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Evaporation modeling with multiple linear regression techniques – a review

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A B S T R A C T

Evaporation is influenced by number of agro-meteorological parameters and one of the integral components of the hydrological cycle and. Usually, estimates of evaporation are needed in a wide array of problems in agriculture, hydrology, agronomy, forestry and land resources planning, such as water balance computation, irrigation management, crop yield forecasting model, river flow forecasting, ecosystem modeling. Irrigation can substantially increase crop yields, but again the scheduling of the water application is usually based on evaporation estimates. Numerous investigators developed models for estimation of evaporation. The interrelated meteorological factors having a major influence on evaporation have been incorporated into various formulae for estimating evaporation. Unfortunately, reliable estimates of evaporation are extremely difficult to obtain because of complex interactions between the components of the land-plant-atmosphere system. In hot climate, the loss of water by evaporation from rivers, canals and open-water bodies is a vital factor as evaporation takes a significant portion of all water supplies. Even in humid areas, evaporation loss is significant, although the cumulative precipitation tends to mask it due to which it is ordinarily not recognized except during rainless period. Therefore, the need for reliable models for quantifying evaporation losses from increasingly scarce water resources is greater than ever before. Accurate estimation of evaporation is fundamental for effective management of water resources. The evaporation models using MLR techniques is discussed her in details.

1. Introduction

Evaporation involves the transformation of water from its liquid state into a gas and the subsequent diffusion of water vapour into the atmosphere. However, the measurement of evaporation in the open environment is difficult and is usually done by proxy. Potential evaporation is the variable most often used. Potential evaporation is a measure of the ability of the atmosphere to remove water from a surface assuming no limit to water availability, whereas actual evaporation is the quantity of water that is removed from that surface by evaporation (Brutsaert, 1982). Therefore, actual evaporation is only equal to potential evaporation when a given surface is saturated. The most widespread measurement method for potential evaporation uses a pan evaporimeter, which quantifies water loss from the instrument itself and not from the surrounding environment. The standard US Class A pan is the most commonly used instrument. It consists of a metal container usually covered by an open wire bird guard that is 1,207 mm across and 254 mm high. Evaporation is the amount of loss (gain) in mm depth with rainfall from an adjacent rain-gauge subtracted. More accurate estimates of potential evaporation can be obtained by applying other meteorological data to empirical, water budget, energy budget, and combination approaches. However, the most accurate approaches tend to be resource-intensive, site-specific and do not provide long-term estimates of change. Therefore pan evaporation records are the largest single source of data on historical evaporation trends and models can be helpful for agricultural research.

The models developed from meteorological data involve empirical relationships to some extent. The empirical relationships account for many local conditions. Therefore, most models may give reliable results when applied to climatic conditions similar to those for which they were developed. Without some local or regional calibration, the use of such models for climatic conditions that are greatly different may give results that may differ considerably. Evaporation reflects the influence of several meteorological parameters like air temperature, sunshine hours, wind velocity, relative humidity, solar radiation, evaporating power of the air and vapour pressure deficit of a locality. But measurement of evaporation with accuracy is difficult task. In such cases, it becomes assertive to use formulae or statistical model that can estimate pan evaporation from available climatic data, may give more accurate results than the measured pan evaporation. In this regard, a number of models have therefore been proposed and developed by several investigators for different locations in India and abroad are reviewed in following sections.

1. General Evaporation models
2. Linear Regression Evaporation models

2. General evaporation models

Evaporation data are not always available for a particular climatic region. Prediction models for evaporation are often used. Accurate estimation of evaporation is difficult because of the complex interaction between the components of the land-plan-atmosphere system. Evaporation rate from the water surface is a function of meteorological conditions of the overlying air, the energy state of the air-water interfacial zone, and the amount of energy stored in the water body. In the absence of measured evaporation rate, the alternative is to use estimation methods. A large number of models have been proposed for estimating evaporation from water surface using climatic data. (Hargreaves, 1968). These may be classified as, aerodynamic model, eddy correlation model, mass transfer model, energy balance model, and combination model. The review of literature on general evaporation models is presented as below.

Baier and Robertson (1965) in their evaluation of meteorological factors influencing evaporation found that the use of complex logarithmic, quadratic and cubic regression models did not significantly improve the estimation of evaporation as calculated from a linear regression.

Christianson (1968) developed a model for estimating USWB Class A pan evaporation under a wide range of climatic conditions. Because of variations in size and shape of pans, their exposure, the growth of algae in water, incorrect water level, weed growth nearby, splashing of water in or out of the pan during rainfall, the protection against use of water by birds and animals, specific methods of measuring the loss of water from the pans and available pan evaporation data may not sometimes be reliable. In such cases pan evaporation, estimated by model expressed as below may give more accurate results than the reported pan evaporation.

$$E_p = K_{ev}. R. C_t. C_w. C_h. C_s. C_e. C_m$$

Where, E_v is the computed pan evaporation equivalent to class A pan evaporation, K_{ev} is a dimensionless empirically developed constant, the value given by Christiansen is 0.473, R is extra-terrestrial radiation in the same evaporation units as E_v and C_t, C_w, C_h, C_s, and C_e are coefficients for temperature, wind speed , relative humidity, percentage possible sunshine hours and elevation respectively and C_m is a coefficient or factor by which all basic formulae would have to be multiplied to adjust the measured evaporation and averaged to obtain mean values of C_m.

