Calibration of Crop Coefficients and Evapotranspiration Rates in Semi-Arid and Sub-Humid Agro climates: Impact on Crop Water Requirement

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Abstract: *Crop water requirement, a key component for Irrigation planning and management depends on Actual Evapotranspiration rates. Variations in Evapotranspiration rates depends on the climatic conditions for a given soil and crop. The objective of this work is to determine the water consumptive use based on crop coefficients for Tomato in Semi-arid and Sub-humid agro climates. The Actual Evapotranspiration was quantified by Lysimeters. Sieve analysis of the soil indicated as sandy soil and has density of 1.859*10^{-3} Kg/cm^3. Depending on density and the root depth of tomato crop, lysimeter of dimensions 52cm depth and 36cm diameter is used to measure actual evapotranspiration rate.*

Regression analysis carried out for the actual evapotranspiraton rates, computed using empirical formula indicated that the FAO-56 PM method is well suited for both the regions having correlation coefficients of 0.94 and 0.92 for Semiarid and sub-humid regions respectively. Further, it was found that Thornthwaite equation being the next suited method has a correlation of 0.90 for semiarid and Hargreaves method the next suited method with correlation of about 0.90 for sub-humid. Crop coefficients used in all this potential Evapotranspiration methods were calibrated with lysimeter insitu measurements.

The crop coefficients vary depending on the different crop stages. The recalibrated crop coefficients for tomato crop are 0.78, 1.045, 1.95 and 1.54 for initial, development, mid and late respectively for Semi-arid Agro-climate. Similarly for Sub-Humid agro climate the crop coefficients were found to be 0.9, 0.98, 1.55 and 1.3 respectively.

Keywords:* *SemiArid and Sub Humid regions, Evapotranspiration rates, caliberated crop coefficients, Tomato crop.

I. INTRODUCTION

Fresh water is a finite resource, is limited in summer and the demand for Agriculture is continuously increasing in Asian countries (Ravikumar et al., 2011). Water availability for agriculture depends on climate and the different losses in the existing water cycle. It is well known that water is a major issue almost in all parts of the world especially for countries that have high population growth rates and thus more crop yield (Dinar et al., 2019). Water deficit owing to the temporal-spatial inconsistency between water supply and demand is expected to become harsh in present scenario. Recently, climate changes has shown imbalance in the losses like evapotranspiration rates, thus varying delta for the crop growth (GoI 2016; Surendran, 2019). Development of irrigation systems with efficient use of water is essential for the sustainability of the crop production system and accurate estimation of crop water use (evapotranspiration) is also a critical component for water resource management (Petropoulos et al., 2018). Evapotranspiration rates, one of the key components required for rainfall runoff modeling, reservoir management and other integrated approaches in agriculture dominating watersheds (Danlu et al., 2016). A better understanding of trends in potential evapotranspiration (ET_0) is crucial for scientific management of water resources in varied Agro climates (Dinpashoh et al., 2018).

Accurate estimations on crop water requirement are needed to avoid the excess or deficit water application, with consequent impacts on nutrient availability for plants, soil salinity and groundwater contamination. Evapotranspiration (*ET*) is an important component in water-balance models and irrigation scheduling, and is often estimated in a two-step process. The evaporative demand of the environment is estimated based on weather conditions, and is often estimated as the evapotranspiration from a theoretical, reference grass crop (*ETo*) with the crop defined as an actively growing, uniform surface of grass, completely shading the ground, and not short of water. The *ETo* value is then adjusted to estimate the evapotranspiration of the particular crop of interest using a crop-specific crop coefficient (Fisher and Pringle, 2013)

Evapotranspiration varies with time, distance and altitude, a number of studies have attempted to investigate the trend of evapotranspiration rates ((Dinpashoh et al., 2018). The various factors affecting the rate of evapotranspiration depend on Weather parameters, Crop factors and Management and environmental conditions. Upon Identification of the best alternative methods for each climate, our intention was to develop regression equations, which could serve as practical tools for estimation of ET_C values estimated by the simpler methods (Nandageri, 2006).

Reference evapotranspiration and crop evapotranspiration are the two types of evapotranspiration which are been defined by the Food and Agriculture Organization (FAO 56). The evapotranspiration rate from a reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as ETo. The reference surface is a hypothetical grass reference crop with specific characteristics. The crop evapotranspiration under standard conditions, denoted as ETc, is the evapotranspiration from disease-free, well fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions (Allen et al., 1998). ETo depends on various factors like Weather parameters, Crop factors, Management and environmental conditions. ET_0 depends only on the climatic conditions and expressing the evaporation power of the atmosphere. While, ET_C depends on the environment and management factors under the given climatic conditions.

There exist a multitude of methods for the estimation of potential evapotranspiration ET and free water evaporation E, which can be grouped into five categories: (1) water budget, (2) mass-transfer, (3) combination, (4) radiation (e.g. Priestley and Taylor, 1972), and (5) temperature-based (e.g. Thornthwaite, 1948; Blaney-Criddle, 1950). The availability of many equations for determining evaporation, 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 for a given study (Xu and Singh, 2002). Hence there is a need to assess evapotranspiration losses for given soil conditions that has implications on efficient water resource management in basins experiencing varied agro climates.

Crop coefficient does not only vary with climate but in combination with crop stage. Irrigation frequency and water supply for each watering depends on crop stage besides evapotranspiration rates, thus crop coefficients are to be computed in combination with climate parameters as well as crop stage (Seidel et al., 2019).

II. MATERIALS AND METHODOLOGY

First stage of the study comprises of the most commonly used empirical methods for estimating Evapotranspiration. Empirical based values were evaluated and compared within each category and the best and good methods are ranked for two dominant agroclimates of Karnataka (Figure. 3). In the second stage of the research, comparison is made for the evapotranspiration rates that are mass-transfer based, radiation-based and temperature based, respectively. Weather parameters for representative selected study site for Semi-arid and Sub-humid regions were collected from the website of Karnataka State Natural Disaster Monitoring Center and using the empirical formula, potential evapotranspiration rates for tomato crop is computed. Soil core samples collected from the spatially dominant soil group in the Semi-Arid agro climate were analyzed in the laboratory for its physico-chemical parameters and therefore the same soil conditions were maintained in both the agro climates. Lysimeter was setup in both the Agro climates to compute the Actual ET rates having similar root zone depth (40 cm). Regression analysis is attempted to understand the best fit model for each agro climate (Figure.1).

2.1 Experimental Setup

2.1.1 Lysimeter Pot

A small Drum with 52cm depth and 36 cm diameter (Figure 2) is used as micro lysimeter, the depth of the lysimeter is decided upon the maximum rooting depth of the crop, Hence providing a sufficient depth for attaining the root growth.

2.1.2 Water Storage Container

A 10 l polyethylene container is used to collect drained water. The excess water after satisfying the water holding capacity of soil and plant needs, gets percolated at the bottom and then accumulates in this container. For ease of recording the amount of water accumulated, Graduations in ml is marked on it. This container is placed in a trench below the foot level of lysimeter drum and also preventing evapotration of collected water.

