Seasonal variability of potential evapotranspiration at sub-taluk level in Karnataka

G. S. SRINIVASA REDDY, O. CHALLA, H. S. SHIVAKUMAR NAIKLAL, K. B. RAJESHWARI and N. G. KEERTHY

Karnataka State Natural Disaster Monitoring Centre, Bengaluru – 560 064, India

(Received 8 December 2016, Accepted 22 January 2018)

e mail : dmc.kar@gmail.com

ABSTRACT. Estimation of potential evapotranspiration (PET) at sub-taluk level during different seasons gains importance in the existing scenario of climate change and aberrant weather conditions in the chronic drought prone state of Karnataka. The PET (water need) estimations in different sub-taluk levels of selected districts under different Agro-climatic/Agro-ecological regions indicate that, the water need was high in semi-arid / arid districts than the humid districts. The average PET of selected districts was in the following order: Koppal > Chitradurga > Dakshina Kannada > Kodagu. The variability in PET was observed among the sub-taluk levels of the same district and different districts. In general the average PET during 9-22 SMW (summer) was relatively higher than the other seasons, in all sub-taluk or districts. The comparison between normal PET and actual calculated PET in the present study shows that the normal PET values were higher in all the seasons of all the districts except in the south west monsoon season (22-39 SMW). It indicates that actual PET is a better estimate since it provides the actual water need specific to the sub-taluk area and season. Hence these actual PET values are better tools for developing location/season specific indices in drought assessment and crop water management planning.

Key words – Potential evapotranspiration, Actual PET, Sub-taluk level, Seasonal variability.

1. Introduction

Under the existing conditions of climate change and unpredictable weather conditions with uneven rainfall events (IPCC, 2008), the availability of water is limited not only for domestic use but also for agricultural and non-agricultural purposes. Hence, in future, the dependency on water is likely to increase manifolds in the world in general and in developing countries, in particular (IFAD, 2008). At present, with the increasing demand for water and its scarcity due to extreme and uneven rainfall events, there is a need for relatively accurate estimation of the water need (PET), both temporally and spatially. For this purpose, Actual evapotranspiration (AET) that depicts the actual evaporative demand of water both from soil surface and surface of the crop canopy is an appropriate index. The measurement or estimation of actual evapotranspiration is difficult and impracticable. Hence, the potential evapotranspiration which can be estimated under presumed ideal conditions is a potential alternative for ‘AET’ estimation. Direct measurement of potential evapotranspiration (PET) across the different locations is difficult and impracticable. Hence, an indirect measurement of potential evapotranspiration which can be estimated under presumed ideal conditions is a potential alternative for PET estimation.
measurement, gravimetric, Lysimetric method, Water Budgeting Technique, Bowen Ratio and Eddy Correlation method, Biological method and Pan Evaporation method. For empirical estimation of ‘PET’ with the use of meteorological data, there are many models in practice. These models could be grouped into (i) Temperature based models (Thornthwaite, 1948; Blaney and Criddle, 1950; Hargreaves and Samani, 1982 & 1985; Hargreaves et al., 1985; Xu and Singh, 2001) (ii) Mass transfer models which are based on vapour pressure/ relative humidity (Harbeck, 1962; Christiansen, 1968), (iii) Radiation models based on radiation (Makkink, 1957; Priestly and Taylor, 1972), (iv) Combination models based on energy balance and mass transfer principles viz., Penman (1948), modified Penman (Doorenbos and Pruitt, 1977) and FAO - 56 - Penman - Monteith (Allen et al., 1998; Cai et al., 2007) method. There are some more models for estimating ‘PET’ (Jensen et al., 1990; Ravelli and Rota, 1999) but these models have limited and local application.

The objectives of the study are (i) To estimate the reference evapotranspiration at sub-taluk level based on real time actual data; (ii) To assess the variation in ‘PET’ across the sub-taluks in different districts; (iii) To assess temporal variation in ‘PET’ during four seasons i.e., Winter (January & February); Summer (March to May); South-West monsoon (June to September) and North-East monsoon (October to December) and (iv) To compare normal ‘PET’ with actual ‘PET’.