Linacre (1977) simplified the Penman formula for the evaporation rate from a lake as below.

$$E_O = \frac{\frac{700Tm}{(100-A)} + 15(T-Td)}{(80-T)} (mm/day)$$

where, Tm = T + 0.006 h, h is the elevation (meters), T is the mean temperature, A is the latitude (degrees) and Td is the mean dew point. Values given by this formula typically differ from measured values by about 0.3 mm/day for annual means, 0.5 mm/day for monthly means, 0.9 mm/day for a week and 1.7 mm/day for a day. The formula applies over a wide range of climates. Monthly mean values of the terms (T - Td) can be obtained either from an empirical table or the following empirical relationship, provided precipitation is at least 0.5 mm/month and (T - Td) is least at 4 ^{0}C:

$$(T - Td) = 0.0023 h + 0.37 T + 0.53 R + 0.35 Rann - 10.9\ ^oC$$

where, R is the mean daily range of temperature and Rann is the difference between the mean temperatures of the hottest and coldest months. Thus the evaporation rate can be estimated simply from values for the elevation, latitude and daily maximum and minimum temperatures.

Krishnan and Kushwaha (1973) examined Class A pan evaporation data for 49 computation periods of 5 days at Jodhapur in the Indian arid zone. The 5-day periods cover the growing seasons of 1963 and 1964 for native vegetation. Multiple regression analysis were carried out of evaporation Y (mm/day) against the climatological factors, total global radiation X_1 (cal. cm/day), estimated net radiation X_2 (cal. cm/day) saturation deficit at maximum temperature epoch X_3 (mm of Hg) saturation deficit at mean temperature X_5 (mm of Hg) and mean daily wind speed X_4 (km/h). The results indicated that the aerodynamic factors were important in the Jodhpur climate and the pair of factors, saturation deficit at a maximum temperature epoch and daily mean wind speed explain 83% of variance by 5% and 1%, respectively.

The respective equations are:

$Y = 0.0122 X_1 + 0.2559 X_3 + 0.5677 X_4 - 9.0657$

$Y = 0.0066 X_2 + 0.3260 X_3 + 0.5150 X_4 - 6.3571$

The multiple correlation coefficients were + 0.94 and + 0.92, respectively. Partial correlation coefficients and beta-coefficients were also presented. All regressions taken singly or in pair or multiple combinations were found to be significant by the analysis of variance. On comparison observed and predicted evaporation points scattered around the straight line Y=X.

Hanson and Frank (1977) studied on class A Pan evaporation data at two locations on the Northern Great Plains indicated evaporation from pans protected from the wind by tree shelterbelts was about 14% less than from unprotected pans. An equation was developed for estimating daily class A pan evaporation from either protected or unprotected pans.

Singh *et al.* (1981) studied the effect of air temperature, wind velocity, relative humidity and number of bright sunshine hours on pan evaporation by using meteorological data for the years 1961-78. The highest correlation coefficient was obtained with wind velocity while the lowest correlation coefficient was obtained for sunshine hours. It was found that wind velocity, air temperature and relative humidity have significant correlation with pan evaporation. The analysis of the data has been based on Dalton's concept as used by Penman. According to this concept the relationship between evaporation (E) and vapour pressure deficit (e_s-e_a) is expressed as: E = f(w) (e_s-e_a). The ratios of E/(e_s-e_a) were plotted against the wind velocity. There exists a linear relationship, which confirms the applicability of Dalton's law. The equations relating to this relationship on yearly and seasonal basis were found.

Tyagi *et al.* (1982) emphasized the need for having the irrigation system capacity design on the peak values of evapo-transpiration at the desired levels of probability. In absence of long term data on evapo-transpiration a procedure of utilizing the readily available data from open evaporimeter was suggested. The recommended procedure was illustrated with worked example for the command area of a canal lateral. The analysis indicated that irrigation system capacity in Karnal region was under designed by as much as 21%, if design was based on long term means of evaporation in place of values of 80% level of probability.

Doyle (1990) compared two evaporation models. Water balance data from the Shannon catchment were used to compare the Penman approach to evaporation modeling with that of Morton. The model parameters were estimated by fitting the models to the water balance data by numerical optimizations. Results suggested that Morton's model represents an improvement over Penman's for the purposes of water balance modeling, in that the prediction of actual evapo-transpiration does not depend entirely on the soil moisture components, the weakest component in most water balance models. However, it was concluded that for general hydrological applications, the Morton model in its present form should be used with caution.

Chiong *et al*., (1990) investigated the variability of monthly evaporation over a long period of time based on monthly evaporation data of 21 stations in Taiwan; The length of records required was computed by absolute change of monthly evaporation between consecutive years gave a series of the percent of variation. The number of years necessary to reach different stability levels were established for each month of the year for each station, the probability of occurrence for extremely high values of evaporation and rainfall is usually low. Frequency analysis showed that monthly evaporation at most stations followed either normal or log normal distribution.

