Estimation of Evapo-Transpiration for Different Crops in Kudachi Rural Area by the FAO56-PM Method

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Abstract— The evapotranspiration and irrigation water demand calculations are to be used in design and management of irrigation systems, for water rights management and consumptive water rights transfer and for hydrologic studies. This paper presents application of Penman-Monteith equation standardized by the Food and Agricultural Organization (FAO56-PM) at the same time with crop constant approach for the estimation values of reference evapotranspiration (ET_o) and crop evapotranspiration underneath standard conditions (ET_c) from different land use/land cover. Daily meteorological data (Jan 2012-Dec 2014) of Kudachi area were collected from Agricultural Department and is of an area of 6200 hectares, out of which 5243 hectares is used as a agricultural plantation and is used in quantification of evapotranspiration. Kudachi rural area covers 13 types of major Agricultural Plantations. The reference crop that used for calculating ET_o was considered as a hypothetical crop with an assumed height of 0.12m having a surface resistance of 70 ms-1 and an albedo of 0.23. The results obtained from this study is beneficial to include the fundamental components of managing water resources efficiently, and additionally an important factor in computing water balance, irrigation system design and management, crop yield simulation and hydrologic studies.

Key words: Crop Coefficient, Crop Evapotranspiration, FAO56-PM Method, Agricultural Plantations, Reference Evapotranspiration

I. INTRODUCTION

Evaporation and transpiration occur at the same time and there is no simple way of identifying between the two processes. Apart from the water availability in the topsoil, the evaporation from a cropped soil is principally determined by the fraction of the radiation reaching the soil surface. This fraction decreases over the growing period because the crop develops and therefore the crop cover shades lot of the ground area. When the crop is small, water is predominately lost by soil evaporation, however once the crop is well developed and completely covers the soil, transpiration becomes the main process. Weather parameters, crop characteristics, management and environmental aspects are factors affecting evaporation and transpiration.

Crop evapotranspiration (ET_c) calculation is important for several studies corresponding to hydrologic water balance, irrigation system design and management, crop yield simulation, and water resources planning and management. Allen (1986) stated that ten forms of the Penman combination evapotranspiration equation are reviewed and compared with lysimeter estimates at 3 locations. Aerodynamic and canopy resistance forms by Monteith and Thom and Oliver and an empirical form by Wright best predict daily lysimeter measurements at Kimberley, Idaho, and Coshocton, Ohio. Tyagi et al. (2000) inferred that wheat and sorghum are necessary cereal crops next only to rice in India and several other Asian countries. The study was to measure daily, weekly, and seasonal crop ET_c of wheat and sorghum directly from sensitive weighing type lysimeters, to measure the hourly evapotranspiration, of wheat and sorghum from 1991 to 1995 at Karnal, India. Results were satisfactory correlation between observed and calculated ET by FAO method. Therefore, these methods can be used as a surrogate to estimate daily ET for areas where limited climate data are available.

Annandale et al. (2001) expressed that the foremost common approach for the estimation of crop water requirements is to pair a crop factor with the evaporation from a reference surface and developed a user-friendly computer tool to facilitate the calculation of daily FAO (Food and Agricultural Organization of the United Nations, Rome, Italy) Penman-Monteith reference crop evaporation (ET_o) and to estimate errors which will arise if solar radiation, wind and vapour pressure data are not available.

Allen et al. (1990, 2005) stated that crop coefficient curves offer easy, reproducible means to estimate crop evapotranspiration (ET) from weather-based reference ET values. The dual crop coefficients K_{cd} method utilizes "basal" crop coefficients representing ET from crops having a dry soil surface and separately predicts evaporation from bare soil based on a water balance of the soil surface layer. Lakshman Nandagiri and Gicy M. Kovoor (2005) stated that reference crop evapotranspiration (ET_o) is a key variable in procedures established for estimating evapotranspiration rates of agricultural crops. The aim of their study was to evaluate variations that might arise in FAO-56 ET_o estimates if no suggested equations are used to compute the parameters.

Rohitashw Kumar et al. (2011) stated that efficient irrigation water management needs an good quantification of evapotranspiration. The precise estimation of water demand of crop is very important factor in the application of irrigation design and scheduling. Different climatological methods are using for estimating reference crop evapotranspiration on a daily basis. They evaluated and reviewed the utilization of various evapotranspiration models and data in studies of geographical ecology, which is also used in the estimation of daily water necessities for agricultural crops grown in numerous climatic regions of India and worldwide.