2. Materials and method

For the present study, the FAO - Penman - Monteith model (FAO-PM) is considered since it is standard and globally acceptable approach and provides the precise and acceptable ‘PET’ estimates in a variety of climates (Adeboye et al., 2009; Garcia et al., 2004; Popova et al., 2006). For the application of this combination model, the requisite weather/meteorological data was collected/compiled by Karnataka State Natural Disaster Monitoring Centre, Karnataka, from the automatic TWS (Telemetric Weather Stations) installed at sub-taluk headquarters in different districts of the study area.

2.1. About the study area

In this study, four districts, covering 75 sub-taluks were considered. These represent all the major regions and different agro-climatic as well as agro-ecological situations of the state. The details of the selected districts (Fig. 1) are as under:

2.1.1. Koppala district

It is in North-Interior Karnataka region and is in northern part of Deccan plateau at an elevation of 525 m above msl and located between 15.22 to 15.87° N latitudes and 75.89 to 76.66° E longitudes with geographical area of 5574 sq. km. It falls under Gulbarga division with four taluks namely Gangavathi, Koppala, Kushtagi and Yelburga spread over 20 sub-taluks. This district falls under Krishna river basin and is drained by Tunga and Bhadra rivers network. It receives an average annual rainfall of 600 mm of which about 13.9% during pre-monsoon (up to May), about 62% during south-west monsoon (June to September) and 24.1% during north-east monsoon (October to December). Major part of the area in the district comes under Agro-climatic zone 3-Northern dry zone and agro-ecological region-1 (arid region).

Out of the total cultivated area, 58% is under cereals, 20% under oil seeds and 20% is under pulses. Limited area is under vegetables and fruit crops (2%).

2.1.2. Chitradurga district

It is in central part of Deccan Plateau at an average elevation of 650 m above msl. It is located between
13.60 to 14.86° N latitudes and 75.43 to 77.02° E longitudes with geographical area of 8430 sq. km. This district falls under south-interior Karnataka and comes under Gulbarga division. It has six taluks namely: Challakere, Chitradurga, Hiriyur, Holalkere, Hosadurga and Molkalmuru and twenty two sub-taluks. This district falls under Krishna river basin and the two tributaries namely Vedavathi and Tungabhadra drain this district. It is one of the chronic drought prone districts with a few of the taluks always affected by drought. It has an average annual rainfall of 535.0 mm of which about 18% is received in pre-monsoon (up to May), about 52% during southwest monsoon (June to September), rest of the amount i.e., about 30% during northeast monsoon (October-December). This district comes under Agro-climatic zone - 4 (central dry zone) and under Agro-ecological region - 6 (semi-arid). Major area is under cereals followed by pulses and commercial crops.

2.1.3. Kodagu district

It is in Malnad region and is a part of Western Ghat hilly region popularly known as “Scotland of India”. It has an average elevation of 900 m above msl and is located between 12.01 to 12.79° N latitudes and 75.52 to 76.05° E longitudes. The district has total geographical area of 4098 sq. km and falls under Mysore division with three taluks namely Madikeri, Somwarpet and Virajpet spread over 16 sub-taluks. This district receives an average annual rainfall of 2900 mm of which 9.4% is received in pre-monsoon, 80.5% in southwest monsoon and 10.1% in northeast monsoon. This district falls under Cauvery basin and is drained by the river Cauvery and its tributaries. It comes under Agro-climatic zone - 9 namely Hilly zone and Agro-ecological region - 6 i.e., sub-humid-humid region. Coffee, paddy, cardamom and black pepper are grown in large area and other cereals are grown to a limited extent in the district.

2.1.4. Dakshina Kannada district

It is in coastal region and is a part of west coastal plains. It has an average elevation of 70 m above msl and is located between 12.55 to 13.09° N latitudes and 74.79 to 75.48° E longitudes. This district has the geographical area of 4866 sq. km and falls under coastal region of Mysore division. It has five taluks namely Belthangadi, Bantwal, Mangalore, Puttur and Sulya spread over 17 sub-taluks. This district receives an average annual rainfall of 4040 mm of which 5.7% is received during pre-monsoon, 85.3% in southwest monsoon and 9% during northeast monsoon. This area is drained by west flowing rivers such as Nethravathi, Phalguni and Payaswini. This district comes under agro-climatic zone - 10 i.e., coastal zone and agro-ecological region - 7 i.e., humid region. Major crops grown in this district are paddy, banana and mango.

