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

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सार – विभिन्न मौसमों के दौरान उप-तालुक स्तर पर संभावित वाष्पीकरण शक्ति (पीईटी) का आकलन, जलवायु परिवर्तन के मौजूदा परिदृश्य में और कर्नाटक राज्य की संभावित पुरानी सूखा में असामान्य मौसम की स्थिति को महत्व देता है। विभिन्न कृषि-जलवायु / कृषि-पारिस्थितिक क्षेत्रों के तहत चयनित जिलों के विभिन्न उप-तालुकों में पीईटी (पानी की आवश्यकता) का अनुमान है कि आर्द्र जिलों की तुलना में अर्ध-शुष्क / शुष्क जिलों में पानी की जरूरत अधिक होती है। चयनित जिलों की औसत पीईटी निम्न क्रम में थी: कोपाला > चित्रदुर्ग > दक्षिणी कन्नड़ > कोडगु। पीईटी में परिवर्तनशीलता को उन्हीं जिलों और विभिन्न जिलों के उप-तालुकों के बीच देखा गया। सामान्य तौर पर 9-22 एसएमडब्ल्यू (ग्रीष्म) के दौरान औसत पीईटी अन्य उप-तालुकों या जिलों में अपेक्षाकृत अधिक था। वर्तमान अध्ययन में सामान्य पीईटी और वास्तविक गणना पीईटी के बीच की तुलना में पता चलता है कि दक्षिणी पश्चिमी मॉनसून ऋतु (22-39 एसएमडब्ल्यू) को छोड़कर सभी जिलों के सभी मौसमों में सामान्य पीईटी मान अधिक थे। यह इंगित करता है कि वास्तविक पीईटी एक बेहतर अनुमान है क्योंकि यह उप तालुक क्षेत्र और मौसम में पानी की वास्तविक आवश्यकता प्रदान करता है। इसलिए इन वास्तविक पीईटी मानों में सूखे का मूल्यांकन और फसल जल प्रबंधन योजना में स्थान / सीजन विशिष्ट सूचकांक विकसित करने के लिए बेहतर उपकरण हैं।

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-taluks 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: Koppala > Chitradurga > Dakshina Kannada > Kodagu. The variability in PET was observed among the sub-taluks 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-taluks 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 also difficult. Hence, an indirect measurement of 'PET' with the use of meteorological /weather data is in vogue. Unavailability of weather data, in different locations, limits application of different methods/approaches for the measurement of 'PET'. There are many approaches for the determination of 'PET' such as direct soil water
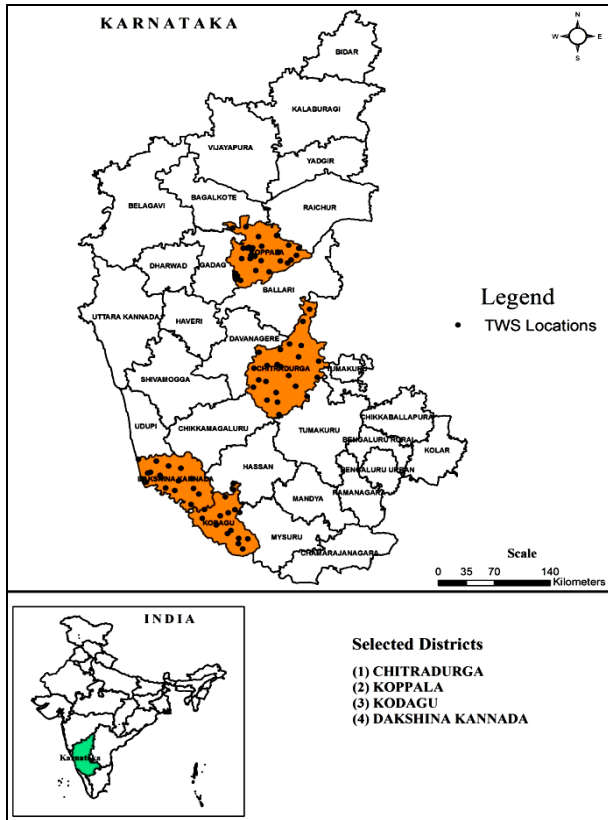
Fig. 1. Location of the study area with Telemetric Weather Stations (TWS)

