Review on Different Evapotranspiration Empirical Equations

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Abstract— *For optimal design and management of hydrologic balance and scheduling irrigation models, the need to measure Evapotranspiration is of great importance. It helps in predicting when and how much water is required for any particular irrigation scheme. Reference Evapotranspiration is a standard nomenclature defined by FAO to provide a reference frame although it is not a full proof equation. Several scientists have developed multiple equations based of three primary directions viz. temperature based methods, radiation based methods and mass – transfer methods. Here in this paper, we have carried out a review on most of the popular equations and the objective is to elucidate the advantages and drawbacks each one of them register when put into use. The reference equation for standardization considered here is FAO 56 Penman Montheith equation. Thirty other equations from the three schools have been analysed here. Statistical Regression Analysis methods and coefficient of determination (R2), Root Mean Square Error (RMSE) and index of agreement (d) are the analytical parameters those are to be used while estimating their acceptance in evaluating the throughputs.*

Keywords— ***Evapotranspiration, empirical equations, mass –transfer methods, temperature based methods, radiation based methods.***

I. INTRODUCTION

Evapotranspiration (ET) is the sum of the evaporation of water from the earth's surface and the total transpiration from plants. It (ET) is an energy-driven process. Evapotranspiration (ET) is the combination of evaporation and transpiration. Evaporation is water movement from wet soil and leaf surfaces. Transpiration is water movement through the plant. This water movement helps move vital nutrients through the plant.Evaporation and transpiration processes occur simultaneously giving no means to distinguish between them, leading to the urge of developing a general equation to defuse the confusion. The ET increases with temperature, solar radiation, and wind. ET decreases with increasing humidity.

The hydrologic cycle is the process, powered by the sun's energy, which moves water between the oceans, the sky, and the land.

Evapotranspiration plays a pivotal role in hydrological balance as it is responsible for 15% of the atmosphere's water vapour.

Spatially calculating ET is necessary because it is a major component in quantifying a water budget scheme and the maps provide the spatial ability to display the distribution. Evapotranspiration assessment is of outstanding importance both for planning and monitoring purposes. ET helps in determining when and how much irrigation water is needed and for designing and management of irrigation system.

Five main processes are included in the hydrologic cycle: 1) condensation, 2) precipitation, 3) infiltration, 4) runoff, and 5) evapotranspiration.

ET varies because of a multitude of factors like wind, temperature, humidity, and water availability. Other than the primary factors, there are secondary factors which also hugely influence ET measurements and they are viz. crop type, crop length/height, soil type, period of growth, soil salinity, macro and micro mineral contents of the soil, leaf area index. All these factors also determine ET rates which are measured in units of mm/time, where the time scale may be hours, days, months, years or even decades.

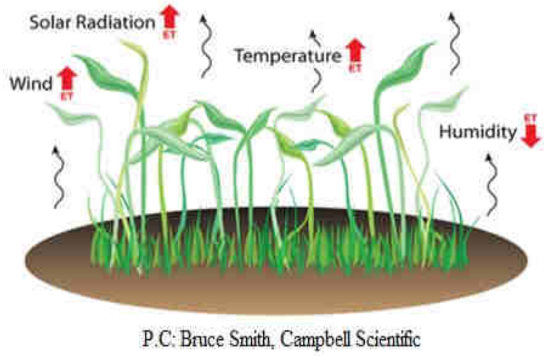


Fig.1: Schematic of Evapotranspiration Process

$$Evapotranspiration = Precipitation - Percolation - \Delta Storage$$

Other climatological and meteorological parameters like latitude, longitude, altitude, sunshine duration, soil heat flux and atmospheric pressure do significantly contribute towards ET measurement.

Several scientists and researchers across the globe over period of time have developed numerous empirical equations to determine evapotranspiration but because of huge differences in climatic conditions all across the globe, none can be established as perfect. In order to bring an end to this confusion, ASCE along with FAO in 1956 came to common grounds and resolved the ambiguity by framing an equation for the determination of Reference Evapotranspiration named as Penman – Montheith equation.

Other researchers have developed popular empirical equations based on the three following categories – temperature based, radiation based and mass – transfer methods.

Here in this paper we will take up multiple equations from all the three categories and scale them against FAO 56 equation and against meteorological data and deduct the most suitable equation. The reason for performing this dry run is to bring congruency among the wide set of equations.