II. FAO PENMAN-MONTEITH EQUATION

In 1948, Penman combined the energy balance with the mass transfer technique and derived an equation to compute the evaporation from an open water surface from standard climatological records of sunshine, temperature, humidity and wind speed. This supposed combination technique was further developed by several researchers and extended to cropped surfaces by introducing resistance factors. The resistance terminology distinguishes between aerodynamic resistance and surface resistance factors (Fig.1). The surface resistance parameters are often combined into one parameter, the 'bulk' surface resistance parameter that operates in series with the aerodynamic resistance.

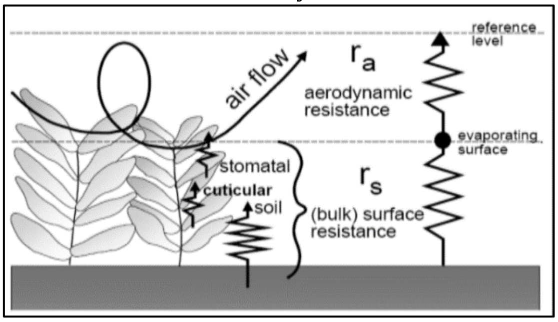

Fig. 1: Simplified representation of the (bulk) surface and aerodynamic resistances for vapour flow (Source: FAO 56, 1990)

The Penman-Monteith form of the combination equation is:

$$\lambda ET = \frac{\Delta(Rn-G)+\rho_a\, c_p \frac{(e_s-e_a)}{r_a}}{\Delta+\gamma\left(1+\frac{r_s}{r_a}\right)} \quad (1)$$

Where R_n is the net radiation, G is the soil heat flux, $(e_s - e_a)$ represents the vapour pressure deficit of the air, ρ_a is the mean air density at constant pressure, c_p is the specific heat of the air, Δ represents the slope of the saturation vapour pressure temperature relationship, γ is the psychrometric constant, and r_s and r_a are the (bulk) surface and aerodynamic resistances. From the original Penman-Monteith equation (1) and the equations of the aerodynamic resistance and bulk surface resistance were combined to develop, the FAO Penman-Monteith method to estimate ET_O can be given as:

$$ET_O = \frac{0.408\Delta(R_n-G)+\gamma\frac{900}{T+273}u_2(e_s-e_a)}{\Delta+\gamma(1+0.34u_2)} \quad (2)$$

Where,
ET_o: reference evapotranspiration [mm/day],
R_n: net radiation at the crop surface [MJ/m^{2}day],
G: Soil heat flux density [MJ/m^{2}day],
T: mean daily air temp at 2 m height [°C],
u_2: wind speed at 2 m height [m s^{-1}],
E_s: Saturation vapour pressure [kPa],
E_a: actual vapour pressure [kPa],
e_s-e_a : saturation vapour pressure deficit [kPa],
Δ: slope vapour pressure curve [kPa°C^{-1}],
γ : psychrometric constant [kPa°C^{-1}].

The reference evapotranspiration, ET_O, provides a standard to which:

- evapotranspiration at different periods of the year or in other regions may be compared;
- Evapotranspiration of different crops can be related.

The equation uses standard climatological records of radiation (sunshine), air temperature, humidity and wind speed. The FAO Penman-Monteith equation is a close, simple representation of the physical and physiological factors governing the evapotranspiration process. By using the FAO Penman- Monteith definition for ET_O, one might calculate crop coefficients at research sites by relating the measured crop evapotranspiration (ETC) with the calculated ETO, i.e., $K_C=ET_C/ET_O$.

III. METHODOLOGY

The area selected for this study as shown in Fig.2 is Kudachi Rural of Raibag Taluk, Belagavi district. The study area lies geographically between 70o 51' 30" E longitude and 16o 37' 12" N latitude. It covers an area of 14185 acres and shows the relief around 357 m (Highest being 871m above MSL and lowest being 514 m above MSL). The study area is derived from Google Earth Satellite Imagery, Survey of India (SOI) topomaps and other collateral data. Due to the declination of rainfall over the years, there would be water scarcity in coming years. In order to maintain the available water resources efficiently, an attempt was made to study the water requirement for different agricultural plantations of Kudachi Rural area.

