

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 (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 (mm d^{-1}).

Table 1: Average ET_o in different agroclimatic zones of Punjab (1971 to 2018)

Agroclimatic zones / stations	Mean±SD (mm)	CV	Rate of Change (mm year ⁻¹)	R ²	Trend
Annual ET_o					
North-east zone					
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
Central plain zone					
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
South-western zone					
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
Kharif ET_o					
North-east zone					
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
Central plain zone					
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
South-western zone					
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
Rabi ET_o					
North-east zone					
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
Central plain zone					
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
South-western zone					
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 ⁻¹)	R ²	Trend
Annual MI					
North-east zone					
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
Central plain zone					
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
South-western zone					
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
Kharif MI					
North-east zone					
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
Central plain zone					
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
South-western zone					
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
Rabi MI					
North-east zone					
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
Central plain zone					
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
South-western zone					
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 ⁻¹)	R ²	Trend
Annual AI					
North-east zone					
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
Central plain zone					
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
South-western zone					
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
Kharif AI					
North-east zone					
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
Central plain zone					
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
South-western zone					
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
Rabi AI					
North-east zone					
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
Central plain zone					
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
South-western zone					
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_o

	North-east region		Central region			South-west region	
	Gurdaspur	SBS nagar	Amritsar	Ludhiana	Patiala	Bathinda	Firozpur
Annual ET							
North-east region							
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)
Central region							
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)
South-western region							
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)	-
Kharif ET							
North-east region							
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)
Central region							
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)
South-western region							
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)	-
Rabi ET							
North-east region							
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)
Central region							
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)
South-western region							
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_o 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	Ferozpur
Annual MI							
North-east region							
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)
Central region							
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)
South-western region							
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)
Ferozpur	-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
Kharif MI							
North-east region							
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)
Central region							
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)
South-western region							
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)
Ferozpur	45.92*(0.000)	53.30*(0.000)	-20.58*(0.000)	-28.40*(0.000)	30.88*(0.000)	1.69(1.000)	-
Rabi MI							
North-east region							
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)
Central region							
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)
South-western region							
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)
Ferozpur	-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	Ferozpur
Annual AI							
North-east region							
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)
Central region							
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)
South-western region							
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)
Ferozpur	-0.38*(0.000)	-0.41*(0.000)	-0.18*(0.000)	-0.21*(0.000)	-0.20*(0.000)	0.01(1.000)	-
Kharif AI							
North-east region							
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)
Central region							
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)
South-western region							
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)
Ferozpur	-0.45*(0.000)	0.53*(0.000)	-0.20*(0.00)	-0.28*(0.000)	-0.30*(0.000)	0.01(1.00)	-
Rabi AI							
North-east region							
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)
Central region							
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)
South-western region							
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)
Ferozpur	-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 Ferozpur (-89.0±5.6), whereas the variability in *rabi* MI was found to be highest in SBS Nagar (-24.75%), Patiala (-12.63%), Ferozpur (-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 Ferozpur 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 ± 0.13) > south-west zone (0.3 ± 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 ± 0.24) > central zone (0.62 ± 0.19) > south-west zone (0.35 ± 0.12). In north-east zone, it was higher in SBS Nagar (0.9 ± 0.3), in central zone in Patiala (0.7 ± 0.3) and in south-west zone in Firozpur (0.4 ± 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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