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 - 4 (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 Netravathi, 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	$\Delta = \dfrac{4098\left[0.618\exp\left(\dfrac{17.27T}{T+237.3}\right)\right]}{\left[T+237.3\right]^2}$	kPa°c^{-1}
2.	Mean saturated vapour pressure	$e_s = \dfrac{e°T_{max(mean)} + e°T_{min(mean)}}{2}$	kPa
3.	Saturated vapour pressure at temp 'T'	$e°(T)=0.6108\exp\left(\dfrac{17.27T}{T+237.3}\right)$	kPa
4.	Actual vapour pressure	$e_a = \dfrac{\left[e°(T_{min})\times\dfrac{RH_{max}}{100}\right]+\left[e°(T_{max})\times\dfrac{RH_{min}}{100}\right]}{2}$	kPa
5.	Vapour pressure deficit	$(e_s - e_a)$	kPa
6.	Clear sky solar Radiation	$R_s=(0.75\times2\times10^{-5}\times Z)R_a$ where, Z = Altitude of location R_a = extra terrestrial radiation	MJm^{-2} d^{-1}
7.	Incoming Solar radiation	$R_s = \sqrt{0.16\times(T_{max}-T_{min})\times R_a}$	MJ m^{-2} d^{-1}
8.	Net short wave radiation	$R_{ns}=(1-\alpha)\times R_s$ where, α = Albedo or canopy reflection constant (0.23)	MJm^{-2}d^{-1}
9.	Net long wave radiation	$R_{nl}=\alpha\left(\dfrac{\left[(T_{max}\,K)^4-(T_{min}\,K)^4\right]}{2}\right)\times(0.34-0.14\sqrt{e_a})\times\left[1.35\left(\dfrac{R_s}{R_{so}}\right)-0.35\right]$ where, K = Stefan Boltzmann constant (4.903 MJ K^{-4} m^{-2} day^{-1})	MJm^{-2}d^{-1}
10.	Net Radiation	$R_n = R_{ns} - R_{nl}$	MJm^{-2} d^{-1}
11.	Wind speed at height 'Z'(m)	$\mu_2 = \dfrac{4.87}{L_n(67.8z-5.42)}\mu_z$	ms^{-1}
12.	Psychrometric constant	$\gamma = 0.655\times10^{-3}\times P$	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) :

$$PET = \frac{0.408\Delta(R_n-G)+\gamma\left(\dfrac{900}{T+273}\right)\mu_2(e_s-e_a)}{\Delta+\gamma(1+0.34\mu_2)}$$

where,

PET - Reference evapotranspiration (mm d^{-1})

TABLE 2

**Variability of PET (mm) in different seasons (SMW)
and sub-taluks of Koppala district**

Sub - taluk name	Average potential evapotranspiration (PET)			
	(1-8) SMW	(9-22) SMW	(23-39) SMW	(40-52) SMW
Gangavathi	23.7	41.9	41.4	23.2
Hulihaider	24.5	38.6	35.3	23.0
Kanakgeri	24.0	36.3	35.2	23.3
Karatgi	22.1	35.2	32.7	22.8
Marali	20.9	38.2	40.6	21.3
Nauli	25.7	37.1	36.1	21.5
Siddapur	20.6	34.5	39.7	22.2
Venkatagiri	24.2	41.5	41.2	23.1
Koppala	22.8	35.3	31.8	22.3
Alawandi	30.9	42.8	36.9	28.9
Hitnal	24.6	37.2	35.5	24.5
Erakalguda	24.5	32.4	24.5	22.6
Kushtagi	25.9	39.9	36.9	24.9
Hanumanhal	27.4	40.1	37.0	25.9
Hanamsagar	25.6	39.7	35.2	25.6
Tavaragera	23.5	36.5	35.5	23.4
Yelburga	26.4	38.8	37.3	24.4
Hire Wankalkunti	26.8	41.0	41.5	24.7
Kuknur	32.3	42.6	35.1	29.1
Manglur	26.6	37.3	33.1	24.2
Seasonal Weekly Average PET (mm)	25.2	38.3	36.1	24.0

Δ - Slope of vapour pressure curve (kPa°c^{-1})

R_n - Net radiation at the crop surface (MJ m^{-2} d^{-1})

G - Soil heat flux density (MJ m^{-2} d^{-1})

γ - Psychrometric Constant

T - Mean of daily maximum & minimum air temperature (°C)

μ_2 - Wind speed at 2 m height (ms^{-1})

e_s - Saturated vapour pressure (kPa)

e_a - Actual vapour pressure (kPa)

$(e_s - e_a)$ - Saturated vapour deficit

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-taluks 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 seasonal weekly average of PET values at sub-taluk level in each district [Tables (2-5)] indicate the variability among the sub-taluks within the district and across the districts in a season. The seasonal variability was also observed among the sub-taluks 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 32.4 to 42.8 mm. The weekly PET values in southwest monsoon (23-39 SMW) varied from 24.5 to 41.5 mm at sub-taluk level. In northeast monsoon (40-52 SMW), the PET ranged from 21.3 to 29.1 mm. The district weekly average PET is 25.2 mm in winter, while it is 38.3 mm in summer and 36.1 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 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 30.8 to 44.8 mm at sub-taluk level with a district weekly average PET