Gupta and Singh (1990) worked out the frequency analysis of weekly rainfall data of 21 years (1965-85) and weekly evaporation data of 16 years (1970-85) of Indian Institute of Technology, Kharagpur, meteorology observatory by using modified Weibull's technique. Weekly frequency analysis is much more useful and provides a better planning and control than monthly, seasonal and annual analysis for planning of irrigated and/or rainfed agriculture. The predicted values of weekly rainfall and evaporation at 20%, 40%, 60% and 90% probability levels have been reported. Based on the frequency analysis, net irrigation requirements for different crops, which are suitable to grow in the area, have been suggested.

Eissa *et al.* (1991) established a system for measurement of evaporation from a class "A" pan and other climatic factors to cover the period from June 1988 to June 1990 inside and outside the plastic greenhouse. Data indicated high correlation between evaporation and water vapour pressure deficit, at mean air temperature (r = 0.88). Class "A" pan evaporation showed a lower correlation with solar radiation under plastic houses (r = 0.60), while r-value was 0.86 for solar radiation measured out side the plastic house.

Paruelo *et al*. (1991) compared different ways of estimating soil evaporation losses in arid region of Patagonian. Micro-lysimeter were used as a reference estimate and tested against approaches based on (i) surface energy balance and (ii) meteorological data. Cumulative losses during 12 days drying cycle, calculated from micro-lysimeter data and from the model that uses meteorological data, were very similar. The energy balance method yield estimates higher than the model based on meteorological data and over estimated the evaporation rate, especially at low rate of evaporation. This feature could be related to the plausibility of an assumptions made by the method.

Cahoon *et al.*, (1991) also investigated the local calibration of equations for estimating pan evaporation. They calibrated three temperature based equations for 13 sites across the Southeastern U. S. After calibration, the fitted equation had r^2 values ranging from 0.05 to 0.48. For the two locations in Georgia, the r^2 values ranged from 0.13 to 0.37. They also performed a regression between pan evaporation and the Penman equation for one location where additional weather data were available. The resulting r^2 from the regression was 0.27. He also observed that the many relationships that predict pan evaporation or potential evapo-transpiration as a function of limited meteorological observations were often empirical, thus they suffer lack of transferability. The relationships between potential evapo-transpiration and pan evaporation facilitates local calibration of established equations using measured pan evaporation data. The three equations selected for calibration were Hargreaves–Samani, Linacre and Cahoon- Feruson. For each site, calibration coefficients were determined using three linear regression models. Hargreaves-Samani equation using local parameters was slightly superior to the other two in terms of accuracy. So this technique is valuable for establishing a calibrated equation for site having pan evaporation data that is then transferable to locations nearby having similar climatic characteristics.

Giambelluca and Nullet (1992) conducted an experiment to measure evaporation at high elevations on a tropical Island mountain and to compare these measurements with estimates from Penman, Penman-Van Bavel, Penman-Monteith and Pristley- Taylor models. Hourly evaporation and other microclimatological data were measured at the sites on Haleakala, Maui and Hawaii. Evaporation during the observed period increased with elevation, averaging 3.3 mm/day at 950 m, 3.6 mm/day at 1650 m and 6.4 mm/day at 2130 m. The special pattern of evaporation on Haleakala is dominantly a function of elevation relative to the position of the inversion. The residual of measured minus modeled evaporation as well as the ratio of evaporation to net radiation increased with elevation. The rate of nighttime evaporation, also increasing with elevation, suggests a source of non-radiative energy. Results indicated that air above and within the inversion layer in the Hawaiian Islands region provides a source of heat of advection that substantially increases potential evaporation at high elevations.

Hope and Evans (1992) evaluated the Linacre Model for estimating monthly mean evaporation in the agriculturally intensive Central Valley, California. The accuracy of the uncalibrated Linacre equation to estimate short wave radiation and ventilation components was examined. Observed monthly mean reference evaporation meteorological data for periods up to 72 months were obtained from 25 stations. Uncalibrated and calibrated Linacre models were used. The uncalibrated model was found to systematically overestimate evaporation with most of the error being attributed to the ventilation components. Calibration of the radiation and ventilation components removed most of the systematic model errors.

Richard and Brutsaert (1992) were tested several well-known evaporation equations with daily data averaged over six stations in a 15×15 km region in Kansas. The equilibrium evaporation and advection aridity evaporation equations produced acceptable results, under the generally moist conditions encountered, with the former performing slightly better. Three methods tested also required soil moisture (SM) availability data. These were the Penman and equilibrium evaporation equations adjusted with SM-dependability coefficients, and the Penman Monteith formulation with surface resistance. All three gave significantly better performance than the unadjusted equilibrium equation. In general, it appeared that the use of simpler temporal (daily) and spatial averages may not be appropriate, especially under conditions of variable SM. The Penman, equilibrium and advection –aridity evaporation equations are linear combinations of same two terms, with different coefficients. The optimal values of these coefficients, determined for various ranges of SM, were consistent with underlying physical models.