II. STATISTICAL CRITERIA

In all these methods and formulae the potential evapotranspiration were evaluated by comparing different empirical equations against Reference Evapotranspiration equation FAO 56 Penman Monteith or by feeding different climatological data from different environmental conditions across the globe. In order to carry out with comparative analysis, certain statistical criteria were considered as we resolve our effort of comparison through statistical regression analysis. The following criteria need to be mentioned here, before we progress any further. The criteria that we have indulged in our effort are

1) Pearson type goodness of fit index or coefficient of determination (R^2)

$$R^2 = \left[\frac{\sum_{i=1}^{n}(E_i - \bar{E})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n}(E_i - \bar{E})^2}\sqrt{\sum_{i=1}^{n}(P_i - \bar{P})^2}}\right]^2 \quad ...0 \leq R^2 \leq 1, optimal\ value\ 1$$

2) Root Mean Square Error (RMSE)

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(E_i - P_i)^2}{n}} \quad mmday^{-1} \quad optimal\ value\ 0.0$$

3) Relative Error (RelRMSE)

$$RelRMSE = RMSE/O_{avg}$$

4) Index of Agreement (d)

$$d = 1 - \left[\sum(E_i - P_i)^2 / \sum(|E_i - \bar{P}| + |P_i - \bar{P}|)^2\right] \quad 0 \leq d \leq 1, optimal\ value\ 1$$

5) Mean Absolute Error (MAE)

$$MAE = \frac{\sum_{i=1}^{n}|E_i - P_i|}{n} \quad optimal\ value\ 0.0$$

Where n = number of observations

E_i = i^{th}empirical equation result

P_i = i^{th} Penman Monteith result

$\bar{E}$ = average of empirical results

$\bar{P}$ = average of Penman Monteith results

III. REFERENCE EQAUTION

The evapotranspiration rate from a reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as ET_o. The reference surface is a hypotheticalgrass reference crop with specific characteristics. The use of other denominations such as potential ET is stronglydiscouraged due to ambiguities in their definitions. (Allen et al. 1998)

Need for a standard ET_o: The FAO Penman-Monteith method is recommended as the sole ET_o method for determining reference evapotranspiration. Over the last five decades many researchers formulated many equations based on local climatological data but they are all subject to rigorous local calibration and hence lack global validity and acceptance. Testing all these individual equations under new sets of data proved to be time consuming, laborious and costly. Therefore attempts were made to come to a global consortium under the aegis of American Society of Civil Engineering where more than 20 different equations were parallelly studied. Side by side, European Community were doing the same so that the discrepancies among measured and calculated data may be minimized.

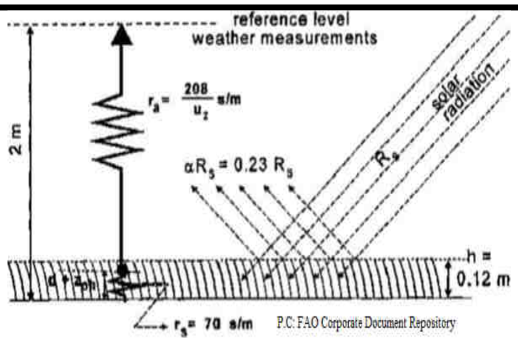
Reference Surface: As prescribed by FAO and ASCE in order to validate ET_o(Reference Evapotranspiration) unambiguously, the concept of reference surface was brought forth which is defined as follows

"A hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m-1 and an albedo of 0.23."

Assumptions which need to be hold for this reference surface to deliver to the best expected results are

i) An extensive surface of green grass
ii) Of uniform height
iii) Completely shading the ground
iv) Actively growing and
v) With adequate water

The panel of experts accepted the Penman Monteith equation as the standardized equation for Reference Evapotranspiration with a reference crop or hypothetical crop which meets the mentioned characteristics as an assumed height of 0.12 m having a surface resistance of 70 s m^{-1} and an albedo of 0.23, closely resembling the evaporation of an extension surface of green grass of uniform height, actively growing and adequately watered.