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TABLE 3

**Variability of PET (mm) of different seasons (SMW)
and sub-taluks in Chitradurga district**

Sub-taluk name	Average potential evapotranspiration (PET)			
	(1-8) SMW	(9-22) SMW	(23-39) SMW	(40-52) SMW
Challakere	30.1	42.9	40.8	28.7
Nayakanahatti	28.3	42.7	37.7	25
Parasurampura	28.5	35.3	32.4	24
Talaku	25.1	35.1	31.7	23.6
Chitradurga	21.2	32.9	28	22.5
Bharmasagara	24.9	33.9	28.4	25.3
Hireguntanur	24.3	33.2	28.7	21.9
Turuvanur	26.3	44.8	41.6	24.2
Hiriyur	23.7	31.3	27.7	22
Aymangala	24.1	32.2	28.8	22
Dharmapura	25.7	35.6	33.2	22.4
Javanagondanahalli	24.1	31.7	28.9	21.5
Holalkere	29.8	36.3	30.8	23.2
B.R.Durga	26.3	33.4	26.2	24.1
Ramagiri	25.9	36.7	30	24.6
Talya	24.3	32.4	29.5	22.3
Hosadurga	23.9	31.5	25.7	20.9
Madadakere	26.8	37.3	28.3	22.8
Mathodu	26.2	33.1	28.2	22.7
Srirampura	22.5	30.8	28.2	21.6
Molakalmuru	23.8	31.5	28.9	20.7
Devasamudra	25.1	36.1	35	23.3
Seasonal Weekly Average PET (mm)	25.5	35.0	30.8	23.1

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TABLE 4

**Variability of PET (mm) in different seasons (SMW)
and sub-taluks of Kodagu district**

Sub-taluk name	Average potential evapotranspiration(PET)			
	(1-8) SMW	(9-22) SMW	(23-39) SMW	(40-52) SMW
Madikeri	22.1	25.9	19.0	19.4
Bhagamandala	25.8	27.6	23.3	23.1
Napoklu	23.8	27.2	22.7	21.7
Sampaje	25.9	28.6	22.2	22.9
Somwarpet	24.6	28.0	20.3	21.7
Kodlipet	24.4	28.6	21.2	22.1
Kushalnagar	25.2	30.3	24.8	22.9
Sanivarsante	24.5	28.3	21.5	21.5
Santhahalli	24.1	27.7	20.1	21.7
Suntikoppa	21.5	26.6	20.6	19.6
Virajpet	22.9	28.3	23.7	20.8
Ammati	23.9	29.1	25.7	21.9
Blale	30.0	29.7	22.5	24.3
Hudakere	23.6	27.3	20.9	20.6
Ponnampet	23.7	27.1	22.1	21.7
Srimangala	23.9	27.7	21.1	20.7
Seasonal Weekly Average PET(mm)	24.4	27.9	22.0	20.7

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 Chitradurga districts showed higher average weekly PET values both at sub-taluk and district levels [Tables (2&3)] in comparison to Kodagu and Dakshina Kannada

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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

TABLE 5

**Variability of PET (mm) of different seasons (SMW)
and sub-taluks in Dakshina Kannada district**

Sub - taluk name	Average potential evapotranspiration (PET)			
	(1-8) SMW	(9-22) SMW	(23-39) SMW	(40-52) 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
Pane Mangalore	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
Sulya	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

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).

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, Kuknur and Hire Wankalkunti 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*