Lian *et al.* (1993) described a mathematical model of evaporation in which dimensional analysis and different equations were used. Only small differences were found between observed and predicted rates of water evaporation. Penman and Morton models were modified using long term solar-radiation observations, evaporation data and meteorological data. The modified models were used to provide reliable estimates of monthly and annual evaporation from lakes and catchment areas in Hubei province

Linacre (1994) stated that there is a shortage of good data for checking the universality of simplified version of Penman formula for lake evaporation (Eo). The simplified version of the formula was modified so that measurement of pan evaporation (Ep) could be used. The value of Ep depends on the solar irradiance, the latitude and solar declination, the amount of cloud and the aridity of the pan's environment. These factors were included in modified equation. In general the error of estimation was nearly 0.6 mm/day.

Gupta and Kumar (1994) developed the stochastic model of the weekly evaporation data of Palampur in Himachal Pradesh. No trend was observed in evaporation series. Periodicity of the periodic component was found to be 52. The stochastic component was analyzed by linear autoregressive model. The second order AR was selected on the basis of least residual variance and final relationship was developed to predict the evaporation on weekly basis.

Chin and Zhao (1995) presented a methodology to assess the relative merit of using evaporation pan network and semi-empirical functions to estimate reference crop evapotranspiration. They proposed estimation error variance for comparison and used ordinary kriging and universal kriging as options for estimation of error variance. For a semi-empirical ET functions, a formulation was developed to express estimation error variance in terms of uncertainties in extrapolating meteorological data from measurement locations. Result showed that universal kriging was preferred for estimating reference crop ET from pan measurement and Penman-Monteith method was preferred for meteorological data. Pan based universal kriging approach yielded low estimation error than Penman-Monteith functions indicating its utility over the area of south Florida.

Sahoo and Mohan (1995) studied stochastic modeling of weekly evapo-transpiration time series pertaining to three stations from different climate zones in Tamilnadu. An additive model consisting of superposition of trend, cyclic and stochastic components was studied. It was found that the number of harmonics required to fit Fourier series to the mean weekly evpo-transpiration series of all the stations is less than or equal to two accounting for more than 90 % of the variance in the mean weekly series. In the case of weekly standard deviation (SD) series the number of harmonics required to fit fourier series is quite large (about 20) demanding a different approach to tackle the problem. The spectral density function of the weekly standard deviation series was estimated and the frequency at which the spectral density function shows peaks was found out. The cyclic decent method was used to optimize the raw frequencies thus obtained to get the exact frequencies of which the standard deviation of the weekly series is periodic. These frequencies were then used to model the standard deviation series. The stochastic component was fitted with an autoregressive model. The postulated model for evapo-transpiration series has been validated by comparing the statistics of the historic series from the model and found to have close agreement.

Martinez-Cob (1996) evaluated ordinary kriging, cokriging and modified residual kriging to interpolate long-term mean total annual reference evapo-transpiration (AETO) and long-term mean total annual precipitation (APRE) in a mountainous region, where the stationary hypothesis does not hold for the whole region, but holds locally. AETO and APRE estimates and estimation errors were evaluated at validation stations. Estimates and computed estimation error variances (used as indicators of estimation uncertainty) were also obtained at 19135 km grid points. Estimates at validation stations generally agreed with observed values for all interpolation methods, although modified residual kriging estimates of APRE were slightly worse than those obtained by the other two methods. Based on mean absolute error (MAE) and mean squared error (MSE) at validation stations, no method ranked clearly above another for interpolation of AETO. At grid points, AETO estimation uncertainty was improved by cokriging by 11.5% and 8.4% compared with ordinary kriging and modified residual kriging, respectively. Likewise, co-kriging was superior for interpolation of APRE in terms of MAE and MSE obtained at validation stations. At grid points, cokriging reduced estimation uncertainty by 18.7% and 24.3% compared with ordinary kriging and modified residual kriging, respectively, whereas modified residual kriging in general did not improve ordinary kriging results. Computed estimation error variance values indicated that modified residual kriging would reduce estimation uncertainty in areas where very few weather stations are available for interpolation.

Chattopadhyay and Hulme (1997) analyzed evaporation time series data for different stations in India, and for the country as a whole, for different seasons on both a short-term (15 years) and long-term (32 years) basis for pan evaporation and on a short-term basis alone for potential evapo-transpiration. The analysis showed that both pan evaporation and potential evapo-transpiration have decreased during recent years in India. The likely causative meteorological parameters for such changes were identified. Future scenarios of potential evapo-transpiration, and its component energy and aerodynamic terms, for India based on results from six global climate model climate change experiments were also calculated and intercompared. Future climatic warming appeared likely to lead in general to increased potential evapo-transpiration over India, although this increase is likely to be unequal between regions and seasons. Such changes could have marked implications for economic and environmental welfare in the country, especially if the increases in evaporation are not compensated by adequate increases in rainfall.

Singh and Xu (1997a) made evaluation and generalization of 13 mass transfer equations for determining free water evaporation. Thirteen equations based on the mass transfer method for determining free water evaporation were expressed in seven generalized equations. These seven equations were then compared with pan evaporation at four climatological stations in northwest Ontario, Canada. The comparison was based on monthly evaporation. Equations were compared by calibrating them on the entire data sets as well as by calibrating on part of the data and then verifying them on the remainder of the data. The results of the comparison showed that all the equations were in reasonable agreement with observed evaporation, and that the effect of wind speed on monthly evaporation was marginal. However, when an equation with parameters obtained at one site was applied to compute evaporation at another site, the computed evaporation was not in good agreement with observed values.