2.2. Meteorological / weather data

Weather parameters such as maximum and minimum air temperatures, relative humidity, maximum and minimum wind speed were received from the Telemetric Weather Stations (TWS) fitted with different sensors and automatic data recorders installed at each sub-taluk headquarters by Karnataka State Natural Disaster Monitoring Centre (KSNDMC), Bengaluru. Each Telemetric Weather Station (TWS), records each weather parameter at every 15 minutes interval and transmits to Head Quarters of KSNDMC, daily. These observed values are averaged to get daily values of each weather parameter. These values are compiled for each standard meteorological week (SMW) and are used in the study. The data received from 75 Telemetric Weather Stations were compiled and used for this study at sub-taluk level (Fig. 1).

2.2.1. Air temperature

The maximum and minimum temperature recorded through sensors (thermistor) daily at 15 minute intervals is received from each sub-taluk headquarters. The daily temperature, both maximum and minimum were compiled from the above observed values. The temperature mean was arrived at from all the daily observations. These daily values of temperature maximum, minimum and mean are used in the ‘PET’ estimation at sub-taluk level.

2.2.2. Relative humidity

The Relative Humidity (RH) data is received through sensor (Hygrometer) from each TWS. The data is compiled for each day at sub-taluk level. These values are utilized for ‘PET’ estimation.

2.2.3. Radiation

In the absence of availability of requisite data on solar radiation, short wave, long wave and net radiation data at each sub-taluk level were calculated with the help of maximum, minimum and mean temperature values; maximum, minimum, mean values of relative humidity and the altitude at each sub-taluk centre (equations 6, 7, 8, 9, 10 of Table 1).

2.2.4. Wind speed

The wind velocity is measured by cup anemometer installed at TWS at 2 m height from the ground. In case of non-availability of wind speed at 2 m from ground level, the data is obtained through equation No. 11 (Table 1) for each location.
TABLE 1
Expressions considered in PM model

| S. No. | Parameter                                                                 | Expression                                                                 | Unit        |
|--------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|-------------|
| 1.     | Slope of the saturation vapour pressure curve                            | $\Delta = \frac{4098 \times 0.618 \exp \left(\frac{17.27T}{T + 237.3}\right)}{[T + 237.3]}$ | kPa°C⁻¹     |
| 2.     | Mean saturated vapour pressure                                           | $e_s = \frac{e^\epsilon (T_{\min}) + e^\epsilon (T_{\max})}{2}$             | kPa         |
| 3.     | Saturated vapour pressure at temp 'T'                                    | $e^\epsilon (T) = 0.6108 \exp \left(\frac{17.27T}{T + 237.3}\right)$        | kPa         |
| 4.     | Actual vapour pressure                                                   | $e_s' = \left[\frac{e^\epsilon (T_{\min}) \times RH_{\min}}{100} + e^\epsilon (T_{\max}) \times RH_{\max}}{2}\right]$ | kPa         |
| 5.     | Vapour pressure deficit                                                 | $\left(e_s' - e_s\right)$                                                   | kPa         |
| 6.     | Clear sky solar Radiation                                                | $R_s = (0.75 \times 2 \times 10^{-5} \times Z) \times R_a$                   | MJm⁻² d⁻¹   |
|        | where, $Z$ = Altitude of location                                         |                                                                           |             |
|        | $R_a = \text{extra terrestrial radiation}$                               |                                                                           |             |
| 7.     | Incoming Solar radiation                                                | $R_i = \sqrt{0.16 \times (T_{\min} - T_{\max}) \times R_a}$                 | MJ m⁻² d⁻¹  |
| 8.     | Net short wave radiation                                                | $R_{sa} = (1 - \alpha) \times R_a$                                         | MJm⁻² d⁻¹   |
|        | where, $\alpha = \text{Albedo or canopy reflection constant (0.23)}$    |                                                                           |             |
| 9.     | Net long wave radiation                                                 | $R_{la} = \alpha \left[\left(\frac{T_{\min} - T_{\max}}{2}\right)^4 \times 0.34 - 0.14 \sqrt{\epsilon_s} \times 1.35 \times \frac{R_a}{R_{sa}} - 0.35\right]$ | MJm⁻² d⁻¹   |
|        | where, $K = \text{Stefan Boltzmann constant (4.903 MJ K}^4 \text{ m}^2 \text{d}^{-1})$ |                                                                           |             |
| 10.    | Net Radiation                                                            | $R_{n} = R_{sa} - R_{la}$                                                   | MJm⁻² d⁻¹   |
| 11.    | Wind speed at height 'Z'(m)                                              | $\mu_2 = \frac{4.87}{L_{\infty}(67.8Z - 5.42)} \mu_s$                      | m s⁻¹       |
| 12.    | Psychrometric constant                                                   | $\gamma = 0.655 \times 10^3 \times P$                                      | kPa°C⁻¹     |

