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Potential Evapotranspiration over India - An estimate of Green Water flow

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सार – इस शोध पत्र में संशोधित पेनमेन विभव वाष्पन वाष्पोत्सर्जन समीकरण का उपयोग करते हुए देश के दूर दराज क्षेत्रों में फैले हुए भारत के कोपन जलवायु स्पैक्ट्रम से चुने गए स्टेशनों द्वारा विभव वाष्पन वाष्पोत्सर्जन (PET) के स्थानिक वितरण का अध्ययन किया गया है। इससे वार्षिक और मौसमी PET की प्रवृत्तियों का पता चला है। चारों मौसमी ऋतुओं और इनके परिवर्तन की दर को तथा समूचे देश की माध्य मौसमी PET की परिवर्तनशीलता को सुचित्रित किया गया है। 1931-1960 की मूल अवधि के संदर्भ में 1961-1995 के काल की वार्षिक और मौसमी PET विसंगतियां तैयार की गई। 1951-1980 की अवधि के कोपन जलवायु वर्गीकरण के अनुसार भारत में जलवायविक प्रकारों के वितरण को पिछली रिपोर्ट की तुलना में अब हुए परिवर्तनों के साथ प्रस्तुत किया गया है। कोपन जलवायु के प्रकारों को PET से P अनुपात के अनुसार प्रतिशत में दर्शाया गया है। स्थान और समय दोनों में वार्षिक PET में किसी प्रकार की उल्लेखनीय कमी, वृद्धि और अन्य कोई प्रवृत्ति नहीं देखी गई है। 20 वीं शताब्दी के उतरार्द्ध में समूचे देश के वार्षिक PET में वृद्धि देखी गई है। उष्णकटिबंधीय मॉनसून जलवायु से शुष्क जलवायु के प्रकारों में माध्य मौसमी विभव वाष्पन वाष्पोत्सर्जन से वर्षा के अनुपात में वृद्धि देखी गई है।

ABSTRACT. The spatial distribution of Potential Evapotranspiration (PET) is studied by selecting stations that are drawn from the Koppen Climate spectrum of India that spread the length and breadth of the country using the modified Penman potential evapotranspiration equation. Annual and seasonal PET trends are reported. Variation of mean seasonal PET for the country as whole for all the four meteorological seasons and its rate of change are graphically shown. Anomalies in the annual and seasonal PET for the epoch of 1961-1995 with reference to the base period 1931-1960 are brought out. Distribution of climatic types over India according to Koppens climate classification for the period 1951-1980 are presented along with the changes that occurred compared to earlier report. Koppen climate types are characterized in terms of PET to P ratio expressed in percentage. Significant decreasing, increasing and no trend are noticed in annual PET both in space and time. Annual PET for the country as a whole is increased in the latter half of the 20th century. The mean seasonal potential evapotranspiration to precipitation ratio is found to be increased from tropical monsoon climates to dry climate types.

Key words – Koppen climate types, Potential evapotranspiration (PET), Precipitation (P), Annual and seasonal PET, Trend.

1. Introduction

Green water concept was introduced by Falkenmark (1995) which originally stands for crop transpiration in rain fed agriculture and ecosystems. Several definitions were introduced later by Falkenmark (1997), Rockström. (1997, 1998) and Savenije (1999) that ultimately sharpened the definition of Green Water concept and in the process White water, Blue water and Green water concepts have emerged. White water constitutes the evaporation from intercepted water by vegetation and from bare soil and from open waters. The blue water is that water that reaches rivers directly as runoff or indirectly through deep drainage to groundwater and subsequently feeding the stream base flow. The Green water is that fraction of rainfall that infiltrates into the soil and is available to plants for transpiration purpose. It depends on soil water holding capacity and the continual replenishment of reserves by rainfall. Precipitation is the ultimate source that falls from the atmosphere and can be accounted as the sum of white, blue and green water components. The atmospheric demand or potential evapotranspiration (PET) drives direct evaporative losses (white water) from soils and transpiration from crops (Green water) and thus if any surplus available directs for deep drainage for groundwater and for base flow for

