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Short Comminucation

Trend and variability in potential evapotranspiration over north-west India

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Evapotranspiration is one of the most important components of hydrological cycle having a significant impact on crop water requirements. It has a great significance in the application of need based irrigation to the crops. Estimation of crop water requirements (ETc) is one of the main components used in irrigation planning, design and operation (Rowshon *et al.*, 2013). In future, evapotranspiration and crop water productivity will be altered due to climate change (Thomas, 2008). Jensen *et al.* (1990) provided detailed reviews of the methods commonly used to determine evapotranspiration and estimated crop water requirements.The present study was undertaken to estimate PET and to assess its trends and distributionin north-west India.

Daily maximum and minimum temperature data of 34 years (1980-2014) of twenty two meteorological stationslocated in north-west India was selected for the study. The geographical information (latitude, longitude and altitude) of all the stations is given in Table 1. Based on the altitude, the study area was divided as hills >1000 meters (Srinagar, Manali, Shimla, Palampur, Solan and Ranichauri) and as Plains < 1000 m (Jammu, Chandigarh, Ambala, Saharanpur, Delhi, Karnal, Patiala, Ludhiana, Rohtak, Bathinda, Hisar, Sirsa, Bawal, Narnaul, Ganganagar and Jaipur). Similarly, the whole year was divided into two seasons namelyeffective growing season (EGS) and dormant season (DS) for regional and seasonal data analysis. EGS for hills was considered from April to October and from March to Octoberfor plains. Similarly DS for hills was considered from November to March and for plains it was from December to February. The effective growing season (EGS) and dormant season (DS) are classified mainly for temperate fruits crops.

Thornthwaite (1943) who first coined a climatologically meaningful term called as potential evapotranspiration. There are many direct and indirect ways of determining potential evapotranspiration (Allen *et al.,* 1998; Kingra, 2015) but, the Thornthwaite method (1948) is the best among different empirical approaches as used by many workers for estimation of PET over several location of India (Krishan Kumar *et al.,* 1987) and also used in the present study.

$PET = 1.6\,(10T/l)^{a}\,(D/12)\,(N/30)$

For a month consisting 30 days and 12 hours a day, the above equation can be written as:

$E = 1.6(10T/I)^{a}$

Where,

E = Unadjusted PET, cm/month; T = Mean air temp, °C; I = Annual heat index. It is the summation of 12 values of monthly heat indices i.

$i = (T/5)^{1.514}$

a = an empirical exponent computed by an expression given as,

$a = 6.75\text{x}10^{-7} I^{3} - 7.71\text{x}10^{-5} I^{2} + 1.79\text{x}10^{-2} I + 0.49239$

For daily computation, the equation is modified as:

$PET = (K\text{x}E\text{x}10)/30$ (mm day^{-1})

Where, K = Adjustment factor

Statistical measures were computed using 'OP Stat" software using daily, monthly and seasonalpotential evapotranspiration of each station.

The annual normal potential evapotranspiration ranged from 500 to 800 mm for Srinagar, Manali, Shimla, Palampur, Solan and Ranichauri and from 1000 to 1800 mm for remaining sixteen stations. The coefficient of variation was between 5 and 11% for Manali, Jammu, Chandigarh, Ambala, Saharanpur, Delhi, Patiala, Ludhiana, Rohtak, Bathinda, Hisar, Sirsa, Bawal, Narnaul, Ganganagar, Jaipur and 2 to 5 for six stations (Table 2). The slope values (mm/year) were positive for all the stations except two stations Ranichauri (-0485) and Narnaul (-0.513). It was between 2 and 8 mm/year for Manali, Solan, Saharanpur, Ludhiana, Rohtak, Sirsa, Ganganagar and Jaipur and was less than 2

Table 1: Geographical information of different meteorological stations of north-west India

Division	Station	Latitude	Longitude	Altitude (m)
Hills	Srinagar	34.09	74.79	1600
	Manali	32.27	77.17	2050
	Shimla	31.11	77.17	2397
	Palampur	32.12	76.53	1219
	Solan	30.92	77.12	1600
	Ranichauri	30.06	78.99	1950
Plains	Jammu	32.73	74.87	327
	Chandigarh	30.75	76.78	321
	Ambala	30.38	76.78	264
	Saharanpur	29.96	77.54	268
	Delhi	28.62	77.21	216
	Karnal	29.69	76.98	245
	Patiala	30.34	76.38	350
	Ludhiana	30.91	75.85	244
	Rohtak	28.89	76.57	220
	Bathinda	30.23	74.95	201
	Hisar	29.15	75.71	215
	Sirsa	29.53	75.01	205
	Bawal	28.08	76.58	266
	Narnaul	28.01	76.01	308
	Ganganagar	29.92	73.88	178
	Jaipur	26.91	75.81	431