2.3. Physical / geospatial parameters

Based on the TWS stations at each sub-taluk headquarters, the latitudes, longitudes and the altitudes are obtained through the use of Google Earth, Google Pro and Google Maps. The altitudes and latitudes thus obtained are utilized in the computation of ‘PET’ at sub-taluk level.

For the estimation of ‘PET’ using meteorological parameters ‘Penman - Monteith Model’ (PM Model) in the following form was considered (Allen et al., 1998):

\[
PET = \frac{0.408\Delta(R_s - G) + \gamma \left(\frac{900}{T_{\max} + 273}\right) \mu_2 (e_s' - e_s)}{\Delta + \gamma (1 + 0.34\mu_2)}
\]

where,

- $PET$ - Reference evapotranspiration (mm d⁻¹)
To arrive at the different values of the parameters in the FAO-56-PM model, different equations/formulae/expressions that were used are listed in Table 1.

The PM model is based on energy transfer and physical principles. FAO adopted this model as global standard. The only limitation of this model is its high data demand which may not be fulfilled due to limited stations in any area other than Karnataka state.

The meteorological data such as maximum and minimum temperature, maximum and minimum relative humidity, wind speed are compiled from 75 Telemetric Weather Stations located at sub-taluk centres. The altitude and latitude of each location are obtained from Google-Pro. This data and computed solar radiation (by expressions: 6, 7, 8, 9, 10 of Table 1) are used as input data for computation of daily evapotranspiration. This daily ‘PET’ is compiled and presented at weekly level. This weekly ‘PET’ is presented as monthly/seasonal level under each district of the study area. The computed ‘PET’ on daily basis through PM model for different sub-taluk levels of the selected districts were presented (Tables 2-5) to elucidate the seasonal and spatial variability in the study area.

### 3. Results and discussion

#### 3.1. Spatio and temporal variability in potential evapotranspiration

The weekly average of PET values at sub-taluk level in each district [Tables (2-5)] indicate the variability among the sub-taluk levels within the district and across the districts in a season. The seasonal variability was also observed among the sub-taluk levels in these districts.

The weekly average ‘PET’ values at sub-taluk level of Koppala district (Table 2) in winter season (1-8 SMW) ranged from 20.6 to 32.3 mm, while in summer season (9-22 SMW), the PET values ranged from 34.5 to 37.1 mm. The weekly PET values in southwest monsoon (23-39 SMW) varied from 22.5 to 24.9 mm at sub-taluk level. In northeast monsoon (40-52 SMW), the PET ranged from 24.5 to 24.9 mm. The district weekly average PET is 25.2 mm in winter, while it is 39.7 mm in summer and 36.9 mm in southwest monsoon and 24 mm in northeast monsoon season.