The Penman Monteith equation for Reference Evapotranspiration looks like

$$ET_0 = \frac{0.408 \times \Delta \times (R_n - G) + \gamma \times (\frac{900}{T+273}) \times u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

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 at 2 m height [°C],
u_2= Wind speed at 2 m height [m s^{-1}],
e_s= Saturation vapor pressure[kPa],
e_a= Actual vapor pressure [kPa],
es-ea= e^0(T) =Saturation vapor pressure deficit [kPa],
D = Δ = Slope vapor pressure curve [kPa °C^{-1}],
γ= g = Psychometric constant [kPa °C^{-1}].
z = altitude in metres.
φ = latitude (radian)
α = albedo or canopy reflection coefficient (0.23)
k_{rs}= adjustment coefficient (0.16 to 0.19 [°C$^{0.5}$])

The other equations and variables that were used in eqn. (1) are given as follows,

Atmospheric Pressure P

$$= 101.3\left[\frac{293 - 0.0065z}{293}\right]^{5.26} \quad \ldots..\text{KPa} \quad (2)$$

Psychometric Constantγ $= \frac{C_p * P}{\varepsilon\lambda}$

$$= 0.665 \text{ x } 10^{-3}\text{P} \quad \ldots\ldots \text{KPa}°C^{-1} \quad (3)$$

Latent Heat of vapourization λ

$$= 2.501 - (2.361 * 10^{-3})T_a \quad \ldots.MJkg^{-1} \quad (4)$$

Slope of the saturation vapour pressure curve *Δ*

$$= \frac{4098\left[0.6108exp\left(\frac{17.27T}{T+237.3}\right)\right]}{(T+237.3)^2} \quad \ldots\ldots\ldots.\text{KPa}°C^{-1} \quad (5)$$

Mean of the saturation vapour pressure e_s

$$= \frac{e^\circ(T_{max}) + e^\circ(T_{min})}{2} \quad \ldots\ldots\ldots \text{ KPa} \quad (6)$$

Saturation vapour pressure ateither maximum or minimum air temperature e°(T)

$$= 0.6108 \text{ x } 2.7183^{\left(\frac{17.27T}{T+237.3}\right)} \quad \ldots\ldots\ldots..\text{KPa} \quad (7)$$

Actual Vapour Pressure e_a

$$= \frac{RH_{mean}}{100}\left[\frac{e^\circ(T_{max}) + e^\circ(T_{min})}{2}\right] \ldots\ldots kPa \quad (8)$$

Vapour Pressure Deficit

$$= e_s - e_a \quad \ldots\ldots\ldots.kPa \quad (9)$$

Extraterrestrial RadiationR_a

$$= \frac{24(60)}{\pi}G_{sc}d_r[\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\sin(\omega_s)] \quad \ldots\ldots \text{MJ}m^{-2}d^{-1} \quad (10)$$

Inverse relative distance d_r

$$= 1 + 0.033\cos\left(\frac{2\pi}{365}J\right) \ldots\ldots\ldots radian \quad (11)$$

Solar declination δ

$$= 0.409\sin\left(\frac{2\pi}{365}J - 1.39\right) \quad \ldots\ldots\ldots..\text{radian} \quad (12)$$

Sun Hour Angle ω_s

$$= \arccos[-\tan(\varphi)\tan(\delta)] \quad \ldots\ldots.radian \quad (13)$$

Possible Day light hour N

$$= \frac{24}{\pi}\omega_s \quad \ldots\ldots..hour \quad (14)$$

Solar Radiation R_s

$$= \left(a_s + b_s\frac{n}{N}\right)R_a \quad \ldots\ldots\ldots\ldots \text{MJ}m^{-2}d^{-1} \quad (15)$$

Clear sky solar radiation R_{so}

$$= (0.75 + 2 \text{ x } 10^{-5})R_a \quad \ldots\ldots\ldots..\text{MJ}m^{-2}d^{-1} \quad (16)$$

Net short wave radiation R_{ns}

$$= (1 - \alpha)R_s \quad \ldots\ldots \text{MJ}m^{-2}d^{-1} \quad (17)$$

Net long wave radiation R_{nl}

$$= \sigma\left[\frac{T_{max}K^4 + T_{min}K^4}{2}\right](0.34 - 0.14\sqrt{e_a})\left(1.35\frac{R_s}{R_{so}} - 0.35\right) \quad \ldots\ldots\ldots \text{MJ}m^{-2}d^{-1}$$

