

## Variability in reference evapotranspiration and moisture availability in three agroclimatic zones of Punjab, India

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### ABSTRACT

A research study was undertaken to estimate reference evapotranspiration ( $ET_o$ ), moisture index (MI) and aridity index (AI) and analyse their trends in different locations/zones of Punjab. Annual and seasonal  $ET_o$  was observed to be highest in south-west and lowest in north-east zone. North-east zone experienced increasing trend in annual as well as seasonal  $ET_o$ . Districts within the central zone had large variability within the zone. MI and AI were in the order of north-east zone followed by Central zone and South-west zone indicating better moisture availability conditions in north-east. Mean difference in annual and seasonal MI and AI also indicated statistical similarities within the districts of north-east and south-west zones but different from other zones. Thus, increasing trend of  $ET_o$  in north-east region and higher  $ET_o$  range in south-west zone along with severe moisture availability necessitates the need for more careful planning of water resources in the region.

**Key words:** Reference evapotranspiration, moisture index, aridity index, Punjab

The agriculture sector is the largest consumer of water resources in Punjab. The total water deficit of Punjab is 8.99 Billion Cubic Meters (BCM) annually which will increase to 9.12 BCM by 2020 (Anon, 2017). Reference evapotranspiration ( $ET_o$ ) is a key factor of water balance.  $ET_o$  expends two-third of the terrestrial precipitation (worldwide terrestrial rainfall is  $98.5 \times 10^3 \text{ km}^3 \text{ year}^{-1}$ , evapotranspiration is  $65.5 \times 10^3 \text{ km}^3 \text{ year}^{-1}$ ) (Mao *et al.* 2015). Reference evapotranspiration can be used for assessment of crop water requirements which is used for maintaining agricultural production and sustaining hydrological cycle. Accurate estimation of  $ET_o$  can be useful for formulating and altering the cropping plans and cultural operations to deal with anomalous weather for improving agricultural production in rainfed regions (Halikatti *et al.* 2010).

Holzman *et al.* (2013) found that soil moisture has direct relationship with the output of rainfed crops and moisture index helps in prediction of yield even before the harvest of the crop. Kaur and Gill (2017) calculated  $ET_o$  for present, mid and end century at central Punjab using Papadakis method and found rise in water requirement from 2011-2040 (1027 mm) to 2071-2100 (1150 mm). Under such conditions, a profound understanding of water availability can be obtained by studying  $ET_o$ , MI and AI on spatial and temporal scale. In view of this, the current research aims to study the variability of these parameters between and

within different agroclimatic zones of Punjab. Under present scenario of increasing water crisis in the state, this study may help in better crop planning through judicious use of water.

### MATERIALS AND METHODS

#### Data collection

The long-term data (1971-2018) of maximum temperature, minimum temperature and rainfall were collected from the Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University (PAU), Ludhiana, Regional Research Stations of PAU and India Meteorological Department. for different districts *viz.* Gurdaspur and SBS Nagar in north-east region, Amritsar, Ludhiana and Patiala in central region and Ferozpur and Bathinda in south-west region of the state.

#### Computation of reference evapotranspiration ( $ET_o$ )

$ET_o$  was computed by using the Hargreaves-Samani method (Hargreaves and Samani, 1985) as following:

$$ET_{oHS} = 0.0023 R_a (T+17.8) \sqrt{T_{max} - T_{min}}$$

Where,  $ET_{oHS}$  is grass reference evapotranspiration ( $\text{mm d}^{-1}$ ), T is daily mean air temperature ( $^{\circ}\text{C}$ ),  $T_{max}$  is daily maximum air temperature ( $^{\circ}\text{C}$ ),  $T_{min}$  is daily minimum air temperature ( $^{\circ}\text{C}$ ) and  $R_a$  is water equivalent of the extra terrestrial radiation ( $\text{mm d}^{-1}$ ).