The weekly average ‘PET’ values at sub-taluk level in Chitradurga district (Table 3) ranged from 21.2 to 30.1 mm in winter season (1-8 SMW) with a district weekly average of 25.5 mm. The average weekly PET values in summer season (9-22 SMW) ranged from 24.5 to 24.9 mm at sub-taluk level with a district weekly average PET.
of 35 mm in the season. The average weekly PET values at sub-taluk level ranged from 25.7 to 41.6 mm during southwest monsoon (23-39 SMW), with a district average PET of 30.8 mm during the season. The PET values ranged from 20.7 to 28.7 mm during northeast monsoon (40-52 SMW) at sub-taluk level and with an average PET of 23.1 mm in the district during the season. The weekly average ‘PET’ values at sub-taluk level (Table 4) in the Kodagu district, ranged from 21.5 to 30 mm in winter season (1-8 SMW), while the PET ranged from 25.1 to 30.3 mm in summer season (9-22 SMW) and in the southwest monsoon season (23-39 SMW), PET ranged from 19.0 to 25.7 mm. In northeast monsoon (40-52 SMW) the PET ranged from 19.4 to 24.3 mm. The weekly average of PET in the district is 24.4 mm in winter season, 27.9 mm in summer, 22 mm in southwest monsoon and 20.7 mm in northeast monsoon.

The weekly average PET at sub-taluk level in the Dakshina Kannada district (Table 5) ranged from 22 to 28.5 mm in winter season (1-8 SMW). The PET ranged from 25.1 to 34.6 mm in summer season (9-22 SMW). During the southwest monsoon (23-39 SMW), the weekly PET value at sub-taluk level varied from 22.7 to 30.7 mm. In north east monsoon (40-52 SMW), the PET ranged from 21 to 24.9 mm. The average weekly PET in the district is 25.7 mm in winter season, 30 mm in summer, 25 mm in southwest monsoon and 23.6 mm in northeast monsoon.

It is observed that the Koppala and Chitrardurga districts showed higher average weekly PET values both at sub-taluk and district levels [Tables (2&3)] in comparison to Kodagu and Dakshina Kannada district.
The annual water need (PET) in these four districts under the study indicate that Koppala and Chitradurga districts have relatively drier climatic conditions (Arid & Semi-arid) than the Kodagu and Dakshina Kannada districts which have sub-humid and humid climatic conditions. The evaporation and transpiration demand which is indicated through ‘PET’ is high in arid and semi arid climate (Martinez - Cob & Tejero- Juste, 2004). The high evaporative demand (PET) in arid and semi arid or hot dry conditions (Saeed, 1986; Goyal, 2004; Er Raki et al., 2010; Rao & Wani, 2011; Jin-Liang Ren et al., 2012) recorded due to the advective energy in the dry environment (Berengen & Gavilan, 2005). Moreover, the meteorological parameters such as high atmospheric radiation related air temperature, low relative humidity, high vapour pressure deficit coupled with high wind velocity, will cause the increased evapotranspiration [Tables (2&3)] from soil surface and surface of crop canopy in these regions. Among the Koppala and Chitradurga districts, Koppala district showed (Fig. 2) higher annual PET (water need) than Chitradurga district. In Koppala district three sub-taluks namely Alwandi, Kukur and Hire Wankalkunku and in Chitradurga district three sub-taluks namely Chellakere, Turuvanur and Narayana hatti showed high PET values indicating higher water need than other sub-taluks.

Sub-humid and humid climatic conditions (Trajkovic, 2007; Bapuji rao et al., 2012) in Kodagu and Dakshina Kannada districts will have low air temperatures, high relative humidity, low vapour pressure deficit and high wind speed, which might have greater impact on evaporative demand or PET [Tables (4&5)]. Additionally, Kodagu district is located at a higher altitude and Dakshina Kannada district in Coastal belt, might have influence on the evaporative demand (Harding, 1978). Among these districts all sub-taluks of Kodagu district showed lower annual PET values than those of Dakshina Kannada district. Comparatively Kadaba, Bantwal, Vittal and Pane Mangalore sub-taluks of Dakshina Kannada district showed higher annual PET values than other sub-taluks (Fig. 2) indicating more water need in these sub-taluks.

Besides the spatial variability in ‘PET’ values in these districts, there is prominent seasonal variability. In general, the lowest PET values [Tables (2-5)] were observed in winter season (1-8 SMW), than summer (9-22 SMW) and monsoon seasons in the Koppala and Chitradurga districts. The higher air temperature high vapour pressure deficit, high wind velocity (speed) and advective energy in summer and monsoon might be responsible for high PET values in these districts. In sub-humid and humid regions (Kodagu & Dakshina Kannada districts), the PET values were lower in southwest and northeast monsoon which might be due to low air temperature and high relative humidity.