Net radiation R_n

$$= R_{ns} - R_{nl} \quad \ldots\ldots\ldots\ldots.\text{MJ}m^{-2}d^{-1} \quad (19)$$

Wind speed at height z(m) u_2

$$= \frac{4.87}{\ln(67.8z - 5.42)}u_z \quad \ldots\ldots\ldots.\text{m}s^{-1} \quad (20)$$

Solar radiationR_s

$$= k_{rs}\sqrt{T_{max} - T_{min}}R_a \quad \ldots\ldots\ldots \text{MJ}m^{-2}d^{-1} \quad (21)$$

Soil Heat Flux G

$$= c_s\frac{T_i - T_{i-1}}{\Delta t}\Delta z \quad \ldots\ldots\ldots \text{MJ}m^{-2}d^{-1} \quad (22)$$

IV. OTHER METHODS

1. Temperature Based:

Evapotranspiration estimation methods those only rely on temperature as input variable are known as temperature based methods.

The general form of the temperature based method is given as

$$\boldsymbol{ET = cT^a}$$

Or

$$\boldsymbol{ET = c_1 d_1 T(c_2 - c_3 H)}$$

Several authors at different points of times under different climatological data sets framed different equations, among which eight stood as more popular ones. They are viz. Thornthwaite (1948), Linacre (1977), Blaney and Criddle (1950), Hargreaves (1975), Kharrufa, (1985), Hamon (1961),Romanenko (1961) and Camargo methods which are summarized briefly here.

1.1 Thornthwaite equation:

He correlated mean monthly temperature with evapotranspiration as determined from water balance from valleys with sufficient moisture available for maintaining transpiration. The follows are the terms that relate to his equation.

$$monthly\ heat\ index\ i = (\frac{T_a}{5})^{1.51}; annual\ heat\ index\ I = \sum_{j=1}^{12} i_j$$

The general equation for unadjusted monthly values is given as follows

$$ET' = C\left(\frac{10T_a}{I}\right)^a$$

$$C = 16;\ \ a = 67.5 * 10^{-8} I^3 - 77.1 * 10^{-6} I^2 + 0.0179I + 0.492$$

The unadjusted evapotranspiration is adjusted depending on the days in a month ($1 \leq N \leq 31$) and the duration of daylight hours which is a function of latitude and season. The expression for the adjusted evapotranspiration is as follows

$$ET = ET'\left(\frac{d}{12}\right)\left(\frac{N}{30}\right)$$

Though criticized for its empirical nature, yet it is highly accepted because of its only dependence on temperature.

1.2 Linacre equation:

For the case of well-watered vegetation with an albedo of about 025, Linacre (1977) simplified the Penman formula to give the following expression for the evaporate rate

$$ET = \frac{\frac{500T_m}{(100-A)} + 15(T_a - T_d)}{(80 - T_a)}$$

$$T_m = T + 0.006h,\quad h = elevation, A = latitude, T_d = mean\ dew\ tempt$$

1.3 Blaney and Criddle equation:

Developed in 1950, this equation finds high acceptance in western part of USA. The expression for the equations follows as

$$ET = kp(0.46T_a + 8.13)$$

ET = potential evapotranspiration

T_a = mean temperature in °C

p = percentage of daytime hours for used period out of total daytime hours of the year

k = monthly consumptive use coefficient (varies between 0.5 and 1.2)

1.4 Hargreaves and Samaniequation:

This equation is expressed as follows

$$ET_0 = 0.0023(T_{mean} + 17.8)(T_{max} - T_{min})^{0.5} R_a$$

1.5 Kharrufa equation:

Kharrufa (1985) derived an equation through correlation of ET=p and T in the form of

$$ET = 0.34pT_a^{1.3}$$

1.6 Hamon equation:

Hamon (1961) derived a potential evapotranspiration method based on the mean air temperature and is expressed as

$$ET = 0.55D^2 Pt$$

$$Pt = \frac{4.95e^{(0.062T_a)}}{100}$$

1.7 Romanenko equation:

Romanenko (1961) derived an evaporation equation based on the relationship using mean temperature and relative humidity (*Rh*).