**Table 1:** Average ET<sub>o</sub> in different agroclimatic zones of Punjab (1971 to 2018)

Agroclimatic zones / stations	Mean±SD (mm)	CV	Rate of Change (mm year <sup>-1</sup> )	R <sup>2</sup>	Trend
<b>Annual ET<sub>o</sub></b>					
<b>North-east zone</b>					
Gurdaspur	1567.3±61.70	3.94	2.80	0.40	Significant
SBS Nagar	1562.5±90.40	5.78	3.92	0.39	Significant
Average	1564.89±73.66	4.71	3.41	0.42	Significant
<b>Central plain zone</b>					
Amritsar	1681.5±47.80	2.84	-0.61	0.03	NS
Ludhiana	1592.3±54.40	3.42	-2.55	0.43	Significant
Patiala	1611.5±58.80	3.65	1.27	0.10	Significant
Average	1628.46±44.53	2.73	-0.48	0.02	NS
<b>South-western zone</b>					
Bathinda	1732.9±53.30	3.07	-1.37	0.13	Significant
Ferozpur	1712.9±40.60	2.37	0.85	0.09	Significant
Average	1722.9±36.94	2.14	-0.26	0.01	NS
<b>Kharif ET<sub>o</sub></b>					
<b>North-east zone</b>					
Gurdaspur	997.4±39.50	3.96	1.49	0.28	Significant
SBS Nagar	979±54.60	5.58	2.16	0.32	Significant
Average	988.21±44.34	4.49	1.81	0.33	Significant
<b>Central plain zone</b>					
Amritsar	1056.6±37.50	3.55	-0.30	0.01	NS
Ludhiana	982.4±45.60	4.64	2.32	0.50	Significant
Patiala	982.9±43.30	4.41	0.55	0.03	NS
Average	1007.28±35.00	3.47	-0.63	0.06	NS
<b>South-western zone</b>					
Bathinda	1078.9±41.10	3.81	-0.83	0.08	Significant
Ferozpur	1070.9±33.10	3.09	0.64	0.07	NS
Average	1074.9±29.86	2.78	-0.09	0.00	NS
<b>Rabi ET<sub>o</sub></b>					
<b>North-east zone</b>					
Gurdaspur	569.3±29.10	5.11	1.41	0.44	Significant
SBS Nagar	583.3±39.90	6.84	1.84	0.43	Significant
Average	576.33±31.96	5.55	1.68	0.52	Significant
<b>Central plain zone</b>					
Amritsar	624.2±23.50	3.77	-0.22	0.02	NS
Ludhiana	609.4±24.90	4.08	-0.23	0.02	NS
Patiala	628.3±29.30	4.67	0.74	0.13	Significant
Average	620.63±24.46	3.94	0.20	0.01	NS
<b>South-western zone</b>					
Bathinda	653.5±27.90	4.28	-0.51	0.06	NS
Ferozpur	641.6±20.30	3.16	0.29	0.04	NS
Average	647.54±21.46	3.31	-0.11	0.01	NS

**Table 2:** Average MI in different agroclimatic zones of Punjab (1971 to 2018)

Agroclimatic zones / stations	Mean±SD	CV	Rate of Change (units year <sup>-1</sup> )	R <sup>2</sup>	Trend
<b>Annual MI</b>					
<b>North-east zone</b>					
Gurdaspur	-35.1±16.50	47.14	-0.231	0.038	NS
SBS Nagar	-32.5±17.80	54.80	-0.133	0.011	NS
Average	-33.82±15.68	46.36	-0.18	0.03	NS
<b>Central plain zone</b>					
Amritsar	-55.1±14.00	25.48	0.008	0	NS
Ludhiana	-52.1±14.90	28.57	0.122	0.01	NS
Patiala	-53.2±15.90	29.96	-0.069	0.00	NS
Average	-53.49±13.15	24.58	0.02	0.00	NS
<b>South-western zone</b>					
Bathinda	-74.8±8.50	11.30	0.092	0.023	NS
Ferozpur	-73.6±8.80	11.97	0.027	0.002	NS
Average	-74.23±7.97	10.74	0.06	0.01	NS
<b>Kharif MI</b>					
<b>North-east zone</b>					
Gurdaspur	-18.4±24.60	133.56	-0.209	0.014	NS
SBS Nagar	-11±26.20	238.05	-0.038	0	NS
Average	-14.7±23.67	161.13	-0.120	0.01	NS
<b>Central plain zone</b>					
Amritsar	-43.7±21.90	50.12	0.23	0.022	NS
Ludhiana	-35.9±25.20	70.10	0.206	0.012	NS
Patiala	-33.4±26.00	77.79	-0.007	0.00	NS
Average	-37.7±18.82	49.95	0.120	0.01	NS
<b>South-western zone</b>					
Bathinda	-66±12.50	18.95	0.166	0.034	NS
Ferozpur	-64.3±12.80	19.92	0.078	0.01	NS
Average	-65.15±11.70	18.05	0.120	0.02	NS
<b>Rabi MI</b>					
<b>North-east zone</b>					
Gurdaspur	-63.9±18.80	29.38	-0.305	0.05	NS
SBS Nagar	-68.6±17.00	24.75	-0.258	0.041	NS
Average	-66.2±16.51	24.93	-0.290	0.06	NS
<b>Central plain zone</b>					
Amritsar	-76.3±14.10	18.47	-0.063	0.004	NS
Ludhiana	-79±12.00	15.17	-0.060	0.005	NS
Patiala	-84.7±10.70	12.63	-0.098	0.02	NS
Average	-79.96±11.01	13.77	-0.070	0.01	NS
<b>South-western zone</b>					
Bathinda	-89±5.70	6.40	-0.046	0.012	NS
Ferozpur	-89±5.60	6.24	-0.092	0.052	NS
Average	-89±5.25	5.90	-0.070	0.03	NS