The extent of deviation in ‘PET’ values during different seasons, among arid and semi arid regions (Koppala & Chitradurga districts) is higher than the sub-humid and humid regions (Kodagu & Dakshina Kannada districts), mainly due to the variation in meteorological parameters in different seasons in these districts.

### 3.2. Spatial comparison of actual & normal PET in different seasons

Spatial and temporal variability of actual (dynamic) PET obtained through location specific weather conditions

### TABLE 5

| Sub-taluks       | Average potential evapotranspiration (PET) |
|------------------|-------------------------------------------|
|                  | (1-8) | (9-22) | (23-39) | (40-52) |
|                  | SMW   | SMW    | SMW     | SMW     |
| Beltangadi       | 27.0  | 31.5   | 24.6    | 24.5    |
| Kokkada          | 26.4  | 31.0   | 24.3    | 24.7    |
| Venur            | 27.7  | 32.0   | 24.6    | 23.2    |
| Bantwal          | 26.7  | 30.8   | 25.9    | 24.8    |
| Kurur            | 27.6  | 31.5   | 25.8    | 24.2    |
| Vittal           | 27.8  | 32.1   | 25.6    | 23.5    |
| Mangaluru (A)    | 24.0  | 26.3   | 22.9    | 21.0    |
| Mangaluru-B      | 22.5  | 25.1   | 26.2    | 24.0    |
| Gurpur           | 28.5  | 29.8   | 22.7    | 23.6    |
| Mulki            | 22.0  | 26.7   | 23.8    | 22.4    |
| Suratkal         | 22.4  | 27.1   | 24.6    | 23.3    |
| Mudbidri         | 25.9  | 29.0   | 23.8    | 22.4    |
| Puttur           | 25.8  | 30.9   | 25.3    | 24.9    |
| Kadaba           | 26.3  | 34.6   | 30.7    | 24.2    |
| Uppinangadi      | 25.5  | 31.3   | 24.9    | 23.7    |
| Sula             | 25.3  | 30.0   | 24.4    | 24.6    |
| Panaje           | 25.5  | 30.1   | 24.5    | 24.2    |
| Seasonal weekly average PET (mm) | 25.7  | 30.0   | 25.0    | 23.6    |

The districts (Tables 4&5) in summer and southwest monsoon seasons. This may be attributed to the variation in the climatic conditions among the districts (Garcia et al., 2004).
Fig. 2. Spatial variability of annual PET in sub-taluk of the study area

Fig. 3. Spatial and temporal comparison of actual & normal PET
parameters and normal PET among the districts (Fig. 3) indicate that the normal PET is higher than the actual PET except in south west monsoon. This may be due to the variations in weather parameters at each sub-taluk level. The actual PET estimates depict the actual situation of the water demand at sub-taluk level while the normal PET averages the variations. Hence the normal PET shows a general trend in the water demand of the district rather than the actual water demand at sub-taluk level.

The standard deviation (SD), mean and coefficient of variation (CV) were estimated for actual PET values during winter (1-8 SMWs), summer (9-22 SMWs), southwest monsoon (23-39 SMWs) and northeast monsoon (40-52 SMWs) in these four districts (Table 6). The SD and CV values of actual PET were found highest in south west monsoon season (23-39 SMWs) of Chitradurga district while it is lowest in Kodagu and Dakshina Kannada districts during summer (9-22 SMWs) season. The SD and CV values of actual PET indicate that there is a variability among the seasons as well as districts. In general the values of normal PET are low as compared to actual PET values in these districts irrespective of the seasons indicating low variability. Besides the mean and RMSE of actual PET in different seasons also indicate that there is a considerable variability (RMSE ranged from 2 to 7) in actual PET among sub-taluks in different seasons. Hence the dynamic PET values obtained through real time weather data at sub-taluks in different seasons will perhaps depict actual water demand in situ at sub-taluk level in these districts.

