulent transfer mechanism with a higher degree of accuracy. This finding justifies the finding of Wartena (1974).

5. For any further work in this field meteorological data must be collected from as many stations as possible to represent the whole region rather than from a single station. This is because evaporation, and for that matter all the meteorological parameters vary spatially and observations in a single meteorological station can not describe the evaporation occurring at all

sites in the region. Davenport (1967) too based on his studies on spatial variations of evaporation emphasised the importance of collecting data from many stations within a particular region for better representation.

6. In general, it is concluded that adequate testing and validation of any evaporation model is a pre-requisite before the model is put to use. Further, any such testing and validation must always be based on a data-base as longer as possible to minimise error in evaluating and validating various terms and coefficients associated with the model.

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