mm/year for the remaining stations. The standard error was highest for Saharanpur (6.4 mm) and lowest for Shimla (0.29 mm). The normal evaporation computed was 679.1 ± 25.0 mm for hills 1395 ± 105.4 mm for plains and 1192.4 ± 83.3 mm for north-west India with the coefficient of variation of 3.7, 7.4 and 6.4%, respectively (Table 2). The slope was positive having values of 0.79, 1.97 and 1.65 mm/year for hills, plains and north-west India with standard error of 0.56, 2.15 and 1.73 mm, respectively. The significance level (p) of slope was 0.160 for hills, 0.330 for north-west India and highest 0.389 for the plains. Similarly Chattopadhyayand Hulme (1997) concluded that future warming seems likely to lead in general to increased potential evapotranspiration over India, although this increase will be unequal between regions and seasons. Madhu*et al.,* (2015) and Goyal (2004) reported an increasing rate of 2.9 mm/decade 5.0mm/decade in evapotranspiration over India and NW India, respectively.

The normal evapotranspiration during the effective growing season was less than 1000 mm for Srinagar, Manali, Shimla, Palampur, Solan and Ranichauri and between 1000 and 1300 mm for Jammu, Chandigarh, Ambala, Saharanpur, Karnal, Patiala and Ludhiana and between 1300 and 1800 for Delhi, Rohtak, Bathinda, Hisar, Sirsa, Bawal, Narnaul, Jaipur and Ganganagar being the highest for Ganganagar (1703.1 mm) and lowest for Shimla (501 mm). The coefficient of variation was highest for Jaipur (11.1%) and lowest (2.9%) for Shimla (Table 3). It was less than 6% for ten stations (Srinagar, Manali, Shimla, Palampur, Solan, Ranichauri, Ambala, Saharanpur, Karnal and Patiala) and varied from 6-12% for twelve stations (Jammu, Chandigarh, Delhi, Ludhiana, Rohtak, Bathinda, Hisar, Sirsa, Bawal, Narnaul, Ganganagar and Jaipur). The slope was negative at four stations (Srinagar, Palampur, Ranichauri and Narnaul) but positive at rest of the eighteen stations ranging from 0.119 mm per year (Karnal) to 8.24 mm per year (Ganganagar). The confidence level of significance (p) of $R^2$was more than 0.70 for Palampur, Delhi, Hisar, Narnaul and less than 0.70 for rest of the stations. The normal evapotranspiration during the effective growing season was 550.2 mm for hills 1329.2 mm for plains and 116.8 mm for north-west India with coefficient of variation of 4.1, 7.9 and 7.4 per cent, respectively (Table 2). The slope value (mm/year) was positive for hills (0.42), plains (1.79) and north-west India (1.94). Similarly Chakravarty*et al.,* (2015) also reported an increasing trend in ET during *rabi*season at Jabalpur.

During dormant season the normal potential evapotranspiration varied from 118 to 135 mm for Manali, Shimla, Palampur, Solan and Ranichauri, from 50 to 80 mm for Srinagar, Jammu, Chandigarh, Ambala, Saharanpur, Delhi, Karnal, Patiala, Ludhiana, Rohtak, Narnaul and Jaipur and from 40 to 50 mm for Bathinda, Hisar, Sirsa, Bawal, and Ganganagar during dormant season. The coefficient of variation was highest for Palampur (56.7%) and varied from 10 to 20% for Srinagar, Manali, Shimla, Solan, Jammu, Chandigarh, Ambala, Delhi, Karnal, Ludhiana, Rohtak, Bathinda, Hisar, Sirsa, Bawal, Narnaul, Ganganagar, Jaipur and was less than 10% for Shimla, Ranichauri, Saharanpur and Patiala (Table 3). The slope value was negative for Ranichauri, Jammu, Chandigarh, Ambala, Delhi, Karnal, Bathinda, Hisar, Sirsa, Narnaul and Ganganagar and positive for Srinagar, Manali, Shimla, Palampur, Solan, Saharanpur, Patiala, Ludhiana, Rohtak and Bawal.

PET was increasing at a rate of 108.5mm/100 years at Palampur followed by Solan 133.7 mm per 100 years and decreasing with a rate of 47.6 mm per 100 years at Jammu

Table 2: Statistical measures for annual potential evapotranspiration at different stations in North-west India