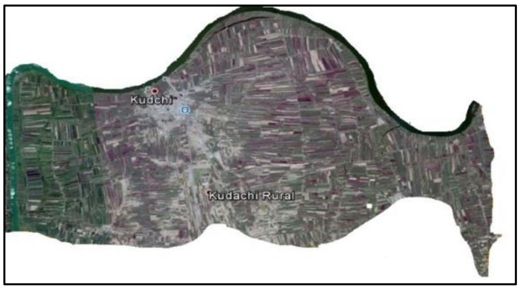

Fig 2: Google Earth Satellite Imagery showing the study area

Information on the existing land use/land cover and pattern of their spatial distribution forms the basis for any developmental planning. Table 1 shows the percentage area of the each land use/land cover type of Agricultural plantations grown in Kudachi Rural Area.

LU/LC Type	Area (ha)	% Area
Agricultural Plantation	5243	84.56
Built up Area	400	6.46
Open Area	490	7.9
Settlement	25	0.4
Water Bodies	42	0.68
Total	6200	100%

Table 1: Land use/cover in Kudachi Rural Area

Crop Name	Area in Acres	Area In %
Sugarcane	8806	68
Maize	1230	9.5
Wheat	880	6.8
Grapes	454	3.5
Soya	388	3
Jowar	259	2
Chick pea	259	2
Brinjal	195	1.5
Sunflower	130	1
Groundnut	130	1
Turmeric	130	1
Banana	65	0.5
Onion	26	0.2

Table 2: Percentage area of the each type of Agricultural plantations grown in Kudachi rural area

IV. ESTIMATION OF ET_C

- The calculation procedure for crop evapotranspiration, ET_c, consists of:

- Identifying the crop growth stages, determining their lengths, and choosing the corresponding K_c coefficients;
- Adjusting the chosen K_c coefficients for frequency of wetting or climatic conditions during the stage;
- Constructing the crop coefficient curve (allowing one to determine K_c values for any period during the growing period); and
- Calculating ET_c as the product of ET_o and K_c.

V. INPUT METEOROLOGICAL DATA

Calculation of ET_O with the Penman-Monteith equation on 24-hour time scales will generally provide accurate results. The meteorological data of the Kudachi rural area for the period of January 2012 – December 2014 were analyzed for estimating ET_O. Many procedures are developed to assess the evapotranspiration rate from needed parameters. ET_O expresses the evaporating power of the atmosphere at a selected location and time of the year.

The calculation procedure consists of the subsequent steps: Derivation of climatic parameters from the daily maximum (T_{max}) and minimum (T_{min}) air temperature and mean wind speed (u_2). Calculation of vapor pressure deficit (e_s-e_a), the saturation vapor pressure (e_s) is derived from T_{max} and T_{min} while the actual vapor pressure (e_a) is derived from the mean relative humidity (RH_{mean}). Determination of the net radiation (R_n) as the difference between the net shortwave radiation (R_{ns}) and the net longwave radiation (R_{nl}) and the impact of soil heat flux (G) is ignored for daily calculations because the magnitude of the flux during this case is comparatively small.

VI. MONTHLY REFERENCE EVAPOTRANSPIRATION (ET_O):

Daily ET_O were computed on daily basis using the procedures which were outlined earlier and Values of monthly ET_O [mm month^{-1}] (Fig.3) are derived. The monthly average value of ET_O for 3 years is 1429.021[mm month^{-1}], the maximum value is 1466.39 [mm month^{-1}], and the minimum value is 1391.78 [mm month^{-1}].

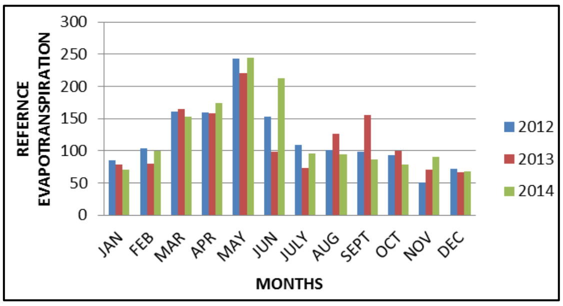

Fig 3: Monthly values of reference evapotranspiration (ETO)

VII. SINGLE CROP COEFFICIENT APPROACH (KC)

In the crop coefficient approach the crop evapotranspiration, ET_C, is estimated by multiplying

The reference crop evapotranspiration, ET_O, by a crop coefficient, K_C:

$$ET_c = K_c ET_o \qquad (3)$$

Where

ET_C: crop evapotranspiration [mm d^{-1}],

K_C: crop coefficient [dimensionless],

ET_O: reference crop ET [mm d^{-1}].