### Computation of moisture index (MI)

The availability of moisture for sufficient and efficient crop production was calculated by moisture index (Krishnan and Singh, 1972) as following:

$$\text{Moisture Index (MI)} = \frac{P - ET_o}{ET_o}$$

Where, P is precipitation and  $ET_o$  is reference evapotranspiration.

Climatic classification based on moisture index

Moisture index value	Climatic group
-80	Extremely dry
-80 to -60	Semi- dry
-60 to -40	Dry
-40 to -20	Slightly dry
-20 to 0	Slightly moist
0 to 50	Moist
50 to 100	Wet
100	Extremely wet

### Computation of aridity index (AI)

Aridity index for different locations has been computed according to the UNESCO (1979) procedure as following:

$$\text{Aridity index (AI)} = \frac{\text{Precipitation (P)}}{\text{Reference Evapotranspiration (ET}_o\text{)}}$$

Climate classification based on aridity index (UNEP, 1997)

Climate class	Aridity index
Hyper-arid	<0.03
Arid	0.03-0.20
Semi-arid	0.20-0.50
Dry sub humid	0.50-0.65
Humid	>0.65

### Trend analysis

Trends in  $ET_o$ , aridity index and moisture index was studied by conducting regression analysis.

## RESULTS AND DISCUSSION

### Variations in reference evapotranspiration

Among the three regions, annual  $ET_o$  was observed to be in the order: south-western zone (1722.9±36.9 mm) > central zone (1628.5±44.5 mm) > north-east zone (1564.9±73.7 mm). In north-east zone, it was higher in Gurdaspur (1567.3±61.7 mm), in the central zone in Amritsar (1681.5±47.8 mm) and in south-western zone in Bathinda

(1732.9±53.3 mm), whereas the variability in annual  $ET_o$  was found highest in SBS Nagar (5.8%), Patiala (3.7 %) and Bathinda (3.1%) in the corresponding regions. Temporal variability conducted by regression analysis indicated a significant increase in annual  $ET_o$  in the north-east region (@ 3.41 mm/year), Patiala (@ 0.10 mm/year), Firozpur (0.09 mm/year), significant decrease at Ludhiana (@ -2.55 mm/year) in central region and Bathinda (@ -1.37 mm/year) in south-west region (Table 1).  $ET_o$  in Gurdaspur and SBS Nagar was statistically similar to Ludhiana, but different from all other locations in central and south-west zone. Annual  $ET_o$  at Bathinda and Firozpur was statistically similar to Amritsar. Similarly at Ludhiana annual  $ET_o$  was statistically similar to that at Gurdaspur, SBS Nagar and Patiala (Table 4).

During *kharif* season,  $ET_o$  was observed in the order: south-west zone (1074.9±29.9 mm) > central (1007.3±35.0) > north-east zone (988.2±44.3 mm). In the north-east region, it was higher in Gurdaspur (997.4±39.5 mm), in central zone in Amritsar (1056.6±37.5 mm) and in south-west zone in Bathinda (1078.9 ± 41.1 mm), whereas the variability in *kharif* season  $ET_o$  was observed to be highest in SBS Nagar (5.6%), Ludhiana (4.6%) and Bathinda (3.8%) in the corresponding zones. Temporal variability analysis indicated a significant increase in  $ET_o$  in north-east region (@ 1.81mm/year), at Ludhiana (@ 2.32 mm/year) in the central plain zone and at Bathinda (0.08 mm/year) in south-west zone (Table 1). Gurdaspur and SBS Nagar district had  $ET_o$  statistically similar to Ludhiana and Patiala. Bathinda and Firozpur in the south-west zone had  $ET_o$  statistically similar to Amritsar (Table 4).