Singh and Xu (1997b) investigated the sensitivity of mass transfer-based evaporation equations to errors in daily and monthly input data from a climatological station in the station of Vaud in Switzerland. Evaporation estimates were found to be particularly sensitive to vapour pressure gradient, less sensitive to wind speed and most insensitive to temperature. A quantitative analysis showed that: (i) systematic errors in vapour pressure data influenced evaporation estimates inversely to more or less the same magnitude for both monthly and daily cases; (ii) systematic errors in wind speed and temperature data influenced evaporation estimates inversely to the magnitude of about a half and a quarter of the magnitude of the influence of vapour pressure errors, respectively: and (iii) evaporation estimate were much more sensitive to random errors in case of monthly data than daily data.

Xu and Singh (1998) evaluated the five major significant factors including comparatively solar radiation, vapour pressure deficit, relative humidity, wind speed and air temperature at different time scale using data from Changines station in Switzerland. The comparative evaluations were made at hourly, daily, 10 day and monthly time scales. The role of controlling variables in evaporation varied with time scale. In next part four equations for calculating evaporation including temperature based methods, humidity based methods, mass transfer methods and radiation based methods, were compared with pan evaporation. The Penman equation, representing the mass transfer method and Romanenko equation, representing the humidity method resulted in evaporation values compared reasonably well with pan evaporation. The Turc equation, representing radiation method and Thornthwaite equation, representing the temperature method significantly underestimated evaporation.

Kumar *et al.*, (2000) used monthly dry days series to compare commonly used distributions and transformations for probability analysis. The observed values were computed by Weibull's formula at different probability levels. The expected values were estimated by normal distribution with no transformation, Normal distribution with Log transformation, Normal distribution with Log-Log transformation, Normal distribution with Smemax transformation, Normal distribution with Power transformation, Gumbel distribution and Log Pearson Type-III distribution. The comparison was made at 0.10, 0.20, 0.50, 0.80 and 0.95 probability levels. Kolmogorov-Smirnov (K-S) test and percentage deviation were used to find the goodness of fit of distributions. The normal distribution with Smemax transformation was found to be best fit for monthly dry days data series of Pantnagar with per cent deviation of 5.66, 3.42, 2.81, 3.19 and 6.63 at 0.10, 0.20, 0.50, 0.80 and 0.95 probability levels.

Bhakar (2000) developed and evaluated appropriate evaporation models for pan evaporation from 20 years data. The highest correlation coefficient was obtained with air temperature (0.776) while lowest correlation coefficient was obtained with sunshine hours and relative humidity was negatively correlated with pan evaporation. Analysis of yearly data of climatic parameters and evaporation was carried out to develop the multiple linear regression equation $Ep = -0.1268 + 1.6020 U_2 + 0.3530 S – 0.0980 RH + 0.2420 T$. Performance of these developed model was found quite satisfactory. He developed stochastic models for pan evaporation by using 20 years data. Validation of the models was done by comparison of the estimated values with measured values. The stochastic model developed to generate weekly evaporation predicted very accurately.

Bhakar (2000) made frequency distribution of evaporation using the database of 20 years. The probability curves of evaporation were developed at 5,10,25,50,70,80,90 and 95 percent levels. For determination of peak crop water requirements for shorter duration probability distribution of daily evaporation for different consecutive day periods were also made. He used two approaches for mass transfer modeling of evaporation. In the first approach only vapour pressure deficit was employed for modeling of evaporation and the model was $Ep = -0.0436 + 3.1761 (e_s - e_d)$ with correlation coefficient of 0 94. In second approach of mass transfer modeling vapour pressure deficit data were used in association with wind speed data, the model became $Ep = (0.2278 + 0.15U_2) (e_s - e_d)$ with correlation coefficient. Performance of these developed models was found quite satisfactory. He also evaluated existing evaporation models viz. Dalton model, Combination model, Christiansen model, Hargreaves model and Morton model and compared with observed pan evaporation. None of the original model was found to perform well in Udaipur region. However, the performance of modified Hargreaves and Christiansen model was found to be better than the original models for prediction of evaporation.

Xu and Singh (2000) evaluated and generalized radiation based methods for calculating evaporation. Eight radiation based equations for determining evaporation were evaluated and expressed in five generalized forms. Five evaporation equations (Abtew, Hargreaves, Makkink, Priestly and Taylor and Turc), where each represents one generalized form, were then compared with pan evaporation measured at Changins station in Swizerland. The comparison was first made using the original constant values involved in each equation and then using the recalibrated constant values. Evaporation of the Priestley and Taylor equation requires net radiation data as input in this study, net radiation was estimated using equation owing to the lack of observation data. The results showed that when the original constants were used, large errors resulted for most of the equations when recalibrated constant values were substituted for the original constant values, four of five equations improved greatly and all the five equations performed well for determining mean annual evaporation. For seasonal and monthly evaporation, the Hargreaves and Turc equation showed a significant bias, especially for cold months. With properly determined constant values that agreed most closely with pan evaporation in the study

Abtew (2001) developed evaporation estimation model for lake Okeechobee. Lake Okeechobee, located in subtropical South Florida, is the second largest completely contained freshwater lake in the United States. The average, annual evaporation is 132 cm, Seven evaporation methods were evaluated to compare their applicability in providing daily lake evaporation estimation for water management purpose. The analysis used five years meteorological data, measured inside the lake. Monthly pan coefficients and annual average pan coefficients were produced for seven pan evaporation stations in the vicinity of Lake Okeechobee. Using the recommended simple models and the remote meteorological data, lake Okeechobee daily evaporation can be reported at the end of each day of water management decision-making.