$$ET = 0.0018(25 + T_a)^2(100 - Rh)$$

$$Rh = \frac{e^0(T_d)}{e^0(T_a)}$$

1.8 Camargo equation:

This equation is expressed as follows

$$ET = f.T_{mean}.R_a.ND$$

R_a = extra-terrestrial radiation

ND = length of time interval (day)

2. Radiation Based:

These group of equations are based on energy – balance methods primarily based on solar radiation and the general expression for them is given as

$$\boldsymbol{\lambda ET = C_r(\omega R_s)\ or\ \lambda ET = C_r(\omega R_n)}$$

There are eight popular radiation based equations related to ET and they are viz. Turc (1961), Makkink (1957), Jensen and Haise (1963), Hargreaves (1975), Doorenbos andPruitt (1977), McGuinness and Bordne (1972), Abtew (1996), and Priestley and Taylor (1972). They are also summarized briefly for quick referencing.

2.1 Turc equation:

Under general climatic conditions of western Europe, Turc (1961) computed ET in millimetres per day for 10-day periods as

$$ET = 0.013\frac{T}{T+15}(R_s+50)\ for\ RH\ \geq 50$$

$$ET = 0.013\frac{T}{T+15}(R_s+50)\left(1+\frac{50-RH}{70}\right)\ for\ RH < 50$$

2.2 Makkink equation:

Proposed in 1957 for estimating ET from grass, the equation stands as

$$ET = 0.61\frac{\Delta}{\Delta+\gamma}\frac{R_s}{\lambda} - 0.12$$

In 1984, the equation was little modified based on further investigation and stands as

$$ET = 0.7\frac{\Delta}{\Delta+\gamma}\frac{R_s}{\lambda}$$

$$\Delta = 33.8639[0.05904(0.00738T+0.8072)^7 - 0.000342]$$

$$\gamma = \frac{c_pP}{0.622\lambda};\ \lambda = 595 - 0.51TP = 1013 - 0.1055EL; EL = elevation\ in\ mts.$$

R_s = total solar radiation
Δ = slope of saturation vapour pressure curve
γ = psychrometric constant; λ = latent heat

2.3 Jensen and Haise equation:

Evaluated over 35 years on 3000 observations, they formulated the general equation as

$$\lambda ET = C_t(T - T_x)R_s$$

This equation was further modified and is expressed as follows

$$ET = (0.0252T_{mean} + 0.078).R_s$$

2.4 Hargreaves equation:

Hargreaves (1975) proposed several equations for calculating potential evapotranspiration, ET (in mm/day). One of the equation is given as such

$$ET_o = 0.0135R_s(T_{mean} + 17.8)$$

2.5 Doorenbos and Pruitt equation:

Doorenbos and Pruitt (1977) presented a radiation method for estimating ET using solar radiation which was an adaptation of Makkink method and recommended over the Penman method with the following expression.

$$ET = a\left(\frac{\Delta}{\Delta+\gamma}R_s\right) + b;\quad b = -0.3\frac{mm}{day}$$

$$adjustment\ factor\ a = 1.066 - 0.13*10^{-2}RH + 0.045U_d - 0.20*10^{-3}RH*U_d - 0.315*10^{-4}RH^2 - 0.11*10^{-2}{U_d}^2$$

2.6 McGuinness and Bordne equation:

McGuinness and Bordne (1972) proposed a method for calculating potential evapotranspiration based on an analysis of a lysimeter data in Florida.

$$ET = \{*0.0082T - 0.19)(R_s/1500)\}2.54$$

2.7 Abtew equation:

Abtew (1996) used a simple model that estimates ET from solar radiation as follows

$$ET = K\frac{R_s}{\lambda}$$

2.8 Priestley and Taylor equation:

In 1972, a simpler equation was proposed by these dual scientists for surfaces generally wet and humid and energy component was multiplied whereas aerodynamic component was deleted. The equation holds the expression like

$$ET = \alpha\frac{\Delta}{\Delta+\gamma}\frac{R_n}{\lambda}$$

In this study, owing to a lack of observation data, R_n is estimated using an equation proposed by Linsley et al. (1982)

$$R_n = 7.14*10^{-3}R_s + 5.26*10^{-6}R_s(T+17.8)^{1.87} - 3.94*10^{-6}R_s^2 - 2.39*10^{-9}R_s^2(T-7.2)^2 - 1.02$$

3. Mass – Transfer Based:

This group falls among the oldest methods for measuring basically evaporationwhere concept of eddy – motion transfer of water vapour from evaporating surfaces to atmosphere is utilized and they are based on Dalton's equation with a generalized expression as

$$\boldsymbol{E = C(e_s - e_a) = f(u)(e_s - e_a)}$$

This method offers the advantage of simplicity of calculation once the constants have been calibrated and this group of equations also finds application is measurement of evaporation from open water bodies.