Similar to annual and *kharif* season,  $ET_o$  during *rabi* season was also observed in the order south-west zone (647.5 ±21.5 mm) > central (620.6±24.5 mm) > north-east zone (576.3±32.0 mm). In the north-east zone, higher  $ET_o$  was observed higher in SBS Nagar (583.3±39.9 mm); in central at Patiala (628.3±29.3 mm) and in south-west at Bathinda (653.5±27.9 mm), whereas variability in *rabi* season  $ET_o$  was observed to be highest in SBS Nagar (6.8%), Patiala (4.7%), Bathinda (4.3%) in the corresponding regions. Temporal variability analysis indicated a significant increase in *rabi* season  $ET_o$  in the north-east region (@1.68 mm/year) and at Patiala (@0.74 mm/year) in the central region (Table 1). Gurdaspur and SBS Nagar in the north-east region has *rabi* season  $ET_o$  statistically different from all other locations in central and south-west zones. In Amritsar, *rabi* season  $ET_o$  was statistically similar to Ludhiana, Patiala and Firozpur

**Table 3:** Average AI in different agroclimatic zones of Punjab (1971 to 2018)

Agroclimatic zones / stations	Mean±SD	CV	Rate of Change (unit year <sup>-1</sup> )	R <sup>2</sup>	Trend
<b>Annual AI</b>					
<b>North-east zone</b>					
Gurdaspur	0.7±0.20	25.41	-0.002	0.039	NS
SBS Nagar	0.7±0.20	26.36	-0.001	0.01	NS
Average	0.66±0.16	24.24	0	0.03	NS
<b>Central plain zone</b>					
Amritsar	0.4±0.10	31.33	0	0	NS
Ludhiana	0.5±0.10	31.06	0.001	0.01	NS
Patiala	0.5±0.20	34.02	-0.001	0.00	NS
Average	0.47±0.13	27.66	0	0.00	NS
<b>South-western zone</b>					
Bathinda	0.3±0.01	33.77	0.092	0.023	NS
Ferozpur	0.3±0.01	33.49	0.027	0.002	NS
Average	0.3±0.01	30.77	0.060	0.01	NS
<b>Kharif AI</b>					
<b>North-east zone</b>					
Gurdaspur	0.8±0.20	30.09	-0.002	0.01	NS
SBS Nagar	0.9±0.30	29.44	0	0	NS
Average	0.85±0.24	28.24	0	0.01	NS
<b>Central plain zone</b>					
Amritsar	0.6±0.22	38.96	0.230	0.02	NS
Ludhiana	0.6±0.30	39.34	0.001	0.01	NS
Patiala	0.7±0.30	39.00	0	0.00	NS
Average	0.62±0.19	30.65	0	0.01	NS
<b>South-western zone</b>					
Bathinda	0.3±0.10	36.57	0.002	0.03	NS
Ferozpur	0.4±0.10	36.06	0.001	0.01	NS
Average	0.35±0.12	34.29	0	0.02	NS
<b>Rabi AI</b>					
<b>North-east zone</b>					
Gurdaspur	0.4±0.20	52.18	-0.003	0.051	NS
SBS Nagar	0.3±0.20	54.07	-0.003	0.054	NS
Average	0.34±0.17	50.00	0	0.06	NS
<b>Central plain zone</b>					
Amritsar	0.2±0.10	59.24	-0.063	0.004	NS
Ludhiana	0.2±0.10	56.69	-0.001	0.01	NS
Patiala	0.2±0.10	69.70	-0.001	0.02	NS
Average	0.2±0.11	55.00	0	0.01	NS
<b>South-western zone</b>					
Bathinda	0.1±0.10	51.79	0.00	0.011	NS
Ferozpur	0.11±0.06	50.19	-0.001	0.05	NS
Average	0.11±0.05	45.45	0	0.03	NS