After the installation, the drum is filled with a measured quantity of soil. The quantity of soil is measured on the basis of density of soil. It is such that the field density is maintained into the lysimeter which is of about $1.859*10^{-3}$ kg/cm^3 and 98.48 kg of soil is filled in the lysimeter. A measured quantity of water is irrigated on a daily basis or in an interval of time and the tomato seeds are allowed to germinate. In this study, the irrigation is provided about 3lts of water for every 2 days. the water loss due to evapotranspiration can be determined by simple calculation i.e. the difference of total water added by irrigation, rainfall or both and the excess water collected into the collecting tank at the bottom through percolation.

$$ETc = WA + R - WP$$

Where, ETc: Crop evapotranspiration, WA: Water added, R: Rainfall, WP: Water percolated

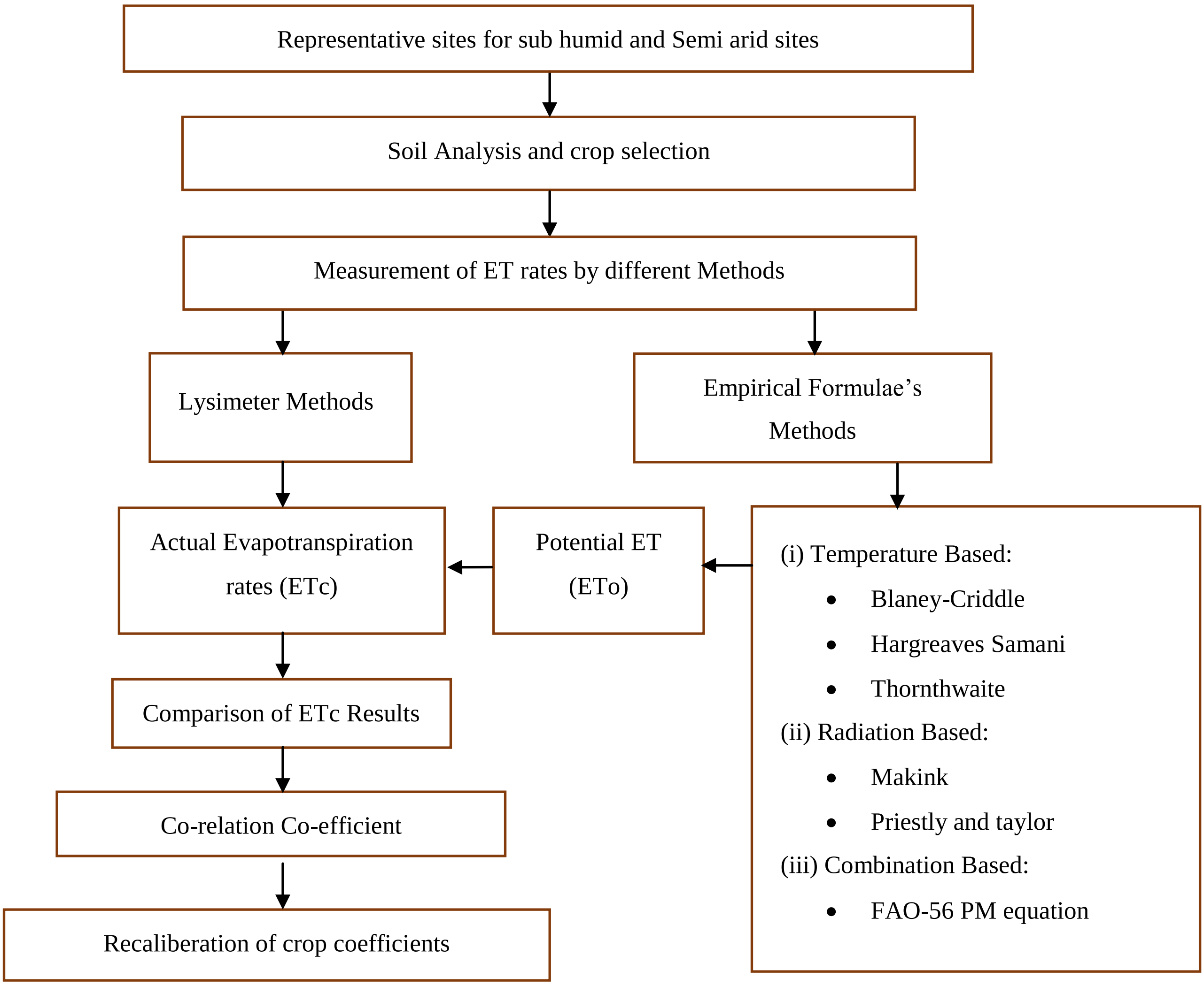


FIGURE 1: Methodology flow chart of the study

(a) **(b)**

FIGURE 2: Lysimeter Setup in both regions (a) Semi-Arid region, (b) Sub-Humid region.

III. PILOT STUDY

This study was carried out in two agro climatic regions during the period from March - June (2019) and the lysimeter were setup in both the regions. The first station ''Devarabelekere'' is an experimental farm representative site for Semi-Arid tropical climate. The farm is located at the city limits between Davanagere and Malebennur (Karnataka, India) and its average geographical coordinates are latitude 14.47^{o} N, longitude 75.91^{o}E and the altitude is 602.5 m above sea level (Figure.3). The Semi-arid region having average temperatures in the coldest month (July) of 5.7 °C and in the hottest month (March) of 46.9 °C approximately. During this study period the mean daily temperature was 29.5°C; the degree of sunshine was high with an average of 12.4 hr/day.

"Balekundri" represents Sub-Humid region which is located between the Belgaum city and Marihal village. Its coordinates lie between Latitude: 15.88^{o} N, Longitude: 74.52^{o} E and at an elevation 751 m above sea level (Figure 3). The surroundings are fully representative of irrigated land in the area. Data are available on thermal and water characteristics of the area over a long period of time. Moreover, the data correspond to the period in which the experiment took place, were obtained from automated agro climatic stations.In the same way, Sub-Humid region has average temperatures in the coldest month (January) of 4 °C and in the hottest month (April) of 39.5 °C approximately and during this study period the mean daily temperature was 28.21 °C; the degree of sunshine was high with an average of 12.51 hr /day.

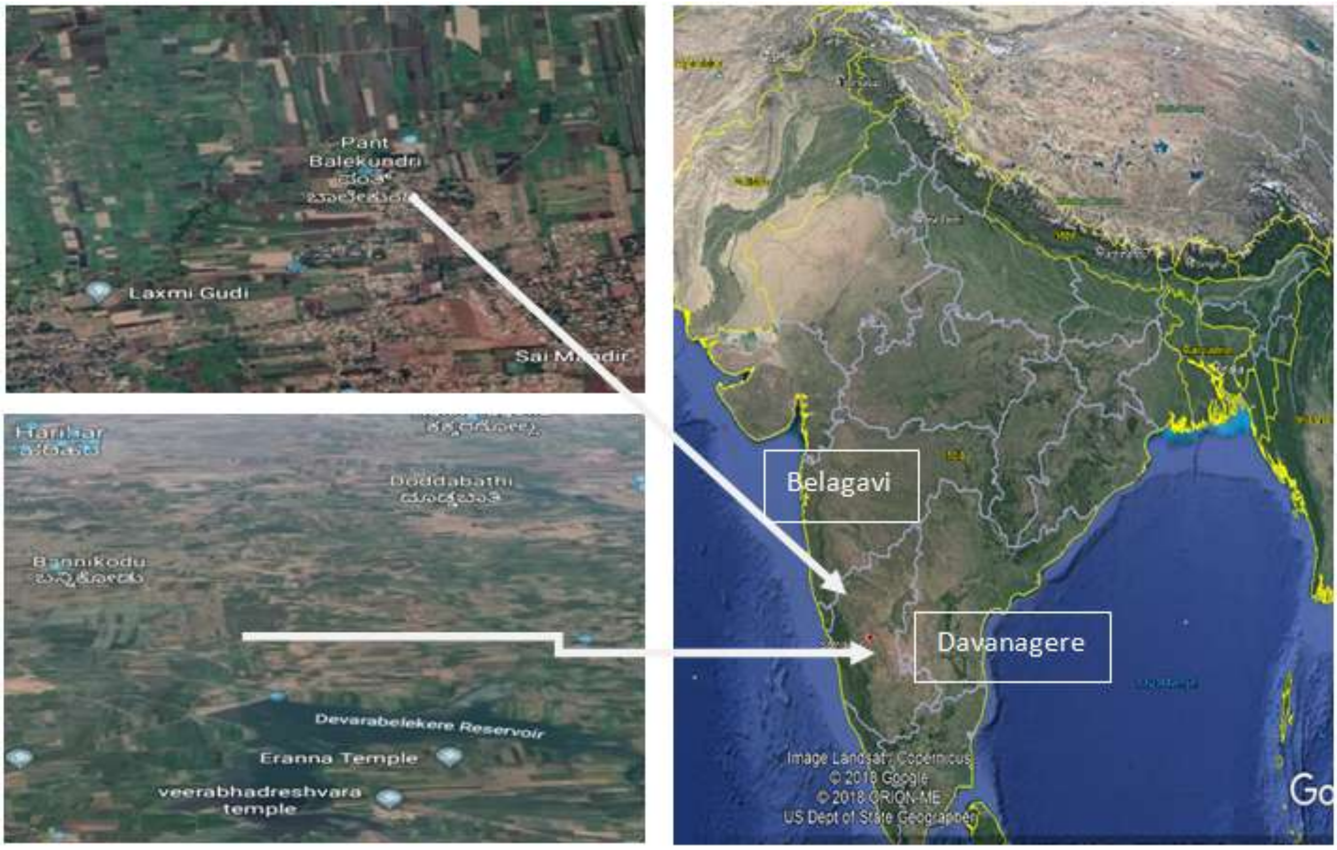


FIGURE 3: Location of both the study area (i.e. Belagavi: Sub-Humid and Davanagere: Semi-Arid region) in Karnataka, India