The generalized equations under this method should possess the following characteristics

i) Be analytical and simple ii) its variables should be easily measurable iii) should comprise the most influencing factors iv) other methods should be special cases of the generalized one v) model parameters should be estimated with acceptable accuracy

There are about thirteen well accepted equations which come under this group of mass transfer. These thirteen equations were further generalized into seven equations for estimating evaporation. The names of these equations are i) Dalton (1802) ii) Fitzgerald (1886) iii) Meyer (1915) iv)Horton (1917) v) Rohwer (1931) vi) Penman (1948) vii) Harbeck et al. (1954) viii) Kuzmin (1957) ix) Harbeck et al. (1958) x)Konstantinov (1968) xi) Romanenko (1961) xii) Sverdrup (1946) and xiii)

Thornthwaite andHolzman (1939). Generalizing these thirteen equations leads to evolution of seven empirical equations which are termed here as equations A, B, C, D, E, F and G.

The weakness of these empirical equations is their limited applicability range because their variables are not easily measurable at other places, their accuracy is limited to a small range and comparison of models is difficult due to model specific variables.

The general forms of these thirteen equations are listed below

Dalton (1802): $E = a(e_s - e_a)$

Fitzgerald (1886): $E = (0.44 + 0.199u)(e_s - e_a)$

Meyer (1915): $E = 11(1 + 0.1u)(e_s - e_a)$

Horton (1917):$E = 0.4[(2 - \exp(-2u)\ (e_s - e_a)]$

Rohwer (1931):$E = 0.77(1.465 - 0.018P_b).(0.44 + 0.118u)(e_s - e_a)$

Penman (1948):$E = 0.35(1 + 0.24u_2)(e_s - e_a)$

Harbeck (1954):$= 0.0578u_8(e_s - e_a)$; $E = 0.0578u_4(e_s - e_a)$

Kuzmin (1957):$E = 6.0(1 + 0.21u_8)(e_s - e_a)$

Harbeck (1958):$E = 0.001813u(e_s - e_a)(1 - 0.03(T_a - T_w))$

Konstantinov (1968):$E = 0.024\frac{(t_w - t_2)}{u_1} + 0.166u_1(e_s - e_a)$

Romanenko (1961):$E = 0.0018(T_a - 25)^2(100 - hn); hn = relative\ humidity$

Sverdrup (1946):$E = (0.623\rho K_0^2 u_8(e_2 - e_8))/[p(\ln{(800/z)})^2]$

Thornthwaite and Holtzman (1939):

$$E = (0.623\rho K_0^2(u_8 - u_2)(e_2 - e_8))/[p(\ln{(800/200)})^2]$$

$$\rho = air\ density;\ K_0 = von\ Karman's constant$$

Generalization of these methods:

It is seen from above equations that E is proportional to vapour pressure gradient and wind speed but it's relation with temperature is not explicitly included in most equations. One general structure from the above equations is like

$$E = f(u)g(e)h(t)$$

$$where\ f(u) = func. of\ wind\ speed,$$

$$g(e) = func\ of\ vapour\ pressure\ deficit\ and\ h(t) = func\ of\ temperature$$

Comparing the thirteen equations with this generalized formula, seven generalized formulas are further evolved as follows

$$(A)\ E = a(e_0 - e_a)$$

$$(B)\ E = au(e_0 - e_a)$$

$$(C)\ E = a(1 - \exp(-u)).(e_0 - e_a)$$

$$(D)\ E = a(1 + b.u)(e_0 - e_a)$$

$$(E)\ E = a.u(e_0 - e_a)(1 - b.(T_a - T_d))$$

$$(F)\ E = a(T_a + 25)^2.(100 - hn)$$

$$(G)\ E = a.(1 + b.u).(e_0 - e_a).(1 - c(T_a - T_d))$$

a, *b* and *c* are parameters, *hn*is the relative humidity.