**Table 4:** Mean difference and analysis of significance (P values) of variability in ET<sub>o</sub>

	North-east region		Central region			South-west region	
	Gurdaspur	SBS nagar	Amritsar	Ludhiana	Patiala	Bathinda	Firozpur
<b>Annual ET</b>							
<b>North-east region</b>							
Gurdaspur	-	4.71(1.00)	-114.29(0.00)	-25.08(0.347)	-44.23*(0.004)	-129.97(0.000)	-144.68*(0.000)
SBS nagar	-4.72(1.000)	-	-119.0(0.000)	-29.81(0.159)	-48.95*(0.001)	-134.69*(0.000)	-149.4*(0.000)
<b>Central region</b>							
Amritsar	114.29*(0.000)	119.01*(0.000)	-	89.20*(0.000)	70.06*(0.000)	15.68(0.842)	-30.39(0.142)
Ludhiana	25.09(0.347)	29.81(0.159)	-89.2*(0.000)	-	19.14(0.674)	-104.88*(0.000)	-119.59*(0.000)
Patiala	44.23*(0.004)	48.95*(0.001)	-70.05*(0.000)	19.14(0.674)	-	-85.73*(0.000)	-100.4*(0.000)
<b>South-western region</b>							
Bathinda	129.97*(0.000)	134.69*(0.000)	15.68(0.842)	104.88*(0.000)	85.74*(0.000)	-	-14.71(0.878)
Firozpur	144.68*(0.000)	149.4*(0.000)	30.39(0.142)	119.6*(0.000)	100.45*(0.000)	14.71(0.878)	-
<b>Kharif ET</b>							
<b>North-east region</b>							
Gurdaspur	-	18.47(0.29)	-59.12*(0.00)	15.07(0.543)	14.55*(0.585)	-53.17*(0.000)	-73.16*(0.000)
SBS nagar	-18.47(0.29)	-	-77.58*(0.00)	-3.39(1.00)	-3.91(0.999)	-71.63*(0.00)	-91.62*(0.000)
<b>Central region</b>							
Amritsar	59.11*(0.00)	77.58*(0.00)	-	74.19*(0.00)	73.67*(0.00)	5.94(0.992)	-14.04(0.627)
Ludhiana	-15.07(0.543)	3.39(1.00)	-74.19*(0.00)	-	0.51(1.00)	-68.24*(0.00)	-88.23*(0.00)
Patiala	14.56*(0.585)	3.92(0.999)	-73.67*(0.00)	0.51(1.00)	-	-67.72*(0.00)	-87.72*(0.00)
<b>South-western region</b>							
Bathinda	53.17*(0.000)	71.63*(0.000)	-5.94(0.992)	68.24*(0.00)	67.72*(0.00)	-	-19.99(0.202)
Firozpur	73.16*(0.000)	91.62*(0.000)	14.04(0.627)	88.23*(0.000)	87.71*(0.000)	19.99(0.202)	-
<b>Rabi ET</b>							
<b>North-east region</b>							
Gurdaspur	-	-14.65(0.127)	-54.3*(0.00)	-39.48(0.000)	-59.04*(0.000)	-76.6*(0.000)	-70.6*(0.000)
SBS nagar	-14.65(0.127)	-	-39.59*(0.00)	-24.82*(0.00)	-44.38(0.000)	-61.91*(0.000)	-55.93*(0.000)
<b>Central region</b>							
Amritsar	54.25*(0.00)	39.59*(0.000)	-	14.76(0.121)	-4.78(0.979)	-22.31(0.002)	-16.34(0.059)
Ludhiana	39.48*(0.000)	24.82(0.000)	-14.77(0.121)	-	-19.55(0.010)	-37.08*(0.000)	-31.11*(0.000)
Patiala	59.04*(0.000)	44.38(0.000)	4.78(0.979)	19.55*(0.010)	-	-17.52(0.032)	-11.55(0.382)
<b>South-western region</b>							
Bathinda	76.56*(0.000)	61.91*(0.000)	-22.31*(0.002)	37.08*(0.000)	17.52*(0.032)	-	5.97(0.938)
Firozpur	70.59*(0.000)	55.93*(0.000)	16.34(0.059)	31.11*(0.000)	11.55(0.382)	-5.97(0.938)	-

and at Patiala also it was statistically similar to Amritsar and Firozpur (Table 4). Maximum ET<sub>o</sub> in South-western zone of Punjab might be due to its prevailing 'arid' climate in this zone (Kingra *et al.* 2017).