3.1 Estimation by Empirical formula

When complete set of weather data required for the FAO-56 PM method are not available, procedures are described for using a reduced set of weather data as input. While air temperature measurements are almost always available, reliable measurements of solar radiation, relative humidity, and wind speed may not be. Extensive discussion and methods for estimating missing values are presented based on temperature measurements, historical and general knowledge of local environmental conditions. The reduced set of values, consisting of measured data and estimated values, is then input to the FAO-56 equation. In this study, this method was used to estimate ETo assuming the availability of maximum and minimum air temperatures only.

3.2 Weather parameters:

The weather parameters on which the Empirical formulae's rely are the daily recorded data's of Temperature, Humidity and Wind Speed, the same having average values are shown in the below (Table. 1).

TABLE 1
WEATHER PARAMETERS FOR SUMMER SEASON OF 2019.

Month	Avg. Daily Temperature (°C)		Avg. Daily Humidity (%)		Avg. Daily Wind Speed (m/s)	
	S-A	S-H	S-A	S-H	S-A	S-H
March	29.6	28.03	41.97	57	1.65	1.77
April	30.61	29.08	50.06	58.6	2.48	1.98
May	29.91	29.12	58.80	59.41	3.52	3.07
June	27.87	26.60	67.75	73.87	4.39	3.86

Note: S-A: Semi-Arid, S-H: Sub-Humid.

The Average daily temperature and wind speed of Semi-arid region if found to have 1.29 °C and 0.34 m/s more than that of Sub-Humid region respectively. But the Humidity level is found to be 7.58% more in Sub-Humid region than semi-arid region. Hence the ET rates will tend to vary depending on these parameters in the respective agro climates.

Different reference evapotranspiration methods exist and range from direct measurement from a reference crop such as a perennial grass (Doorenbos and Pruitt, 1977) or computed from weather data using:

a) Temperature models (Thornthwaite, 1948; Doorenbos and Pruitt, 1977),
b) Radiation models (Doorenbos and Pruitt, 1977; Hargreaves and Samani, 1985), and
c) Combination models (FAO-56 PM) (Allen et al., 1998).

The standardized Penman–Monteith equation had been adopted and recommended for reference evapotranspiration estimation. The various methods adopted in this study are listed below: Crop water use is generally estimated by multiplying the reference evapotranspiration by pre-determined crop-specific coefficient, which is dependent on many factors, including irrigation regimes and management (Djaman and Irmak, 2013).

3.3 Temperature Based Models:

3.3.1 BlaneyCriddle Method:

This method is suggested for areas where available climatic data cover air temperature data only. It requires only mean daily temperatures T (°C) over each month (Blaney and Criddle, 1962):

$$\mathrm{ET_o} = \mathrm{p} * (0.46\mathrm{T} + 8)\mathrm{mm/day} \quad (1)$$

Where, ETo: Reference evapotranspiration (mm/day), p: mean daily percentage (for the month) of total annual daytime hours for Northern Hemisphere, T: Mean daily temperature in (°C) over the month considered.

3.3.2 Thornthwaite Equation:

Thornthwaite correlated mean monthly temperature with evapotranspiration as determined from water balance from valleys with sufficient moisture available for maintaining transpiration. To calculate Potential Evapotranspiration (PET) using Thornthwaite method, first the Monthly Thorthwaite Heat Index (i) calculation is required, using the following formula (Thornthwaite, 1948):

$$i = \left(\frac{t}{5}\right)^{1.514} \quad (2)$$

Where, t: mean monthly temperature

The Annual Heat Index (I) is calculated, as the sum of the Monthly Heat Indices (i):

$$I = \sum_{i=1}^{12} i \quad (3)$$

Potential Evapotranspiration (PET) estimation is obtained for each month, considering a month is 30 days long and there are 12 theoretical sunshine hours per day, applying the following equation:

$$PET_{noncorrected} = 16 * \left(\frac{10*t}{I}\right)^{\alpha} \quad (4)$$

$$\text{Where } \alpha = (675 * 10^{-9} * I^3) - (771 * 10^{-7} * I^2) + (1792 * 10^{-5} * I) + 0.49239 \quad (5)$$

Obtained values are later corrected according to the real length of the month and the theoretical sunshine hours for the latitude of interest, with the formula:

$$PET = PET_{noncorrected} \quad * \frac{N}{12} * \frac{d}{30} \tag{6}$$

Where, N: Theoretical sunshine hours for each month and d number of days for each month

3.3.3 Hargreaves & Samani Equation:

The Hargreaves & Samani equation estimates ETo based on maximum and minimum air temperature, and is written as (Hargreaves and Samani, 1985):

$$\mathrm{ETo} = 0.023(0.408)(\mathrm{T_{mean}} - 17.8)(\mathrm{T_{max}} - \mathrm{T_{min}})^{0.5}\mathrm{Ra} \tag{7}$$

Where, Tmax = maximum air temperature (˚C), Tmin = minimum air temperature (˚C), Ra = extraterrestrial radiation ($MJ \cdot m^{-2}$), and 0.408 is a factor to convert MJ m^{-2} to mm. Extraterrestrial radiation, Ra, is estimated based on the location's latitude and the calendar day of the year.

3.4 Radiation Based Models

3.4.1 Priestley–Taylor Equation

The PriestlyTaylor equation is a simplification of the original Penman method, where the aerodynamic term is replaced by an empirical coefficient, known as the Priestley– Taylor parameter (Priestley and Taylor, 1972). The method is expressed by:

$$\mathrm{ETo} = 1.26 * \frac{\Delta}{\Delta+\gamma}\left[\frac{\mathrm{R_n} - \mathrm{G}}{\lambda}\right] \tag{8}$$

Where, λ: Latent Heat of Vaporization (2.45 MJ kg^{-1}). In fact, the Priestly Taylor parameter varies with different vegetation types, soil moisture conditions, and strength of advection (Priestley and Taylor, 1972; Stannard, 1993), and should be calibrated for different environmental conditions.

3.4.2 Makkink Equation

Makkink equation was proposed in 1957 for estimating ET from grass, the equation Stands as (Djaman et al., 2015):

$$ET = 0.61 * \frac{\Delta}{\Delta+\gamma} * \frac{R_s}{\lambda} - 0.12 \tag{9}$$

Where, Rs: Total Solar Radiation, Δ: slope of Saturation Vapor Pressure curve, γ : psychrometric constant, λ: latent heat.

IV. RESULTS AND DISCUSSIONS

4.1 Potential Evapotranspiration rates:

Reference evapotranspiration rates in both the regions by all the six methods are presented in table 2. It is observed that the ETo rates are less in sub humid region when compared to semi-arid region. The average ETo rates by FAO-56 PM equation n are 7.18 and 6.98 mm/day in Semi-Arid and Sub-Humid region respectively where as Thornthwaite equation it is 5.43 and 4.9 mm/day in the respective regions. BlaneyCriddle method in 6.23 and 5.66 mm/day respectively, by Hargreaves Samanieqn: 5.62 and 5.81 mm/day respectively, by Priestly Taylor eqn: 7.13 and 6.9 mm/day respectively and lastly by Makkinkeqn it is found to be 5.33 and 5.31 mm/day respectively.