Station	**Normal**(mm)	SD	CV(%)	Intercept	Slope(rate)	S.E.	't' value	p	R^2
Srinagar	591.9	18.6	3.1	587.2	0.35	0.49	0.70	0.472	0.020
Manali	663.6	38.4	5.8	618.9	2.48	0.49	5.08	0.000	0.439
Shimla	644.7	21.1	3.3	619.7	1.47	0.29	5.05	0.000	0.451
Palampur	773.3	21.9	2.8	763.2	1.06	0.99	1.07	0.271	0.067
Solan	769.9	31.3	4.1	738.0	2.37	0.68	3.48	0.001	0.336
Ranichauri	631.2	18.9	3.0	638.8	-0.49	0.39	-1.23	0.213	0.051
Jammu	1233.2	102.6	8.3	1208.3	1.72	2.42	0.71	0.484	0.019
Chandigarh	1312.7	79.6	6.1	1285.4	1.61	1.45	1.11	0.276	0.038
Ambala	1290.6	69.4	5.4	1267.5	1.21	1.06	1.14	0.261	0.036
Saharanpur	1114.9	55.5	5.0	1099.8	2.74	6.40	0.43	0.645	0.022
Delhi	1410.4	90.7	6.4	1406.1	0.27	1.85	0.15	0.886	0.001
Karnal	1246.2	55.2	4.4	1225.0	0.96	0.67	1.44	0.158	0.048
Patiala	1298.3	69.5	5.4	1286.0	0.77	1.41	0.54	0.592	0.010
Ludhiana	1253.4	73.7	5.9	1183.5	4.66	1.40	3.32	0.002	0.290
Rohtak	1492.1	129.8	8.7	1448.3	2.09	1.70	1.23	0.228	0.037
Bathinda	1431.2	126.9	8.9	1408.8	1.45	2.71	0.53	0.585	0.010
Hisar	1368.1	94.7	6.9	1358.6	0.41	1.10	0.38	0.709	0.003
Sirsa	1483.0	127.6	8.6	1366.8	7.49	2.35	3.20	0.002	0.267
Bawal	1427.4	116.0	8.1	1409.1	1.11	2.25	0.49	0.626	0.008
Narnaul	1428.6	143.8	10.1	1438.6	-0.51	2.16	-0.24	0.808	0.002
Ganganagar	1751.5	176.6	10.1	1615.0	8.03	2.95	2.73	0.010	0.193
Jaipur	1617.0	172.0	10.6	1512.1	5.83	2.74	2.13	0.041	0.121

p: probability of error; 't' = 2.750 at 1% and 2.042 at 5%

Table 3: Statistical measures of annual and seasonal potential evapotranspirationat different areas in North-west India

Station	Normal(mm)	SD	CV(%)	Intercept	Slope(rate)	S.E.	't' value	p	R^2
Annual evapotranspiration									
Hills	679.1	25.0	3.7	664.7	0.79	0.56	2.36	0.160	0.207
Plains	1395.0	105.4	7.4	1350.0	1.97	2.15	1.24	0.389	0.127
NW India	1192.4	83.3	6.4	1163.0	1.65	1.73	1.52	0.330	0.146
Effective Growing Season (EGS)									
Hills	550.2	22.6	4.1	675.6	0.42	0.49	0.67	0.214	0.169
Plains	1329.2	105.5	7.9	1191.0	1.79	2.11	1.27	0.379	0.111
NW India	1116.8	82.9	7.4	1073.6	1.94	1.67	1.11	0.334	0.100
Dormant Season (DS)									
Hills	128.9	12.8	9.9	118.9	0.73	0.29	2.57	0.177	0.225
Plains	55.7	7.2	13.0	54.8	-0.08	0.16	-0.72	0.402	0.045
NW India	75.7	8.7	11.5	72.3	0.14	0.19	0.18	0.341	0.094

p: probability of error; 't' = 2.750 at 1% and 2.042 at 5%

followed by Delhi 24 mm per 100 years. The significance level of confidence for R^2 (p) was more than 0.60 for Ranichauri, Patiala, Ludhiana, Rohtak, Hisar, Bawal, and Jaipur and less than 0.20 for Srinagar, Shimla, Palampur, Jammu, Chandigarh, Ambala, Delhi, Karnal, Sirsa, Narnaul, Ganganagar, Manali and Solan. The normal PET for hills was 128.9 mm, for plains was 55.7 mm and for north-west India was 75.7 mm with coefficient of variation of 9.9, 13 and 11.5 per cent, respectively (Table 3).

- PET showed increasing trend for all the stations except Ranichauri (-48.5 mm/100years) and Narnaul (-51.3 mm/100years). The increasing rate was from 209 to 803 mm/100years for Manali, Solan, Saharanpur, Ludhiana, Rohtak, Sirsa, Ganganagar and Jaipur and 200 mm /100 years at rest of the stations.
- The annual normal PET on regional basis was 679.1, 1395, and 1192.4 mm with the coefficient of variation of 3.7, 7.4 and 6.4% and showed an increasing rate of 0.79 mm/years, 1.97mm per years and 1.65 mm per years for hills, plains and north-west India, respectively.
- During effective growing season the normal value of PET was 550.2, 1329.2, and 116.8 mm with coefficient of variation of 4.1, 7.9 and 7.4% and showed an increasing rate of 4.2, 17.9 and 19.4 mm per decade for hills, plains and north-west India, respectively.
- Similarly during dormant season the normal PET was 128.9, 55.7 and 75.7 mm for hills, plains and north-west India and it was increasing at the rate of 73 and 14mm/100 years for hills and north-west India but it was decreasing at the rate of 8 mm/100 years in plains.

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