#### Variations in moisture index (MI)

Among the three regions, annual MI was observed to be in the order north-east zone (-33.82±15.68) > central

zone (-53.49±13.15) > south-western zone (-74.23±7.97). In north-east zone, it was higher in SBS Nagar (-32.5±17.8), in central zone in Ludhiana (-52.1±14.9) and in south-western zone in Firozpur (-73.6±8.8), whereas the variability in annual MI was found to be highest in Gurdaspur (47.1%), Amritsar (25.4%) and Bathinda (11.3%) in the corresponding zones. Analysis of temporal variability didn't indicate any significant trend (Table 2). Annual MI within districts of a

**Table 5:** Mean difference and analysis of significance (P values) of variability in MI

	North-east region		Central region			South-western region	
	Gurdaspur	SBS nagar	Amritsar	Ludhiana	Patiala	Bathinda	Firozpur
<b>Annual MI</b>							
<b>North-east region</b>							
Gurdaspur	-	-2.55(0.975)	20.02*(0.000)	-17.02*(0.000)	-18.12*(0.000)	39.7*(0.000)	38.54*(0.000)
SBS nagar	-2.55(0.975)	-	-22.58*(0.000)	-19.57*(0.000)	-20.68*(0.000)	-42.26*(0.000)	-41.10*(0.000)
<b>Central region</b>							
Amritsar	-20.02*(0.000)	-22.58*(0.000)	-	-3.00(0.946)	1.900(0.995)	19.68*(0.000)	-18.51*(0.000)
Ludhiana	-17.02*(0.000)	19.57(0.000)	-3.00(0.946)	-	-1.10(1.000)	-22.68*(0.000)	-21.51*(0.000)
Patiala	-18.12*(0.000)	-20.68*(0.000)	1.9(0.995)	-1.10(1.000)	-	21.58*(0.000)	-20.4*(0.000)
<b>South-western region</b>							
Bathinda	-39.71*(0.000)	-42.26*(0.000)	-19.68*(0.000)	-22.68*(0.000)	-21.58*(0.000)	-	-1.16(1.000)
Firozpur	-38.54*(0.000)	-41.10*(0.000)	-18.51*(0.000)	-21.51*(0.000)	-20.41*(0.000)	-1.16(1.000)	0
<b>Kharif MI</b>							
<b>North-east region</b>							
Gurdaspur	-	-7.37(0.656)	25.3*(0.000)	17.51*(0.002)	15.03*(0.016)	47.61*(0.000)	-45.92*(0.000)
SBS nagar	7.37(0.656)	-	-32.71*(0.000)	24.89*(0.000)	22.41*(0.000)	54.9*(0.000)	53.30*(0.000)
<b>Central region</b>							
Amritsar	-25.3*(0.000)	-32.7*(0.000)	-	-7.81(0.591)	-10.29(0.252)	22.27*(0.000)	20.58*(0.000)
Ludhiana	-17.51(0.002)	-24.89(0.000)	7.81(0.591)	-	-2.48(0.998)	30.10*(0.000)	28.40*(0.000)
Patiala	-15.03*(0.016)	-22.41*(0.000)	10.29(0.252)	2.48(0.998)	-	32.57*(0.000)	30.88*(0.000)
<b>South-western region</b>							
Bathinda	-47.61*(0.000)	-54.99*(0.000)	-22.27*(0.000)	-30.09*(0.000)	-32.57*(0.000)	-	-1.69(1.000)
Firozpur	45.92*(0.000)	53.30*(0.000)	-20.58*(0.000)	-28.40*(0.000)	30.88*(0.000)	1.69(1.000)	-
<b>Rabi MI</b>							
<b>North-east region</b>							
Gurdaspur	-	4.76(0.535)	12.35*(0.000)	14.91*(0.000)	20.50*(0.000)	24.94*(0.000)	-24.77*(0.000)
SBS nagar	-4.76(0.535)	-	-7.59*(0.060)	-10.15*(0.002)	-15.74*(0.000)	-20.18*(0.000)	-20.01*(0.000)
<b>Central region</b>							
Amritsar	-12.35*(0.000)	-7.59(0.060)	-	2.56(0.958)	8.14*(0.032)	-12.59*(0.000)	12.42*(0.000)
Ludhiana	-14.91*(0.000)	-10.15*(0.002)	-2.56(0.958)	-	-5.58(0.334)	10.02*(0.003)	-9.86*(0.004)
Patiala	-20.50*(0.000)	-15.74*(0.000)	-8.14*(0.032)	-5.58(0.334)	-	4.44(0.617)	4.27(0.659)
<b>South-western region</b>							
Bathinda	-24.94*(0.000)	-20.18*(0.000)	-12.59*(0.000)	-10.02*(0.003)	-4.44(0.617)	-	-0.165(1.000)
Firozpur	-24.7*(0.000)	-20.01*(0.000)	-12.42*(0.000)	-9.86*(0.004)	-4.27(0.659)	0.16(1.000)	-

zone was statistically similar but different from districts in other zones (Table 5).