TABLE 2
POTENTIAL EVAPOTRANSPIRATION RATES BY EMPIRICAL EQUATONS IN SEMI-ARID AND SUB-HUMID REGION.

Month	FAO-56 PM		TW		BC		H&S		P&T		MK	
	S-A	S-H	S-A	S-H	S-A	S-H	S-A	S-H	S-A	S-H	S-A	S-H
Mar	7.03	6.72	5.71	4.86	6.08	5.64	5.71	6	6.69	6.56	5.33	5.24
Apr	8.01	7.19	5.54	5.11	6.22	5.77	6.74	6.27	6.86	6.98	5.5	5.42
May	8.15	7.61	5.36	5.12	6.35	5.77	5.63	6.39	7.36	7.04	5.41	5.4
June	5.54	6.43	5.12	4.52	6.27	5.46	4.41	4.58	7.61	7.03	5.08	5.18
Avg.	7.18	6.98	5.43	4.9	6.23	5.66	5.62	5.81	7.13	6.9	5.33	5.31

Note: S-A- Semi-Arid region, S-H:- Sub Humid region, FAO-56 PM: Penman Monteith's method, TW: Thornthwaite method, BC: Blaney Criddle method, H&S: Hargreaves Samani method, P&T: Priestly and Taylor method, MK: Makkink method.

4.2 Crop Factor:

In the case of ETo grass is used as the reference crop. However other crops may not use the same amount of water as grass, due to changes in rooting depth, crop growth stages and plant physiology. The crop coefficient (Kc) takes into account the crop type and crop development to adjust the ETo for that specific crop. There may be several crop coefficients used for a single crop throughout an irrigation season depending on the crop's stage of development.

Crop coefficient (Kc) for tomato for every growing stages of the tomato crop differs hence the Kc value used in this study are 0.45(initial stages), 0.75(development stage), 1.15(mid-stage) and 0.80(late stage) (Rowell and Soe, 2016).

4.3 Computation of ETc:

The actual Evapotranspiration rates for tomato crop by various empirical reference ET methods are calculated. These results are obtained by multiplying the reference evapotranspiration rates with the suitable crop coefficients. Hence, The Actual ET is estimated by using the crop coefficients of tomato mentioned above.

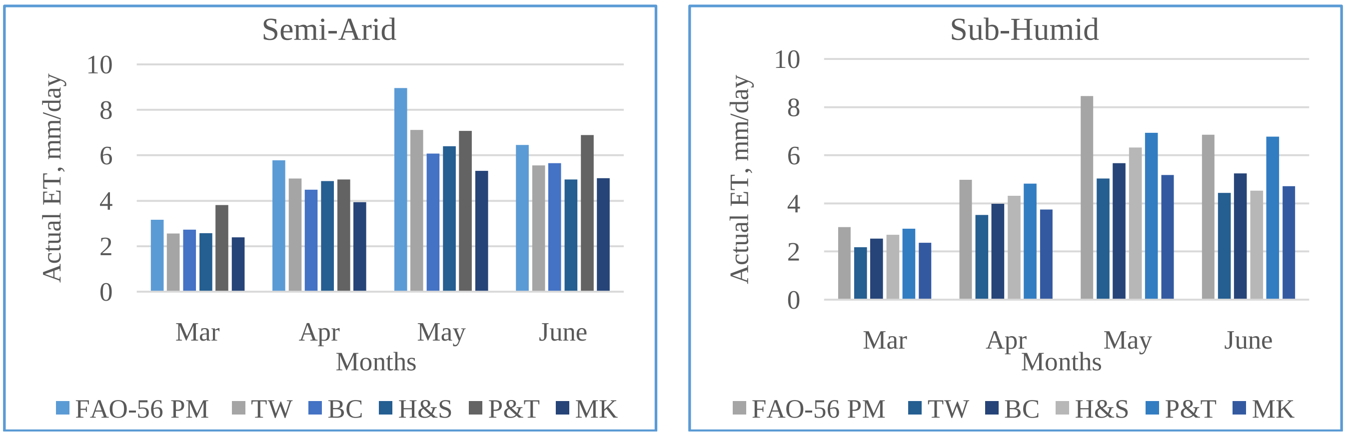


FIGURE 4: Actual ET rates by Empirical formulaes using crop coefficients

The Actual Evapotranspiration rates is primarily dependent on the climatological factors. Hence we can see in figure 4 the variations in ETc rates due to greater temperature of about 1.29°C more in Semi-Arid region than that of Sub-Humid region, 7.57% lesser humidity in Semi-Arid than Sub-Humid and 0.39m/s greater wind speed in Semi-Arid region than Sub-Humid region. In Semi-Arid region, there is a slight increase in temperature of about 1.01°C in the month of April and the corresponding Humidity also increased of about 8.09% and also the wind speed of about 0.821 m/s. We can see that the ETc rates by various formulaes, as the temperature increases the Priestly Taylor Equation falls down gradually and again when there is increase in temperature the same equation shows rising values. The Actual evapotranspiration rates by lysimeter method was found to be maximum at the development stage i.e. during the month of May of about 12.7 mm/day in semi-arid region and 10.7 mm/day in sub-Humid region. Average ETc is measured to be 8.40 and 7.77 mm/day in both regions respectively.

4.4 Insitu Methods: Lysimeter

Insitu evapotranspiration is measured using lysitmeter. Lysimeter is defined as a device for measuring the percolation of water through soils and for determining the soluble constituents removed in the drainage. The water use (evaporation, transpiration, or ET) can be determined by a balance of the water above this boundary. Weighing lysimeters determine ET directly by the mass balance of the water as contrasted to non-weighing lysimeters which indirectly determine ET by volume balance.

4.5 Soil Analysis:

Lysimeters in both the agro climates are filled with the same type of soil (sandy soil) was used that has density of $1.859*10^{-3}$ kg/cm^3. The water holding capacity is measured to be 40.02 lts (25gms = 10ml) and the moisture content of the soil was 1.61(Table 3). The pH and electrical conductivity of soil was measured to be 7.96 and 0.35 respectively. The nutrients concentration also was analyzed for Nitrogen, Phosphorous and Potassium, The obtained K value(21.94) (Table 3) is less than the 200 kg/ha which shows the soil has less K and not sufficient nutrient to grow plant. N(10.4), the limitations of N is 150-600 kg/ha, the N content of soil is below limitation is due to less N fixation and less microbial decomposition in soil. So that the collected soil sample is not suitable for crop production. P(0.310) less than 5 kg/ha which shows the less content of P for growth of plant (Table 3).. Hence additional nutrients is applied during the growing stage of plants. The pH and Electrical conductivity was determined by the standard pH meter method and electrometric method which was found to have low electrical conductivity and slightly towards alkaline. The soil held water of about 10ml per 25 gms of soil and the nutrients level was also found to be present is less amount.

TABLE 3
SOIL PROPERTIES OF THE SAMPLE COLLECTED IN FIELD LOCATED IN SEMI-ARID

Sl. No.	Characteristics	Values
1.	Soil type	Sandy soil
2.	Hp	7.96
3.	Electrical conductivity (dS/m)	0.35
4.	Density (kg/cm^3)	1.859*10^{-3}
5.	Quantity of soil used (kg)	98.59
6.	Water Holding Capacity for 98.59kg (L)	40.02
7.	Moisture content	1.61
8.	Nitrogen (kg/Ha)	10.4
9.	Phosphorous (kg/Ha)	0.310
10.	Potassium (kg/Ha)	21.94

4.6 Actual evapotranspirations Rates

In this Study an Experimental measurement of Evapotranspiration rates in the two regions mentioned above was performed using a typical tomato (*Lycopersicon esculentum*) crop, this crop having a base period of 90 to 150 days and is grown throughout the year and every season, Hence this crop was considered in this project. Simple Lysimeters were setup in both the regions. Materials used in this project are Soil, Plastic drum, Plastic Container, water pipe and Tomato seeds.Lysimeter observations for both Semi-arid and Sub-humid region are presented in Table 4.