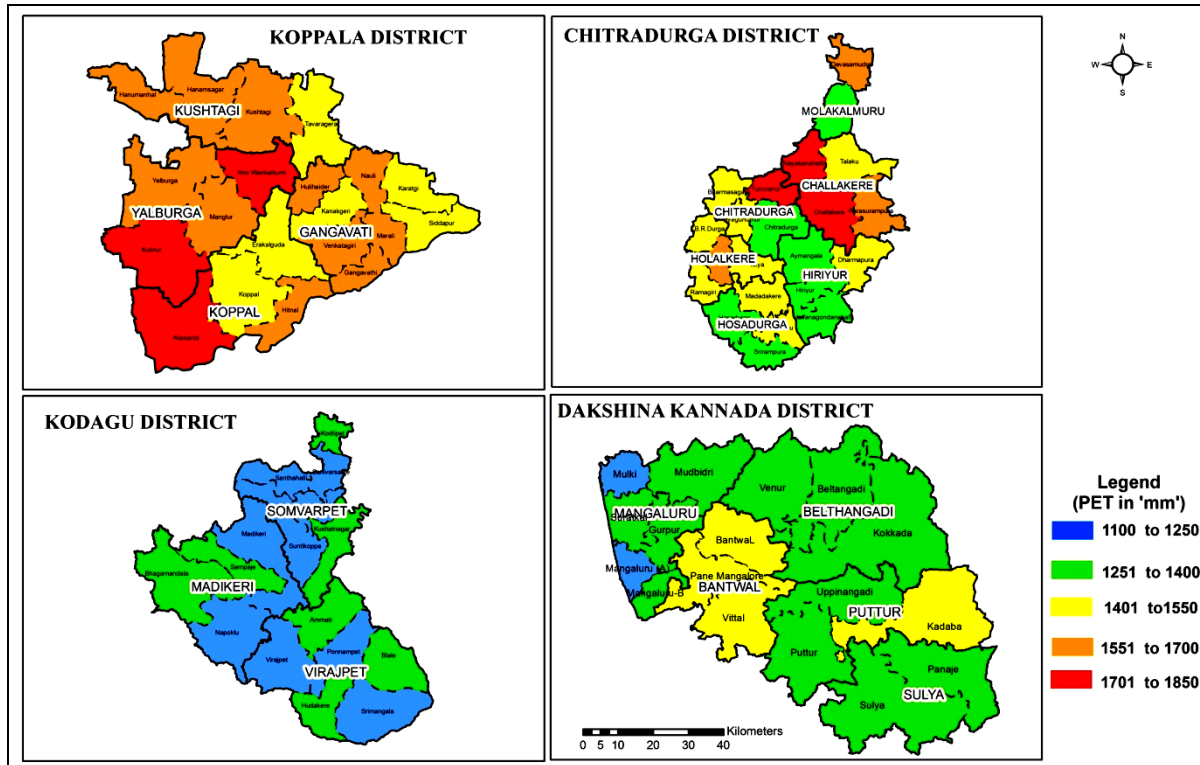Spatial and temporal variability of actual (dynamic) PET obtained through location specific weather

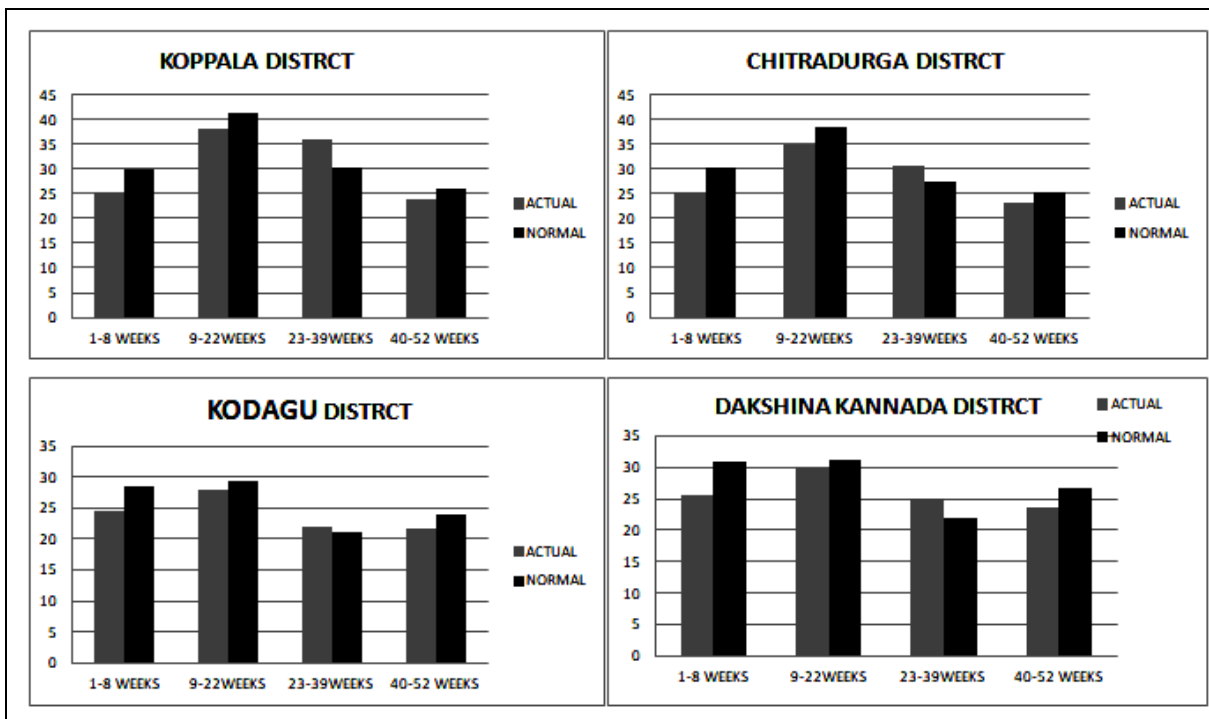**Fig. 2.** Spatial variability of annual PET in sub-taluks of the study area

Fig. 3. Spatial and temporal comparison of actual & normal PET

TABLE 6

Mean and standard deviation of actual PET in different seasons (SMW) of districts

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

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.

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.

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