### Table 6

| District              | Stat. variable | 1-8 SMW | 9-22 SMW | 23-39 SMW | 40-52 SMW |
|-----------------------|---------------|--------|---------|----------|----------|
| Koppala               | SD            | 2.9    | 2.9     | 4.0      | 2.1      |
|                       | Mean          | 25.2   | 38.3    | 36.1     | 24.0     |
|                       | CV            | 11.5   | 7.5     | 10.9     | 8.8      |
| Chitradurga           | SD            | 2.2    | 3.9     | 4.4      | 1.8      |
|                       | Mean          | 25.5   | 35.0    | 30.8     | 23.1     |
|                       | CV            | 8.7    | 11.2    | 14.1     | 7.7      |
| Kodagu                | SD            | 1.9    | 1.2     | 1.8      | 1.3      |
|                       | Mean          | 24.4   | 27.9    | 22.0     | 21.7     |
|                       | CV            | 7.9    | 4.4     | 8.0      | 5.8      |
| Dakshina Kannada      | SD            | 2.0    | 2.5     | 1.8      | 1.0      |
|                       | Mean          | 25.7   | 30.0    | 25.0     | 23.7     |
|                       | CV            | 7.6    | 8.2     | 7.1      | 4.4      |

#### 4. Conclusions

This study revealed that there is variation in the evaporative demand of water among the sub-taluks with in a district in different seasons. The arid/semi arid /sub-humid/humid environs of the districts contribute to variation in PET. Besides these, the evaporative demand of water varies with season irrespective of the regions. This comprehensive study, brought out clear view about dynamic evaporative demand both temporally & spatially for water management based planning and for drought classification through hydrological water balance studies.

**Disclaimer**: The contents and views expressed in this research paper/article are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

#### References

Adeboye, O. B. Osubitan, J. A., Adekolu, K. O. and Okunade, D. A., 2009, “Evaluation of FAO-56 Penman-Monteith and Temperature based Models on estimating Reference Evapotranspiration”, *Agricultural Engineering International (CIGR, J.),* Volume XI, 1-15

Allen, R. G., Pereira, L. S., Raes, D. and Smith, M., 1998, “Crop Evapotranspiration Guidelines for Computing Crop Water Requirements”, *In: Irrigation and Drain, Paper No. 56, FAO, Rome, Italy,* p300.

Bapuji Rao, B., Sandeep, V. M., Rao, V. U. M. and Venkateswarlu, B., 2012, “Potential Evapotranspiration estimation for Indian conditions: Improving accuracy through calibration coefficients”, *Tech. Bull. No 1/2012, All India Co-ordinated Research Project on Agrometeorology, Central Research Institute for Dryland Agriculture, Hyderabad,* p60.

Berengen, J. and Gavilan, P., 2005, “Reference evapotranspiration estimation in a highly advective semiarid Environment”, *J. Irrig. Drain. Engg., ASCE,* 131, 1, 147-163.

Blaney, H. F. and Cridge, W. D., 1950, “Determining Water Requirements in Irrigated Areas from climatologically and Irrigation Data - USDA (SCS) TP 96 48, By the FAO56 Penman-Monteith method”, *Agric. Water Manage.,* 81, 1-22.

Cai, J., Liu, Y., Lei, T. and Pereira, L. S., 2007, “Estimating reference evapotranspiration with the FAO Penman-Monteith equation using daily weather forecast messages”, *Agric. Forest Meteorol.,* 145, 22-35.

Christiansen, J. E., 1968, “Pan evaporation and evapotranspiration form climatic data”, *J. Irrig. and Drain., Div., ASCE,* 94, 243-265.

Dooorenbos, J. and Pruitt, W. O., 1977, “Crop Water Requirements”, In: *FAO Irrigation and Drainage No. 24, Food and Agriculture Organization of the United Nations, Rome,* p144.

Er-Raki, S., Chehbouni, A., Khabba, S., Simonneaux, V., Jarlan, L., Ouldbba, A. Rodriguez, J. C. and Allen, R. G., 2010, “Assessment of reference evapotranspiration methods in semi-arid regions: Can weather forecast data be used as alternate of ground meteorological parameters?”, *Journal of Arid Environments,* XXX (2010), 1-10.
Garcia, M., Raes, D., Allen, R. and Herbas, C., 2004, “Dynamics of reference evapotranspiration in the Bolivian highlands (Altiplano)”, Agricultural and Forest Meteorology, 125, 1-2, 67-82.