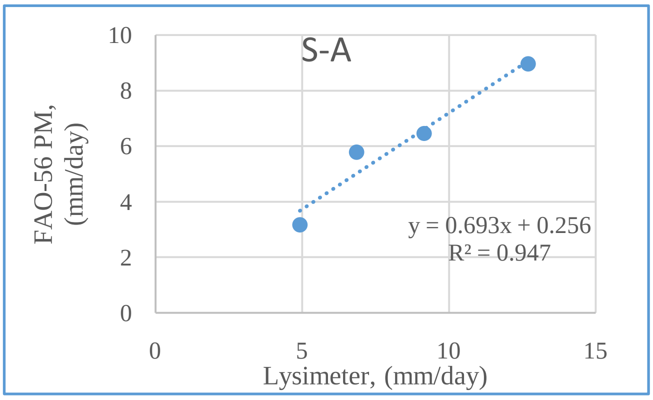
TABLE 4
LYSIMETER OBSERVATIONS IN SEMI-ARID AND SUB-HUMID REGION

Month	Semi-Arid				Sub-Humid			
	Water Added (lt)	Rain fall (lt)	Water Drained (lt)	ETc (mm/day)	Water Added (lt)	Rain Fall (lt)	Water Drained (lt)	ETc (mm/day)
Mar	19	0.012	9.506	4.92	16	2.224	9.112	5.74
Apr	36	1.315	16.4	6.85	30	1.396	9.100	6.55
May	52	1.480	13.6	12.65	40	0.294	2.700	10.7
June	56	7.055	40.700	9.15	38	15.049	30.900	8.10
Total	163	9.862	80.206	8.39	124	18.963	51.812	7.77

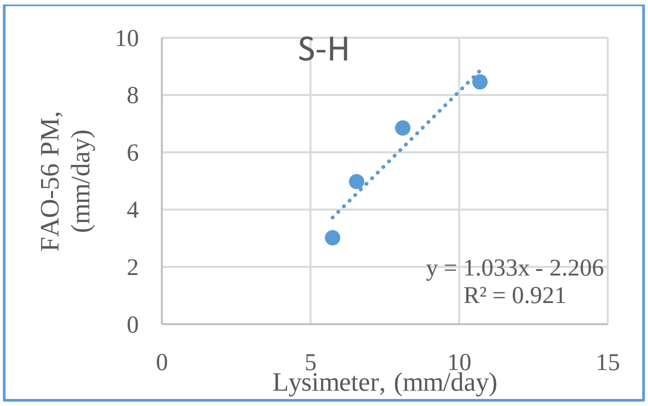
The above lysimeter observations were recorded in both regions and the Average actual evapotranspiration rate of Tomato crop in Semi-Arid region is 8.39 mm/day and in Sub-Humid region it is 7.77 mm/day. This indicates more water requirement for crop growth in semi- arid region. Further, owing to rainfall in the month of June water required for the crop in sub humid region is less.

4.7 Regression Analysis

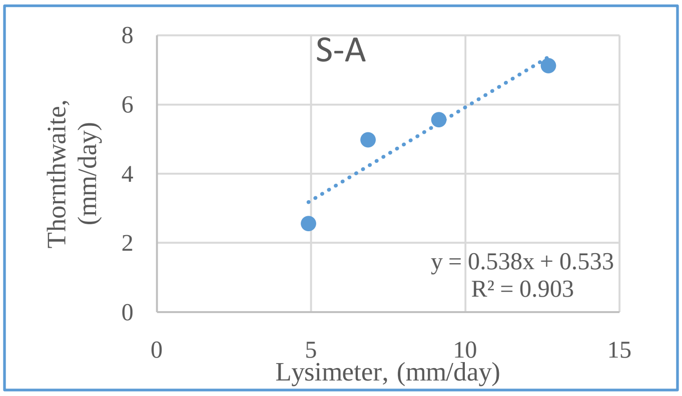
The correlation amongst the Lysimeter method taken as independent variable and the various empirical methods taken as dependent variable, mathematically defines whether the average values of actual Evapotranspiration by lysimeter are interrelated to higher or lesser than average values of empirical methods.


S-A
FAO-56 PM, (mm/day)
Lysimeter, (mm/day)
y = 0.693x + 0.256
R² = 0.947

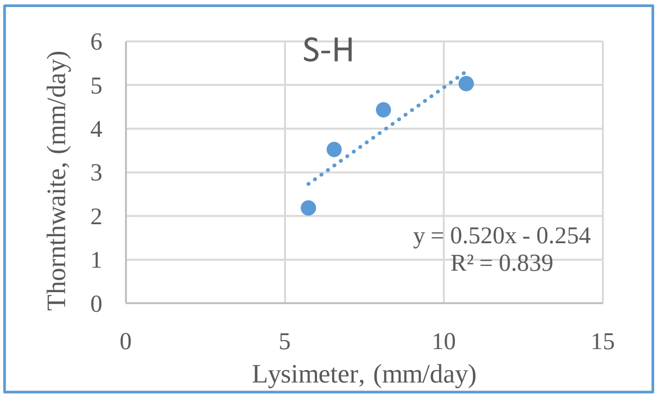
(a)


S-H
FAO-56 PM, (mm/day)
Lysimeter, (mm/day)
y = 1.033x - 2.206
R² = 0.921

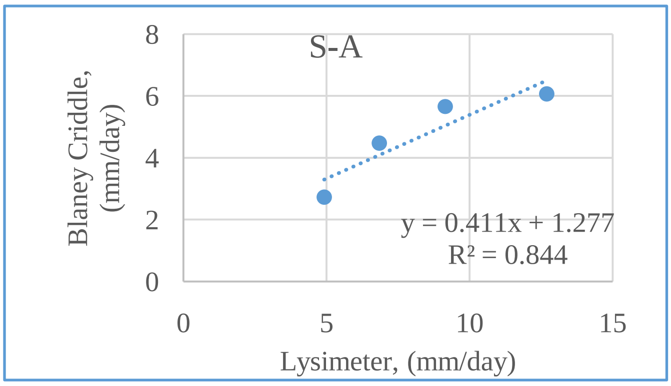
(b)


S-A
Thornthwaite, (mm/day)
Lysimeter, (mm/day)
y = 0.538x + 0.533
R² = 0.903

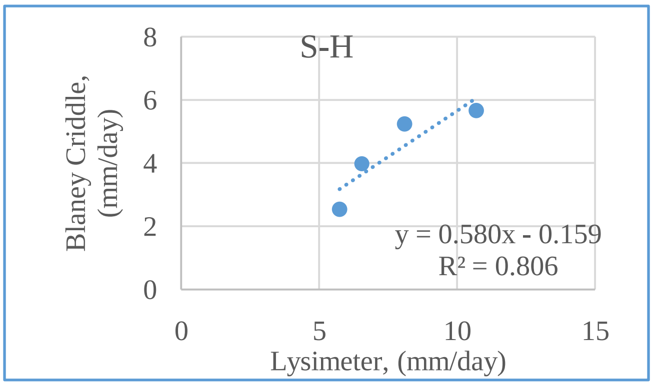
(c)


S-H
Thornthwaite, (mm/day)
Lysimeter, (mm/day)
y = 0.520x - 0.254
R² = 0.839

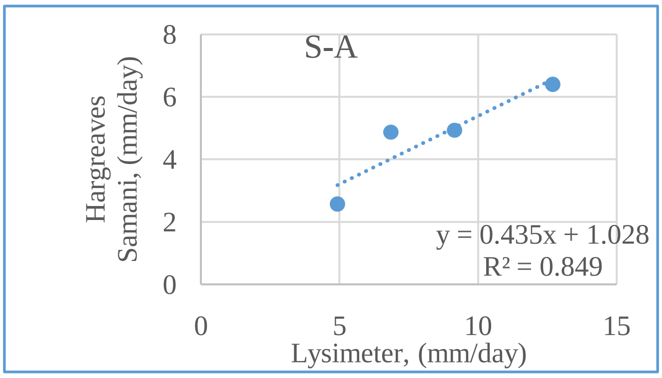
(d)