Xu and Singh (2001) have evaluated seven temperature-based equations, each representing a typical form and compared for determining evaporation at two climatological stations (Rawson Lake and Atikokan) in north-western Ontario, Canada. The comparison was first made using the original constant values involved in each equation, and then using the recalibrated constant values. The results showed that when the original constant values were used, larger bases existed for most of the equations for both stations. When recalibrated constant values were substituted for the original constant values, six of the seven equations improved for both stations. Using locally calibrated parameter values, all seven equations worked well for determining mean seasonal evaporation values, the modified Blaney-Criddle method produced least error for all months for both stations, followed by the Hargreaves and Thornthwaite methods. The Linacre, Kharrufa and Hamon methods showed a significant bias in September for both stations. With properly determined constant values, the modified Blaney-Criddle, the Hargreaves and Thornthwaite methods can be recommended for estimating evaporation in the study region, as far as temperature-based methods are concerned.

Hordofa (2004) developed vapour pressure deficit based model from linear regression analysis. The derived equations have shown a relatively low but a highly significant correlation coefficient associated with slightly high standard error on weekly basis in most agro-climatic stations of Ethiopia. This indicated that derived equations were quite satisfactory for estimation of pan evaporation in most agro-climatic stations of Ethiopia.

Mishra *et al.*, (2004) presented a method for estimating rainfall of different return period without going for testing the suitability of different distribution functions. The study indicated that *f* (TND) the transformed normal distribution can be used as a deterministic approach towards frequency analysis. The behavior of rainfall extremes for different stations of Vindhyan plateau of Madhya pradesh can be well described by *f* (TND) for power γ less than 0.2.

3. Linear regression evaporation models

The review on literature related to the linear regression evaporation models at various locations are presented as below.

Iruthayaraj and Morachan (1978) carried out an investigation during 1971 to 1973 at the TamilNadu Agricultural University, Coimbatore, India to develop appropriate relationship between a USWB Class A pan evaporimeter, a sunken screened open pan evaporimeter and a can evaporimeter and found out the relationship between the meteorological parameters and evaporation from different evaporimeters. It was observed that a sunken-screened open pan evaporimeters recorded much lower values of evaporation as shown by the ratios to the can evaporimeter evaporation to USWB Class A pan evaporimeter. Hence a can evaporimeter can be advocated for cheapness and easy installation in calculating the USWB Class A pan evaporation, which is generally taken as the consumptive use of water for rice. This is obtained by using the regression equation $Y = 0.2 + 0.87\ X$ for monsoon season and $Y = 3.87 + 0.54\ X$ for summer season where Y is the USWB Class A pan evaporimeter evaporation in mm/day and X is the can evaporimeter evaporation in mm/day. Further it was found that the wind velocity, sunshine and solar radiation were positively correlated, whereas relative humidity and mean air temperature were negatively correlated with evaporation in all evaporimeters. The five parameters used linearly together gave a higher coefficient of determination for all evaporimeter measurements under different seasons and water management treatments.

Senapati *et al.*, (1985) studied the relationship between pan evaporation and various meteorological parameters like air temperature, wind speed, relative humidity and bright sunshine hours. Dalton's type equation was developed on seasonal and annual basis to predict evaporation. A linear multiple regression analysis revealed that the above meteorological parameters were found well correlated with pan evaporation with multiple correlation coefficient of 0.975.

Flilho and Ridiero (1986) studied evaporation data from a class A pan in Amazonia, Brazil and showed a coefficient of determination with the air saturation deficit of $R^2 = 0.91$ and the coefficient of determination between actual and potential evaporation being $R^2 = 0.79$.

Chandra *et al.*, (1988) studied the effect of meteorological parameters such as air temperature, relative humidity, wind speed and number of sunshine hours on pan evaporation. The prediction equations for the three seasons decided as per the trend of the parameters developed through single and multiple linear regression analysis. The study reveals that the above meteorological parameters can well be correlated with pan evaporation.

Hanson (1989) showed that Class A pan evaporation from three sites on the Reynolds Creek Experimental Watershed in Southwest Idaho a single equation $Ev = R (0.281 + 0.030 T)$ that incorporated solar radiation and mean temperature could be used to estimate daily pan evaporation. The estimate could be improved by adding a daily wind run term to the basic equation, so the following algorithm was investigated as $Ev = R (0.102 + 0.034 T) + 0.0045 W$. The correlation coefficients ranged from 0.84 to 0.90, which indicated that the equations obtained from the optimization represented measured daily evaporation values quite well. Daily evaporation varied between 7.5 mm/day at the mid elevation site (1,649 m) and 6.5 mm/day at the highest elevation site (2,097 m). Daily amounts were very similar for the low elevation site (1,193 m) and the mid elevation site. Total summer evaporation was 1255, 1082 and 795 mm for the low, mid, and high elevation sites respectively.