During *kharif* season, MI was observed to be in the order: North-east zone (-14.7±23.67) > central zone (-37.7±18.82) > south-west zone (-65.15±11.7). In north-east zone, it was higher in SBS Nagar (-11±26.2), in central zone in Patiala (-33.4±26) and in south-west zone in Bathinda (-66.0±12.5),

whereas the variability in *kharif* MI was found to be highest in Gurdaspur (133.5%), Amritsar (50.12%), Bathinda (18.95%) in the corresponding regions. Temporal variability analysis didn't indicate significant trend (Table 2). *kharif* MI within districts of a zone was statistically similar but different from districts in other zones (Table 5).

During *rabi* season, MI was observed to be in the order:

**Table 6:** Mean difference and analysis of significance (P values) of variability in AI

	North-east region		Central region			South-western region	
	Gurdaspur	SBS nagar	Amritsar	Ludhiana	Patiala	Bathinda	Firozpur
<b>Annual AI</b>							
<b>North-east region</b>							
Gurdaspur	-	-0.025(0.978)	0.20*(0.000)	0.17*(0.000)	0.18*(0.000)	0.39*(0.000)	0.38*(0.000)
SBS nagar	0.02(0.978)	-	0.22(0.000)	0.19*(0.000)	0.20*(0.000)	0.42*(0.000)	0.41*(0.000)
<b>Central region</b>							
Amritsar	-0.20*(0.000)	0.22*(0.000)	-	-0.03(0.940)	-0.01(0.995)	0.19*(0.000)	0.18*(0.000)
Ludhiana	-0.17*(0.000)	-0.19*(0.000)	0.03(0.940)	-	0.01(1.000)	0.22(0.000)	0.21*(0.000)
Patiala	-0.18*(0.000)	0.20*(0.000)	0.01(0.995)	-0.01(1.000)	-	0.21*(0.000)	0.20*(0.000)
<b>South-western region</b>							
Bathinda	-0.39*(0.000) -0.01(1.000)	-0.42*(0.000)	-0.19*(0.000)	-0.22*(0.000)	-0.21*(0.000)	-	-0.01(1.000)
Firozpur	-0.38*(0.000)	-0.41*(0.000)	-0.18*(0.000)	-0.21*(0.000)	-0.20*(0.000)	0.01(1.000)	-
<b>Kharif AI</b>							
<b>North-east region</b>							
Gurdaspur	-	-0.07(0.663)	0.25*(0.00)	0.17*(0.002)	0.15*(0.016)	0.47*(0.000)	0.45*(0.000)
SBS nagar	0.07(0.663)	-	0.32*(0.00)	0.24*(0.00)	0.22*(0.999)	0.54*(0.00)	0.53*(0.000)
<b>Central region</b>							
Amritsar	-0.25*(0.00)	-0.32*(0.00)	-	0.07*(0.595)	-0.10*(0.253)	0.22*(0.000)	0.20*(0.000)
Ludhiana	-0.17*(0.002)	-0.24*(0.00)	0.07(0.595)	-	0.25(0.998)	0.30*(0.000)	0.28*(0.00)
Patiala	-0.15*(0.016)	-0.22(0.000)	0.10(0.253)	0.25(0.998)	-	0.32*(0.000)	-0.30*(0.00)
<b>South-western region</b>							
Bathinda	-0.47*(0.000)	-0.54*(0.000)	-0.22(0.000)	-0.30*(0.00)	-0.32*(0.00)	-	-0.01(1.000)
Firozpur	-0.45*(0.000)	0.53*(0.000)	-0.20*(0.00)	-0.28*(0.000)	-0.30*(0.000)	0.01(1.00)	-
<b>Rabi AI</b>							
<b>North-east region</b>							
Gurdaspur	-	0.04(0.127)	0.12*(0.000)	0.14*(0.000)	0.20*(0.000)	0.24*(0.000)	0.24*(0.000)
SBS nagar	-0.04(0.537)	-	0.07(0.062)	0.10*(0.003)	0.157*(0.000)	0.20*(0.00)	0.19*(0.000)
<b>Central region</b>							
Amritsar	-0.12*(0.00)	-0.07(0.062)	-	0.02*(0.962)	0.08*(0.032)	0.12*(0.002)	0.12*(0.000)
Ludhiana	-0.14*(0.000)	-0.10*(0.003)	-0.02(0.962)	-	0.05(0.32)	0.10*(0.003)	0.09*(0.004)
Patiala	-0.20*(0.000)	-0.15(0.000)	-0.08(0.032)	-0.05(0.320)	-	0.044(0.616)	0.04(0.682)
<b>South-western region</b>							
Bathinda	-0.24*(0.000)	-0.20*(0.000)	-0.12*(0.000)	-0.10*(0.003)	-0.04(0.616)	-	-0.002(1.00)
Firozpur	-0.24*(0.000)	-0.19*(0.000)	0.12*(0.000)	-0.09*(0.004)	-0.04(0.682)	0.002(1.000)	-