S-A
Blaney Criddle, (mm/day)
Lysimeter, (mm/day)
y = 0.411x + 1.277
R² = 0.844

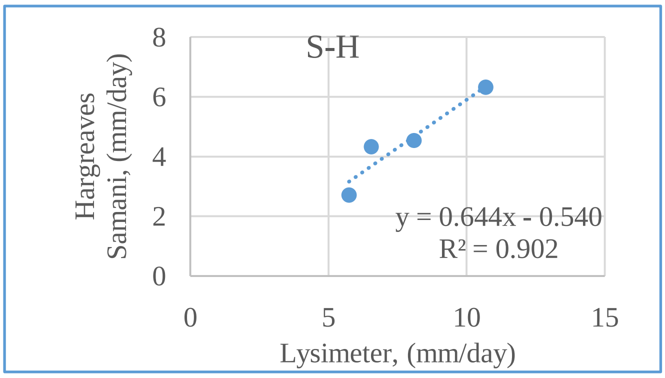
(e)


S-H
Blaney Criddle, (mm/day)
Lysimeter, (mm/day)
y = 0.580x - 0.159
R² = 0.806

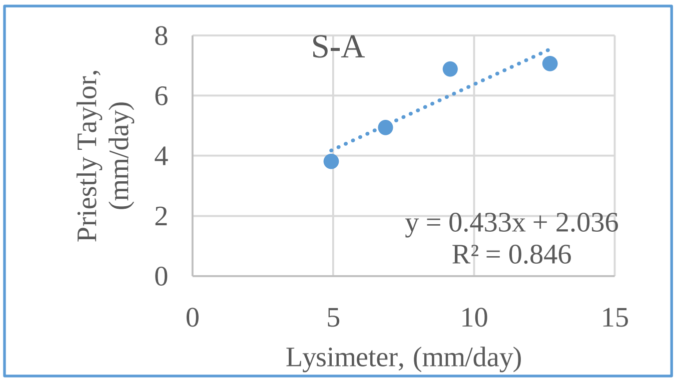
(f)


S-A
Hargreaves Samani, (mm/day)
Lysimeter, (mm/day)
y = 0.435x + 1.028
R² = 0.849

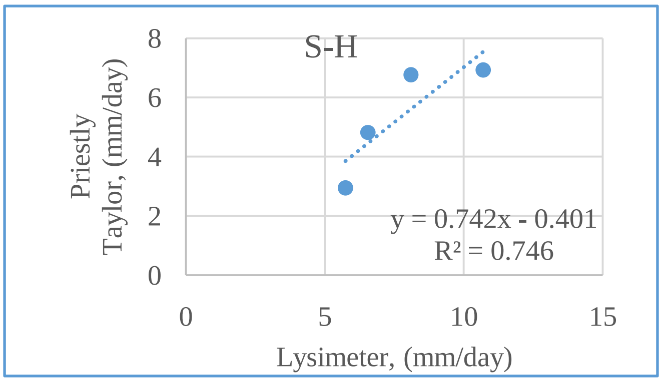
(g)


S-H
Hargreaves Samani, (mm/day)
Lysimeter, (mm/day)
y = 0.644x - 0.540
R² = 0.902

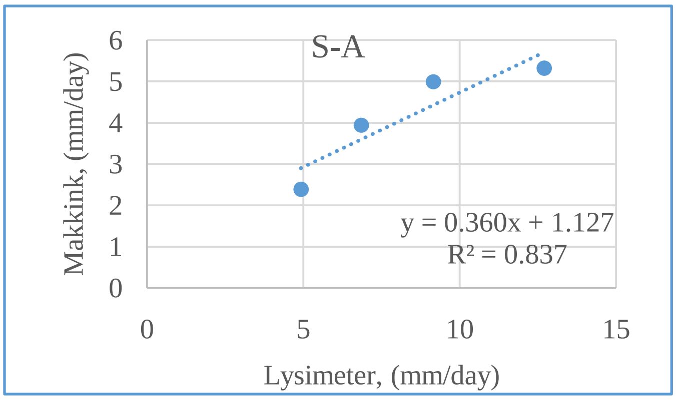
(h)



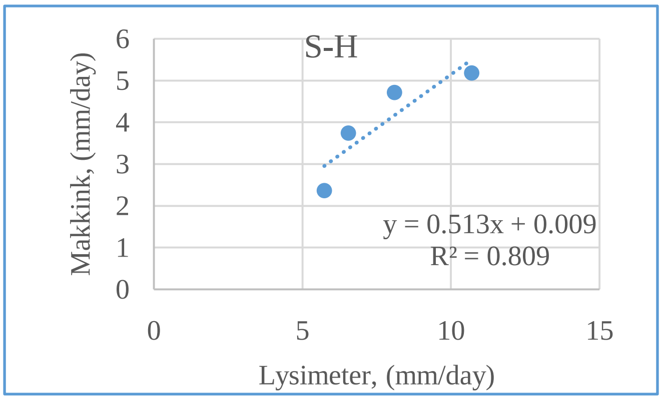
(i)



(j)



(k)



(l)

FIGURE 5: Regression plots for various methods with respect to lysimeter method

(Note:- S-A: Semi-Arid, S-H: Sub-Humid, fig 5(a & b): FAO-56 Penman Monteith method, Fig 5(c & d): Thornthwaite method, Fig (e &f): Blaney Criddle method, Fig5 (g & h): Hargreaves and Samani Method, Fig 5(i & j): Priestly and Taylor method, Fig5 (k & l); Makkink method).

Regression analysis indicates a good correlation for all the empirical methods (table 5). Amongst the empirical methods, The FAO-56 Penman Monteiths equation is the best (R^2 value 0.94 and 0.92 for both semi-arid and sub-humid agroclimates respectively). The Thornthwaite equation has the next highest R^2 value of 0.90 in Semi- Arid climate. The Hargreaves equation has the next highest R^2 value of 0.90 in Sub-Humid climate.

4.8 Recalibrated crop coefficient (kc):

Using the crop coefficients mentioned above shows results with 5 to 20 % errors. These errors are due to the changes in the climatological parameters and hence the crop coefficients need to be recalibrated using the formula:

$$k_c = \frac{ET_c}{ET_o} \tag{10}$$

Where, ETc: Actual Evapotranspiration measured by lysimeter and ETo: Reference Evapotranspiration evaluated by empirical formulae's.

TABLE 5
RECALIBRATED CROP COEFFICIENTS FOR THE EMPIRICAL EQUATIONS IN SEMI-ARID AGRO CLIMATE

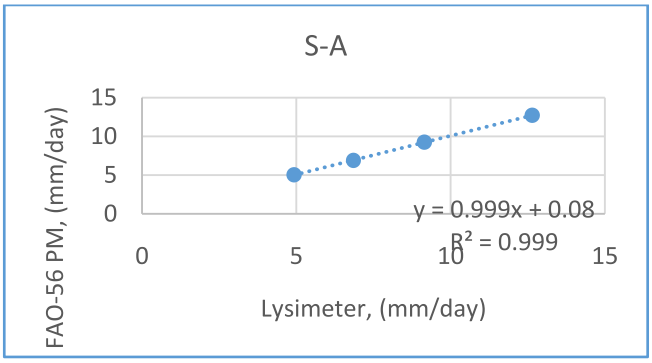
Month	Crop Stage	FAO-56 Penman Monteith	Thornthwaite	BlaneyCriddle	Hargreaves & Samani	Priestly & Taylor	Makkink	Avg. Kc
Mar	Initial	0.71	0.86	0.8	0.86	0.74	0.92	0.78
Apr	Development	0.86	1.23	1.09	1.03	0.99	1.24	1.045
May	Mid	1.56	2.35	1.99	2.27	1.72	2.33	1.95
Jun	Late	1.30	1.78	1.45	2.11	1.21	1.75	1.54

TABLE 6
RECALIBRATED CROP COEFFICIENTS FOR THE EMPIRICAL EQUATIONS IN SUB-HUMID AGRO CLIMATE.