Singh *et al.*, (1992) investigated relationship between evaporation from US Class A open pan evaporimeter and meteorological parameters at Hisar. All five meteorological parameters (wind speed, maximum and minimum temperature, per cent relative humidity, bright sunshine hours per day and solar radiation) had significant influence at 1% level on evaporation rate at Hisar. Wind velocity, sunshine hours, mean air temperature and solar radiation were positively correlated with evaporation and relative humidity was negatively correlated with evaporation. The highest correlation value (r = 0.78) were obtained with relative humidity. Multiple regression equation $E = -1.41 + 0.10 T - 0.03 RH + 0.20 S + 0.21 W + 0.04 SD$ showed a maximum coefficient of determination ($R^2 = 0.96$) when all the major meteorological parameters were considered together.

Sahu *et al.*, (1994) have established quantitative relationship between the pan evaporation and eight different meteorological parameters using stepwise multiple regression analysis. A software package MICROSTAT was used for the analysis The variables viz. evaporating power of the air (Ea) and solar radiation (Rs) were found to be significant factors influencing pan evaporation for annual and seasonal basis while the weather parameters like air temperature, relative humidity and wind speed showed a significant effect during summer season. The prediction equations fitted for different seasons and annual basis explained more than 91 per cent variation in pan evaporation. With the help of the regression equations developed in this study, it may be possible to estimate pan evaporation in South Saurashtra agro-climatic zone. The multiple regression on annual basis was expressed as $E_0 = -3.7629 + 0.5983Ea + 0.7218Rs + 0.1949W$.

Singh *et al.*, (1995) obtained simple correlations between different meteorological parameters and evaporation measured from US Class A open pan evaporimeter. The highest value of correlation coefficient (0.85) was found with maximum temperature followed by wind speed (0.82). The coefficient of determinates for minimum air temperature, relative humidity and bright sunshine hours were 0.70, – 0.56 and 0.15, respectively. After considering all these meteorological parameters together, a multiple regression equation $Y = 26.679 - 0.585 Tmax + 0.653 Tmin - 0.277Rh + 0.215 Ss + 0.336 Ws$ ($R^2 = 0.92$) has been developed for the calculation of evaporation for Hisar region. The estimated values were very close to the observed values of evaporation.

Prasad and Sinha (1996) estimated pan evaporation with meteorological parameters. In a field study in Bihar, meteorological data (mean air temperature, relative humidity, solar radiation and wind speed) were successfully used in estimating evaporation.

Ozturk and Apaydin (1998) estimated pan evaporation from limited meteorological observations using simplified version of Penman's evaporation formula, which requires only temperature, wind and dew point data in addition to latitude and tested its universality. Estimates differed from measured values by about 0.65 mm/day at 19 locations in Turkey.

Alshaikh (1998) carried out evaporation studies in the arid Riyadh region of Saudi Arabia to assist water management issues such as water balance and estimation of irrigation water requirements. Monthly data were collected on air temperature, solar radiation, air humidity and wind speed. Single linear, multiple linear, single non linear and multiple nonlinear regressions were conducted with respect to measured values of evaporation in order to come out with the best fit evaporation model. An aerodynamic equation form was used to develop an evaporation model for the study area.

Khanikar and Nath (1998) established relationship between meteorological parameters and evaporation from an open pan evaporimeter. The coefficient of determination for maximum temperature (0.64), minimum temperature (0.65), wind speed (0.53) and soil temperature at 5 cm depth (0.68) was positively correlated. The relative humidity (0.03) was negatively correlated. Stepwise regression showed that maximum temperature, wind speed and relative humidity are the most significant parameters that control pan evaporation at Jorhat, Assam. The coefficient of determination was 0.91, when these three parameters were considered together for estimating pan evaporation. Stepwise regression equation was the better model for estimating evaporation at Jorhat.

Shrivastava *et al*., (2000) made correlation between pan evaporation and other climatic parameters for Sundrebans, West Bengal. Weekly climatic data of 25 years (1963-87) have been statistically analyzed. To establish the relationship between pan evaporation and climatic parameters, the method of regression was adopted as suggested by Mendenhall and Sincich. The linear, quadratic and cubic regression equations have been developed for individual parameters and over all utility of the model has been tested considering the significance of leading coefficients for all the parameters. On the basis of overall utility of the model, a linear relationship was obtained between evaporation and parameters named minimum temperature, maximum humidity and wind speed. The relationship was quadratic for maximum temperature and minimum humidity whereas cubic relationship was obtained for sunshine hours. The multiple regression model $E = 17.2646 + 1.6613\ Tmax - 0.6575\ RH_1 + 1.8715\ SH + 0.9462\ WS$ ($R^2 = 0.921$) was developed. The evaporation values estimated using the existing methods namely, modified Blaney-Criddle Penman, Thornthwaite, Radiation and Christiansen and by the developed regression model were compared with the observed values. It has been observed that the multiple linear regression model gives better estimation of rate of evaporation for Sunderbans.