In the single crop coefficient approach, the effect of crop transpiration and soil evaporation are combined into a single K_C coefficient. As soil evaporation could fluctuate daily as a result of rainfall or irrigation, the single crop coefficient expresses only the time-averaged (multi-day) effects of crop evapotranspiration. The curve represents the changes in the crop coefficient over the length of the growing season. The shape of the curve represents the changes in the vegetation and ground cover throughout plant development and maturation that affect the ratio of ET_C to ET_o. From the curve, the K_C factor and hence ET_C can be derived for any period within the growing season. The generalized crop coefficient curve is shown in Fig 4.

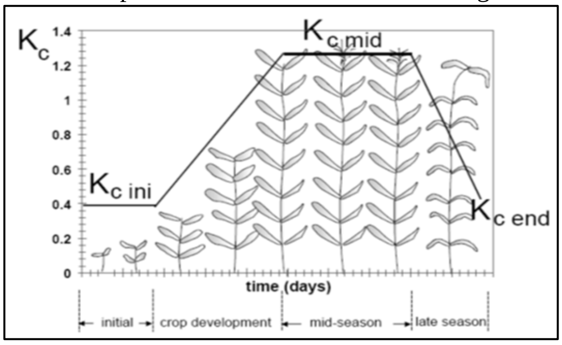

Fig. 4: Generalized crop coefficient curve for single crop coefficient approach (Source: FAO 56, 1990)

The crop season and the crop coefficient K_c values (Chaudary and Kadam, 2006; Gopalakrishnan, 2007; Mishra and Ahmed, 1987; Singh, 2006) for different agricultural plantations grown in Kudachi Rural area are collected and used in estimation of ET_C.

VIII. RESULTS AND DISCUSSION

ET_C and Volume of ET for different Agricultural Plantations. ET_C is estimated by multiplying ET_O by K_C, a coefficient expressing the difference in evapotranspiration between the cropped and reference grass surface. The difference are often combined into single crop coefficient, or it can be split into 2 factors describing separately the variations in evaporation and transpiration between both surfaces. In a present study, a single time-averaged crop coefficient is used to calculate ET_C on daily basis. ET_C value per day varies from mm to mm. Comparison of crop evapotranspiration for the year 2012, 2013 & 2014 is shown in Fig 5. It is observed that the average yearly maximum ET_C value for sugarcane is 1559.033 mm month^{-1} and average minimum ET_C value for chick pea is 191.65 mm month^{-1}.

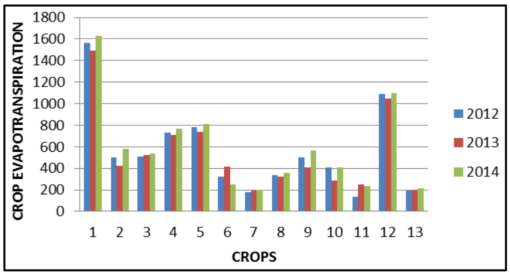

Fig. 5: Comparison of crop evapotranspiration for 2012, 2013 and 2014

The consolidated values of ETC of crops were computed. Figure 6A, Figure 6B and Figure 6C shows the

ETC for seasonal crops and yearly crops respectively. Volume of ET for the year 2012 is less for Onion crop of 20.62x103 m3season⁻¹ and high for Sugarcane crop of 55663.90x103 m3season⁻¹. Volume of ET for the year 2013 is less for Onion crop of 21.22x103 m3season⁻¹ and high for Sugarcane crop of 53062.45x103 m3season⁻¹. Volume of ET for the year 2014 is less for Onion crop of 22.50x103 m3season⁻¹ and high for Sugarcane crop of 57948.19x103 m3season⁻¹.