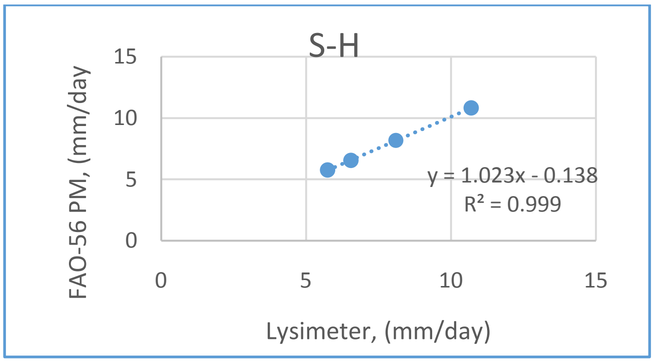
Month	Crop Stages	FAO-56 Penman Monteith	Thornthwaite	BlaneyCriddle	Hargreaves &Samani	Priestly & Taylor	Makkink	Avg
Mar	Initial	0.85	1.18	1.01	0.95	0.879	1.09	0.9
Apr	development	0.91	1.28	1.13	1.05	0.94	1.20	0.98
May	Mid	1.42	2.08	1.85	1.68	1.51	1.97	1.55
Jun	Late	1.27	1.78	1.48	1.33	1.15	1.56	1.55

Table 5 and 6 include the Kc values recalibrated for both the agro climates. Using these crop coefficients the new Actual evapotranspiration rates are evaluated which results less errors when compared with the actual evapotranspiration rates by lysimeter. The mean monthly and seasonal (March- June) values calculated by these equations with the calibrated Kc values. For illustrative purposes the same regression analysis was carried out for the monthly values of evapotranspiration and the results are plotted in Figure 6.

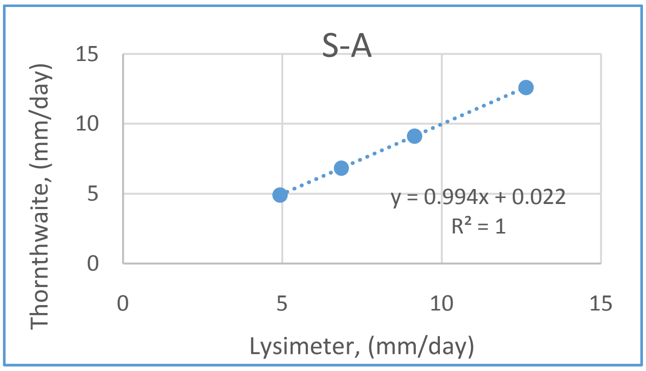
4.9 Regression Analysis using Recaliberated Crop Coefficients:



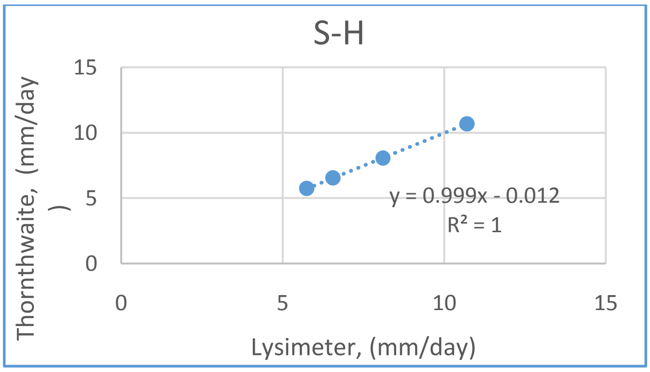
(a)



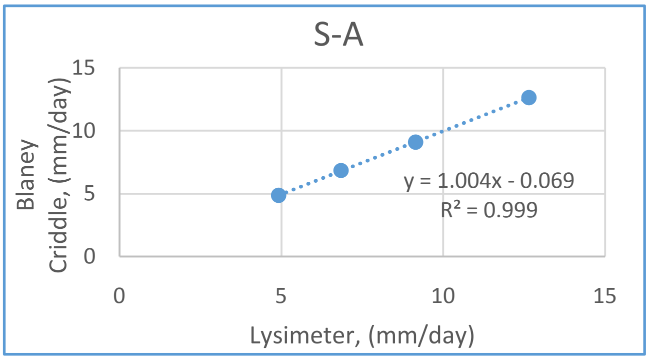
(b)



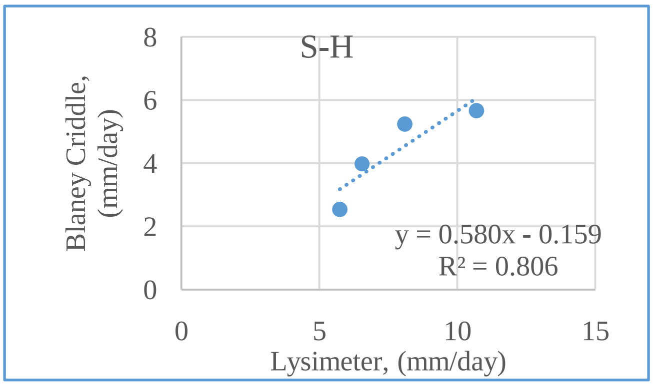
(c)



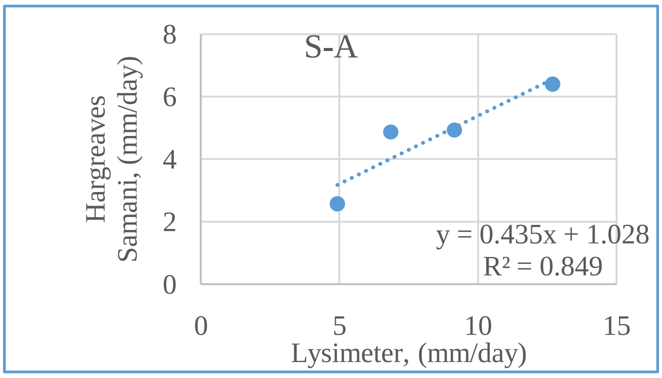
(d)



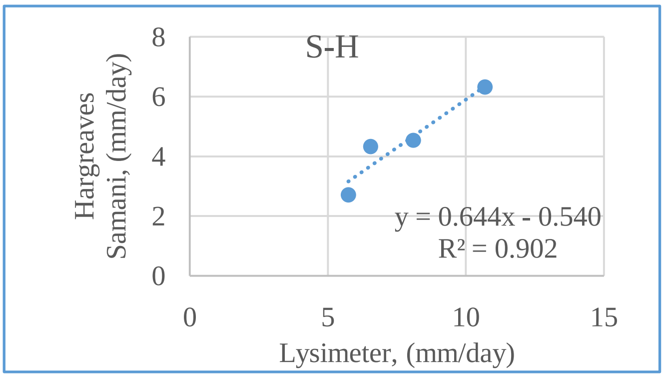
(e)



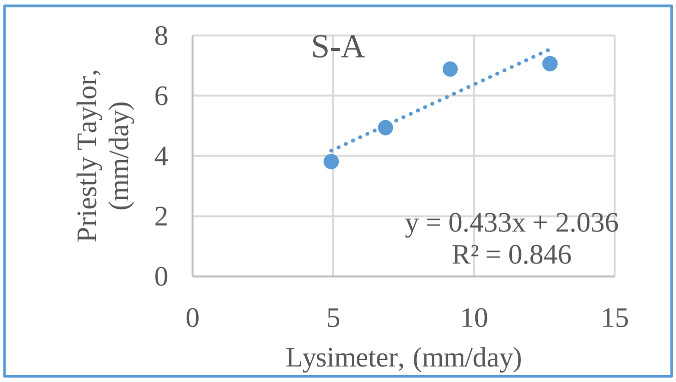
(f)