TABLE I: Few Popular Methods with their required Inputs

Method	Required inputs
Thornthwaite	average temperature, latitude
Linacre	elevation above sea level, latitude, average dew point temperature, average temperature
Blaney-Criddle	average temperature, latitude, coefficient dependent on the vegetation type, location and season
Kharrufa	average temperature, latitude
Hargreaves	latitude, average minimum and maximum temperature, average temperature
Hamon	average temperature, latitude
Remanenko	average temperature, average relative humidity of air
Turc	temperature of air, relative humidity of air, net solar radiation
Makkink	temperature of air, elevation above sea level, net solar radiation
Jensen-Haise	temperature of air, net solar radiation
Hargreaves	temperature of air, net solar radiation
Doorenbos and Pruitt	temperature of air, net solar radiation, average relative humidity of air, average daily wind speed
McGuinness and Bordne	temperature of air, net solar radiation
Abtew	temperature of air, net solar radiation, dimensionless coefficient
Priestley and Taylor	temperature of air, net solar radiation
Penman-Monteith	net solar radiation, relative humidity of air, temperature of air, wind speed, elevation above sea level, latitude

The general conclusion that we can draw about these mass – transfer based equations is that no acceptable level of confidence can be shown as we consider the climatological data based on geographical locations and therefore the parameters values need localized calibration to derive to valid results.

TABLE I shows few of the most popular equations and the inputs parameters on which they are primarily dependent.

V. THE VERDICT

The availability of many equations for determining evapotranspiration, the wide range of data types needed, and the wide range of expertise needed to use the various equations correctly, make it difficult to select the most appropriate evaporation method even from a chosen group of methods for any given study. It therefore leads to the analysis of these various methods on different sets of data to find the suitability of one over another.

Thornthwaite’s equation has been widely criticized though it finds wide application because of its only dependence of temperature and this also led to misuse of this equation in arid and semi-arid regions without maintaining the requirements. Linacre equation depends on dew point temperature and geographical data (location and altitude) making it a simple equation for use. The main drawback of BlaneyCriddle method is its demand to calibrate the constants based on the climatological data available and environmental conditions prevailing there. Hargreaves, Camargo and Hamon methods require only air temperature data whereas Romanenko equations work better with the knowledge of air temperature and relative humidity for the site under inspection. It is further observed as general rule that all these temperature based equations need to recalibrate their constants time and again to optimize their throughputs and if not exactly, all these equations produce results more or less in alignment with each other leading to their selection as subject to discretion of the user. Referring to a comparative study carried out by Xu and Singh et. al in 2001 based on a locality of Canada, it may be stated that BlaneyCraddle method gave the most appreciated results whereas Thornthwaite and Hamon methods suffered from maximum errors, but certainly this study does not conclude that the earlier was a better choice of equation over the latter globally.

Xu and Singh et al in 2000 carried out similar comparative analysis on eight radiation based methods considering meteorological data from a weather station in Switzerland and the findings were like, using the original constant values leads to greater percentage errors but a slight recalibration of them leads to much stable and less erroneous outputs. The main drawback of these set of equations is underestimation during cold months. It was further found that theMakkink and Priestley and Taylor equations are good choices under these circumstances.

Albeit there are hundreds of mass transfer based equations for evaporation determination, thirteen of these find more acceptance over others. Again these thirteen equations can be brought down into seven generalized equations and all these equations generate comparable and satisfactory estimates. Here again the study region was some place in Canada, study carried out by Xu and Singh in 1997.

VI. CONCLUSION

Afterthorough study of the several evapotranspiration equations from different schools and heuristic analysis of the same on actual field data based from meteorological sensors, we run comparative studies aimed at figuring out the best or most suitable equation(s). In our study, it is revealed that the general consensus that we can draw after analysing all these equations from different methods is that they all work more or less quite significantly though none of them is a full proof equation without any limitation. Secondly the wide variety of climatological data is the most influencing factor and therefore every time we need to recalibrate the constants used in all these equations for more agreeable results, otherwise only a small acceptance level of confidence can be drawn for a small region that too with fairly similar climates.

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