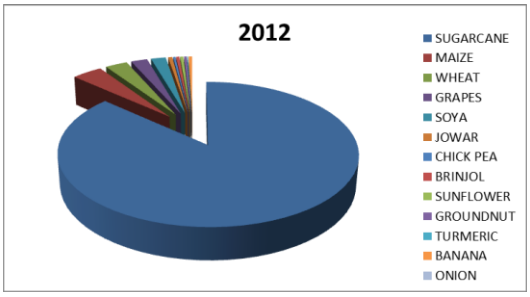

Fig 6: (a). Volume of water required of seasonal crops for the year 2012

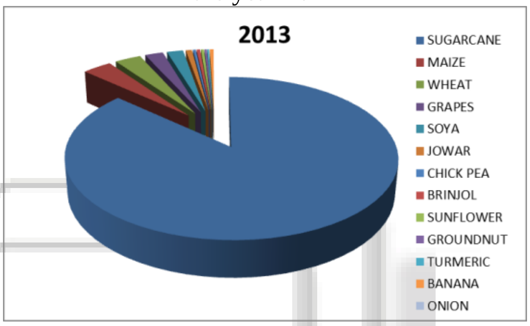

Fig. 6(b): Volume of water required of seasonal crops for the year 2013.

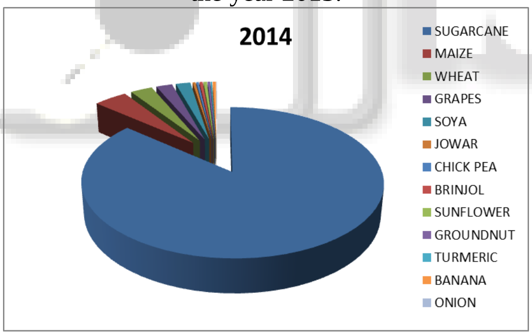

Fig. 6(c): Volume of water required of seasonal crops for the year 2012.

IX. Conclusions

It is observed that the water demand for this seasonal/yearly crop average daily ETC demand is 4936.38 m3 and micro-level studies revealed daily basis ETC values ranges from 21.45 m3 to 55558.18 m3. This information should be taken into account in irrigation planning and scheduling design aspects.

It is clearly observed that, the monthly requirements were also varying considerably from month to month depending upon the growth of crop. Hence, water demand for month and daily basis requirements can be taken care in the water supply and demand requirements.

The results of crop evapotranspiration of all the crops of Kudachi rural area that were obtained from this study is helpful to include the fundamental elements of managing water resources with efficiency, and additionally as necessary factors in computing water balance, irrigation system design and management, crop yield simulation and hydrologic studies.

References

[1] Allen, R.G. (1986). A Penman for All Seasons, Journal of Irrigation and Drainage Engineering, ASCE, 112 (4): 348-368

[2] Allen, R.G., Pereira, L.S., Smith, M., Raes, D. and Wright, J.L. (2005), FAO-56 Dual Crop Coefficient Method for Estimating Evaporation from Soil and Application Extensions, Journal of Irrigation and Drainage Engineering, ASCE, 131 (1): 2-13

[3] Allen, R.G, Pereira, L.S, Raes, D and Smith, M. (1990), FAO Irrigation and Drainage Paper No 56, Crop Evapotranspiration (guidelines for computing crop water requirements), 300 p.

[4] Annandale, J.G., Jovanovic, N.Z., Benade, N. and Allen, R.G. (2002) Software for missing data error analysis of Penman-Monteith reference evapotranspiration. Irrg Sci 21: 57-67.

[5] Chaudary M.L. and U.S. Kadam (2006), Micro-Irrigation for Cash Crops, Westville publishing, pp162

[6] Gopalakrishnan T.R. (2007), Vegetable Crops, Vol.04. Horticulture Science Series, New India Publishing Agency, New Delhi, India, pp 343

[7] Mishra R.D. and F. Ahmed (1987), Manual on Irrigation Agronomy, Department of Agronomy, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttar Pradesh.

[8] Nandagiri, L. and Kovoor G.M. (2005), Sensitivity of FAO Penman-Monteith Evapotranspiration Estimates to Alternative Procedures for Estimation of Parameters, Journal of Irrigation and Drainage Engineering, ASCE, 131 (3): 238-248

[9] Rohitashw Kumar, Vijay Shankar and Mahesh Kumar (2011), Modelling of Crop Reference Evapotranspiration: A Review, Universal Journal of Environmental Research and Technology, 1(3): 239-246.

[10] Singh A.K. (2006), Flower Crops, Cultivation and Management, New India Publishing, pp 463

[11] 1Tyagi, N.K., Sharma, D.K. and Luthra, S.K. (2010), Evapotranspiration and Crop Coefficients of Wheat and Sorghum, Journal of Irrigation and Drainage Engineering, ASCE, 126 (3): 215-222.