North-east zone (-66.2±16.51) > central zone (-79.96±11.01) > south-west zone (-89.0±5.25). In north-east zone, it was higher in Gurdaspur (-63.9±18.8), in central zone in Amritsar (-76.3±14.1) and in south-west zone there was no difference between Bathinda (-89.0±5.7) and Firozpur (-89.0±5.6), whereas the variability in *rabi* MI was found to be highest in SBS Nagar (-24.75%), Patiala (-12.63%), Firozpur (-6.24%) in the corresponding regions. Analysis of temporal variability didn't indicate any significant trend (Table 2). *Rabi* MI in

Amritsar was statistically similar to SBS Nagar and Ludhiana. Similarly, *rabi* MI in Patiala was statistically similar to Ludhiana in central zone and Bathinda and Ferozpur in south-west zone. Likewise, *rabi* MI in Bathinda and Firozpur was statistically similar to Patiala in central zone (Table 5).

#### Variations in aridity index (AI)

Among the three regions, annual AI was observed in the order: North-east zone (0.66±0.16) > central zone



( $0.47 \pm 0.13$ ) > south-west zone ( $0.3 \pm 0.01$ ) (Table 3). In north-east zone it didn't vary significantly between Gurdaspur and SBS Nagar, in Central it was higher in Ludhiana and Patiala and in south-west zone also there was no significant difference between Bathinda and Ferozpur, whereas variability in annual AI was observed to be highest in SBS Nagar (26.3%), Patiala (34.02%) and Bathinda (33.7%) in the corresponding zones. Analysis of temporal variability didn't indicate any significant trend Annual AI within districts of a zone was statistically similar but different from districts in other zones (Table 6).

During *kharif* season, AI was observed to be in the order: North-east zone ( $0.85 \pm 0.24$ ) > central zone ( $0.62 \pm 0.19$ ) > south-west zone ( $0.35 \pm 0.12$ ). In north-east zone, it was higher in SBS Nagar ( $0.9 \pm 0.3$ ), in central zone in Patiala ( $0.7 \pm 0.3$ ) and in south-west zone in Firozpur ( $0.4 \pm 0.1$ ), whereas the variability in *kharif* AI was found to be highest in Gurdaspur (30.09%), Ludhiana (39.34%), Bathinda (36.57%) in the corresponding regions. Analysis of temporal variability didn't indicate any significant trend (Table 3). Mean difference of AI among different districts and analysis of their significance indicated that *kharif* AI within districts of a zone was statistically similar but different from districts in other zones (Table 6).

During *rabi* season, AI was observed to be in the order: North-east zone ( $0.340.17 \pm$ ) > central zone ( $0.20.11 \pm$ ) > south-west zone ( $0.110.05 \pm$ ). In north-east zone, it was higher in Gurdaspur ( $0.40.2 \pm$ ), in central zone it was similar in all the three locations viz. Amritsar, Patiala and Ludhiana ( $0.20.1 \pm$ ) and in south-west zone in Firozpur ( $0.110.06 \pm$ ), whereas the variability in *rabi* AI was found to be highest in SBS Nagar (54.07%), Patiala (69.7%), Bathinda (51.79%) in the corresponding regions. Analysis of temporal variability didn't indicate any significant trend (Table 5). *Rabi* AI in SBS nagar was statistically similar to Amritsar. Similarly, *rabi* AI in Patiala was statistically similar to Ludhiana in central zone and Bathinda and Ferozpur in south-west zone. Likewise, *rabi* AI in Bathinda and Firozpur was statistically similar to Patiala in central zone (Table 6).

### CONCLUSION

The study concluded that large spatio-temporal variability in  $ET_o$ , MI and AI warns about the critical situation of moisture availability in the region as the water resources are already over-exploited thus warning about dire need of water management technologies to sustain water resources and crop productivity in the region.

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