Goyal, R. K., 2004, “Sensitivity of Evapotranspiration to global warming: A case study of Arid-Zone Rajasthan (India)”, Agricultural Water Management, 69, 1-11.

Hardback Jr. G. E., 1962, “A Practical Field Technique for measuring reservoir evaporation utilizing mass-transfer-theory”, U. S. Geological Survey paper, 272-E, 101-105.

Harding, R. J., 1978, “The Variation of the Altitudinal Gradient of Temperature within the British Isles”, Geografiska Annaler, Series A, Physical Geography, 60, 1-2, 43-49.

Hargreaves, G. L. and Samani, Z. A., 1982, “Estimating potential evapotranspiration”, J. Irrig. Drain. Eng., ASCE, 108, 3, 225-230.

Hargreaves, G. L. and Samani, Z. A., 1985, “Reference Crop Evapotranspiration from Temperature”, Applied Engng., In Agric., 1, 2, 96-99.

Hargreaves, G. L., Hargreaves, G. H. and Riley, J. P., 1985, “Agricultural benefits for Senegal River Basin”, J. Irrigation and Drainage Engng., ASCE., 111, 113-124.

IFAD, 2008, “Water and the rural poor interventions for improving livelihoods in sub-Saharan Africa”, Ed. Jean Marc Faures and Guido Santini with FAO.

IPCC, 2008, “Special report on managing the risks of extreme events and disasters to advance climate change adaptation”, http://www.ipcc-wg2. Gov/SREX/ images/ uploads / SREX-All_FINAL.pdf.

Jensen, M. E., Burman, R. D. and Allen, R. G. (ed.), 1990, “Evapotranspiration and Irrigation Water Requirements”, ASCE Manuals and Reports on Engineering Practices No. 70, Am. Soc. Civil Engns., New York, p360.

Jin-Liang Ren, Qiong-Fang, Mei-Xiu Yu and Hao-Yang Li., 2012, “Variation trends of variables and their impacts in potential Evapotranspiration in Hailar Region”, Water science and Engineering, 5, 137-144.

Makkink, G. F., 1957, “Testing the penman formula by means of Lysimeters”, J. Inst. Water Engineers, 11, 277-278.

Martinez-Cob, A. and Tejero-Juste, M., 2004, “A wind-based qualitative calibration of the Hargreaves ETo estimation equation in semiarid regions”, Agric. Water Manage., 64, 251-264.

Penman, H. L., 1948, “Natural evaporation from open water, bare soil and grass”, Proc. R. Soc. Lond., A193, 116-140.

Popova, Z., Kercheva, M. and Pereira, L. S., 2006, “Validation of the FAO methodology for computing ETo with missing climatic data application to South Bulgaria”, Irrig. Drain., 55, 201-215.

Priestly, C. H. B. and Taylor, R. J., 1972, “On the assessment of the surface heat flux and evaporation using large scale parameters”, Monthly weather review, 100, 81-92.

Rao, A. V. and Wani, S. P., 2011, “Evapotranspiration paradox at a semiarid location in India”, J. Agro-Meteorologi., 13, 3-8.

Ravelli, F. and Rota, P., 1999, “Monthly frequency maps of Reference evapotranspiration and crop water deficits in southern Italy”, Rome, Italy: Irrigation Experimentation office of the formersouthern Italy Development Agency.

Saeed, M., 1986, “The estimation of evapotranspiration by some equations under hot and arid conditions”, Trans. ASAE, 29, 2, 434-438.

Thornthwaite, C. W., 1948, “An approach toward a rational classification of climate”, Geographic. Rev., 38, p55.

Trajkovic, S., 2007, “HargreavesversusPenman-Monteithhumid conditions”, J. Irrig. Drain. Engng., 133, 38-42

Xu, C. Y. and Singh, V. P., 2001, “Evaluation and generalization of temperature based methods for calculating evaporation”, Hydrological Processes, 15, 305-319.