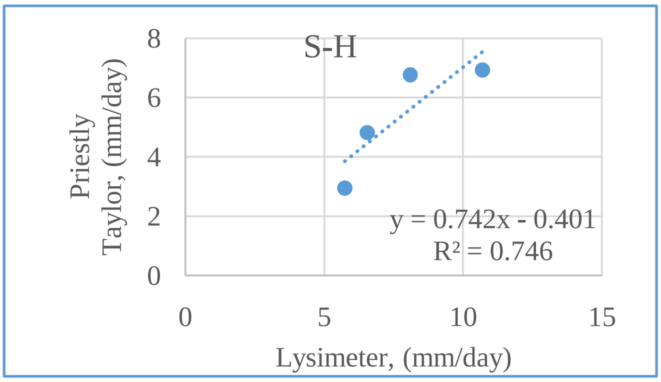
(g)



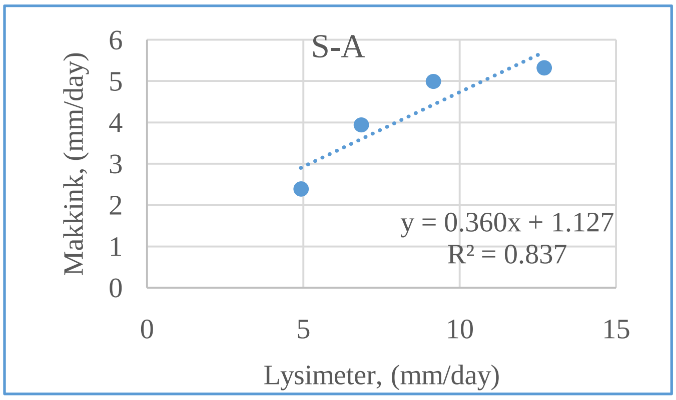
(h)



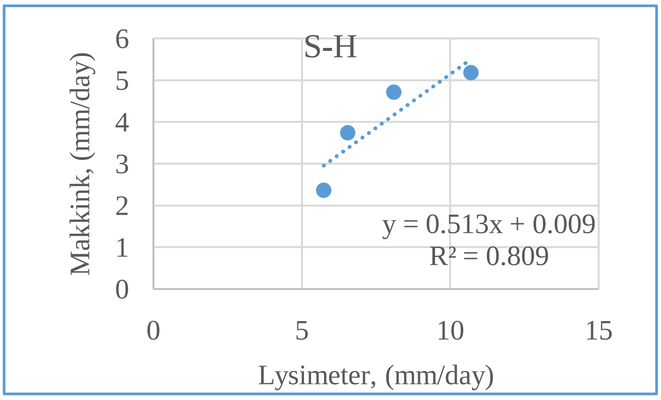
(i)



(j)



(k)



(l)

FIGURE 6: Regression plots for Actual evapotranspiration rates using recalibrated crop coefficients

(Note:- S-A: Semi-Arid, S-H: Sub-Humid, Fig (a & b): FAO-56 Penman Monteith method, Fig (c & d): Thornthwaite method, Fig (e &f): Blaney Criddle method, Fig (g & h): Hargreaves and Samani Method, Fig (i & j): Priestly and Taylor method, Fig (k & l): Makkink method).

TABLE 7
PERCENTAGE ERRORS BY ORIGINAL KC AND RECALIBRATED KC VALUES FOR SEMI-ARID AGRO CLIMATE

Methods	Original Kc	%Error	RecaliberatedKc	P
	(mm/day)	(%)	(mm/day)	(%)
FAO-56 PM	6.08	27.46	8.46	0.89*
Thornthwaite	5.055	39.76	8.36	0.29*
BlaneyCriddle	4.735	43.58	8.35	0.41*
Hargreaves &Samani	4.6925	44.08	8.49	1.25**
Priestly & Taylor	5.6775	32.35	8.4	0.12*
Makkink	4.16	50.43	8.38	0.06*

The presented simulation-based continuous Kc curves could support an objective and justifies that there is low water consumption at the initial growth stages of the crop and thereby gradually increases for development stage of the crop and reaches to a maximum level at the mid stage and later gradually tends to fall down at the late stages of the crop. Site-specific irrigation scheduling on a daily basis. The evaluation and comparison were made based on both the original constant values involved in each equation and the recalibrated Kc values. In case of using original Kc values of the six original equations evaluated, the FAO-56 Penman Monteith equation resulted in mean seasonal evapotranspiration values that agreed most closely with lysimeter evapotranspiration values, next to FAO-56 Penman Monteith's Equation Thornthwaite and Hargreaves Samani Equation values were most close to lysimeter values.

TABLE 8
PERCENTAGE ERRORS BY ORIGINAL KC AND RECALIBRATED KC VALUES FOR SUB-HUMID AGRO CLIMATE

Methods	Original Kc	%Error	Recaliberated Kc	P
	(mm/day)	(%)	(mm/day)	(%)
FAO-56 PM	5.83	24.96	7.815	0.54*
Thornthwaite	3.79	51.22	7.75	0.22*
Blaney Criddle	4.35	44.01	7.74	0.32*
Hargreaves & Samani	4.47	42.47	7.86	1.12**
Priestly & Taylor	5.37	30.88	7.79	0.28*
Makkink	3.99	48.64	7.74	0.32*

(Note: ** P<0.05, *P<0.01)

V. IMPACT ON CROP WATER REQUIREMENT

Irrigation requirements are developed with the help of crop water requirement of every crop. Hence for designing the irrigation system Evaluation of ET rates are very essential. For a typical tomato crop, while designing the crop water requirement this study provides proper crop coefficient values that can be used for evaluating the actual evapotranspiration rates. We can see that there are about 5% to 20% errors occurred by using the original Kc values as given by Rowelland Soe, 2016. Therefore, after recalibrating the crop coefficients the same models provided good results hence using these recalibrated crop coefficients provide goods results with less errors about 0.06% - 1.25 % (Table 7). In designing the crop water requirement now using these crop coefficients for determining the consumptive use of a tomato crop results more accurate requirement. Crop coefficient does not only vary with climate but in combination with crop stage. Irrigation frequency and water supply for each watering depends on crop stage besides evapotranspiration rates, thus crop coefficients are to be computed in combination with climate parameters as well as crop stage.

VI. CONCLUSION

Irrigation requirements are developed with the help of crop water requirement of every crop. Hence for designing the irrigation system Evaluation of ET rates are very essential. Actual Evapotranspiration using various Empirical methods and field experiments by lysimeters and recalibrating the crop coefficients for different agro climates and upcoming with the suitable method for computation of Evapotranspiration rates for the respective climates. The average Actual ET for tomato crop by lysimeter method for Semi-Arid region was estimated to be 8.39 mm/day and in Sub-Humid region it was about 7.77 mm/day and therefore the corresponding correlations with FAO-56 PM equation was found to be 0.94 for Semi-Arid region and 0.92 for Sub-Humid region. Thornthwaite equation when correlated with the lysimeter gave a value of 0.9 and therefore is next well suited method for computing ET in semi arid region. In the same way Hargreaves Samani Equation correlated well with a value of about 0.9 and hence is the next well suited method in Sub Humid region. Due to large climatological data requirement by FAO-56 PM equation it becomes non feasible for estimation ET though it gives accurate results, But in some areas climate data are not available, there this method is difficult to carry out. Together with weather forecasts of rain and evapotranspiration for the next days, such a simulation model platform could be part of a decision support systemon crop irrigation. In a next step, the simulated Kc curves could be generated and mapped for other field crops and for relevant agronomic regions including applications with national and global data sets with noticeably differing weather conditions including gridded weather data.

ACKNOWLEDGEMENTS

The authors would especially like to thank the farmers for their cooperation and support in carrying out the project in their fields. The authors wish to acknowledge the Karnataka State Natural Disaster Monitoring Center for providing weather data needed for this study. The scholar expresses his thankfulness to Librarians of UBDT college of Engineering Library, Davanagere; for their help rendered to her in providing relevant books, journals and data concerning my research study. The scholar also submits all her praise and thanks to her loved ones i.e., Parents and friends from the depth of heart for their blessings and helping in all aspects of life and the research work.

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