Shrivastava *et al*., (2001) developed a statistical relationship between the pan evaporation and the meteorological parameters recorded at Jabalpur. The method of regression was adopted as suggested by Mendenhall and Sincich. From the analysis, it is revealed that the morning relative humidity and the maximum temperature have a significant influence on the rate of evaporation. Apart from the relative humidity, number of rainy days is also found to be negative correlated with evaporation. The highest correlation value is obtained with morning relative humidity ($R^2 = 0.95$) followed by the maximum temperature ($R^2 = 0.94$). The following multiple regression model, $E = 3.52 + 0.18\ Tmax – 0.09\ RH1 + 0.04\ RH2 + 0.68\ WS – 1.16\ RD$ was emerged as the best ($R^2 = 0.992$) for estimation of pan evaporation at Jabalpur. On verification, the model showed a variation in the relative error from – 0.45 to + 1.45 for the year 1994 and from – 0.35 to + 1.55 for the year 1995.

Hordofa (2003) evaluated existing evaporation models viz., Penman combination, Dalton model, Christiansen model, Hargreaves model and Mortan model and compared with observed pan evaporation. It was found that no single model was suitable for all agro climatic stations of Ethiopia.

Gupta (2003) analysed the long-term monthly evaporation data of 25 stations of India over a period of twenty five to twenty seven years for evaluating the distribution pattern on monthly basis. The monthly dependable evaporation at 5,10,,25,50,70,80,90 and 95 per cent probability levels were determined.

Gupta (2003) developed stochastic model for monthly evaporation using 25 to 27 years data of the different climatic regions of India. The evaporation series of the different climatic zones were found to be free from trend component. The generated series was compared with observed pan evaporation series. The model developed at each station was validated by predicting two years ahead and compared with the observed pan evaporation series. The test results indicated a high degree of model fitness to observed data series in all agro climatic stations implying to predict evaporation very accurately.

Satpute (2004) developed autoregressive models for estimating weekly water deficits for different agro climatic zones of Maharashtra in India. The validation results indicated the adequacy of the fitted model.

Jhajharia *et al.* (2006) studied the correlation between pan evaporation and meteorological parameters under climatic conditions of the Jorhat. The monthly meteorological data was collected from Tocklai Tea Research station, Jorhat from 1970-1998. The regression methods namely linear, exponential, power and logarithmic have been used to correlate the pan evaporation with meteorological parameters at Jorhat, Assam. The stepwise regression method was used to observe the combined effect of various meteorological parameters on pan evaporation. The wind speed, the sunshine duration and the temperature were found to have significant positive influence on the evaporation. But, the relative humidity has no significant influence on evaporation. It is observed that the evaporation is found to be mainly influenced by the combined effect of the wind speed and the maximum air temperature at Jorhat. The developed regression model for predicting the pan evaporation under climatic condition of Jorhat is $E_{pan} = 3.094 \times T_{max} + 1.168 \times WS – 59.124$ the predicted values obtained from the developed evaporation model of Jorhat matched closely with the observed pan evaporation values.

Kirono and Jones. (2007) described the use of the bivariate test for detecting and adjusting discontinuities in Class A pan evaporation time series for 28 stations across Australia, and illustrates the benefit of using corrected records in climate studies. Ninety-two per cent of the inhomogeneities detected by the bivariate test are consistent with station metadata. Even though the test was designed to detect a single discontinuity in the mean, it can also be sensitive to multiple shifts in the mean. These show the suitability of the bivariate test as a tool for screening pan evaporation data. Having identified inhomogeneities, the adjustments were only applied to records which contained inhomogeneities that could be verified as having a non-climatic origin. The use of original and adjusted records in correlation analysis and in trend analysis produce very different conclusions. At Esperance and Woomera, for instance, unadjusted pan evaporation records do not correlate with potential evapo-transpiration and are positively correlated with rainfall, whereas those of adjusted pan evaporation result in a more sensible inter-variable relationship (i.e. pan evaporation is negatively correlated with rainfall and is positively correlated with estimated potential evaporation). In a trend analysis, most unadjusted pan evaporation records show a statistically significant negative bias, which in most cases, is removed with adjustment. This is consistent with the effect of bird guard installation, early in the time series, that reduces pan evaporation. The trend in the original average of all stations was adjusted from -2.8 ア 1.7 to -0.7 ア 1.6 mm year-2 for 1970-2004, demonstrating the importance of screening the data before their use in climate studies.

Trajković and Vladimir (2008) established a reliable estimation of the reference evapo-transpiration (E_{t0}) is of critical importance for irrigation systems' design. The goals of this research are: firstly, comparison of the evaporation methods, and secondly, analysis whether the evaporation of a Class A pan can be used as a substitution for FAO-56 PM method. In the paper, a comparison of the evaporation methods is done on the basis of the daily data from the Griffith station, Australia. It can be concluded that the Christiansen method is in better agreement with the FAO-56 PM method than the FAO-24 pan method. One of the reasons for a better agreement is a larger number of climatic parameters used than in FAO-24 pan method. The research has demonstrated that the evaporation data can be used as a substitution for FAO-56 PM ET0.

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