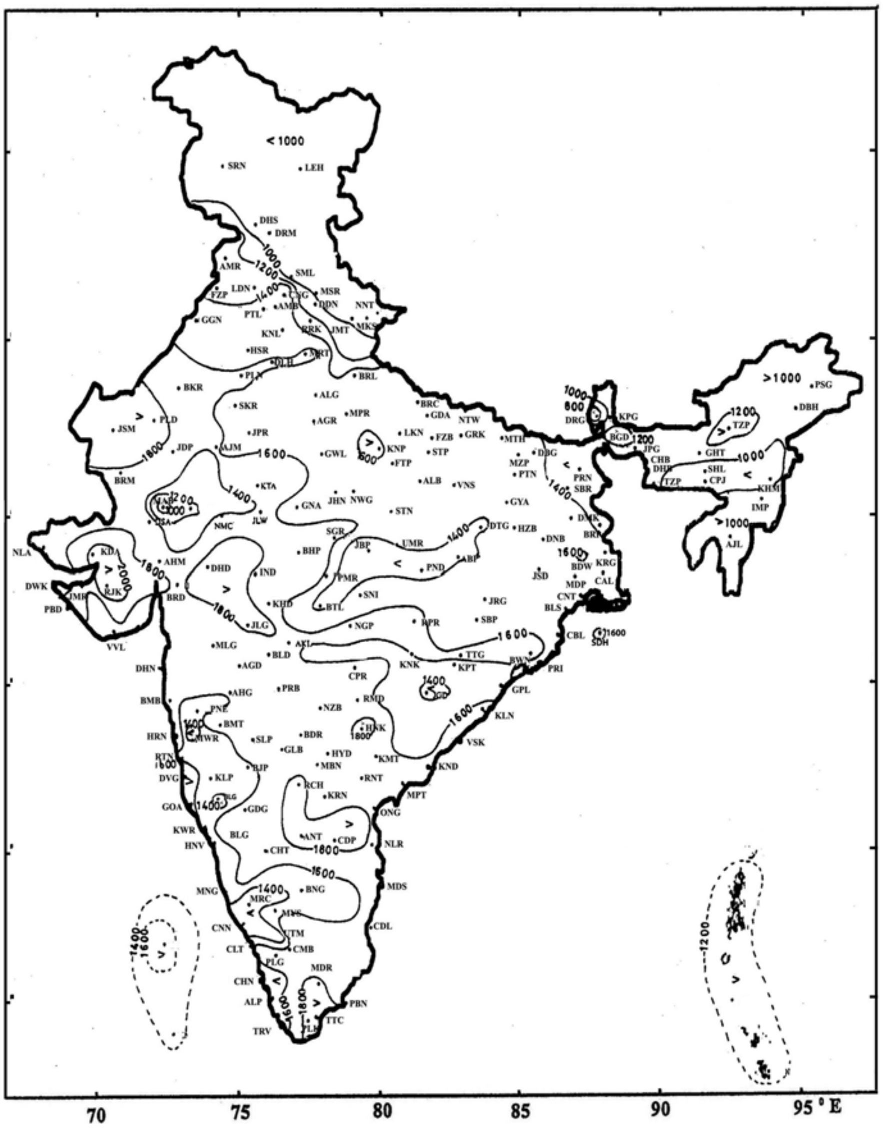


Fig. 1. Annual pattern of potential evapotranspiration (PET) – India

streams (blue water). It plays a vital role in agro-meteorological studies particularly in water budgeting practices for irrigation scheduling and water conservation. Debnath and Samui (1988) have reported the variations in potential evapotranspiration and its implications on the water requirement of crops. Verma *et al*. (2008) studied the variations and trends in potential evapotranspiration over India. In the recent years, the topic of climate change has assumed immense importance in most of the fields of meteorology and environmental sciences. Variation in basic meteorological parameters, which is apparent due to global climate change have its impact on PET. Chattopadhyay and Hulme (1997) and Mckenny and Rosenberg (1993) have found that relative humidity and solar radiation parameters influence the potential evapotranspiration value greatly compared to other parameters. Parker (1989) and Jones (1988) have reported the increase in mean surface air temperature over the globe during the past century. Studies made over Indian region by Hingane *et al.* (1985) and Srivastava *et al.* (1992) revealed the increase in mean surface air temperature over southern parts (south of 23° N) and decrease over northern parts (north of 23° N) of India and confirmed the warming for the country as a whole. Therefore the paper pays attention to understand the spatial distribution of PET over India along with the variations during different epochs and trend using linear trend analysis technique to identify the specific periods wherein significant changes occurred and to quantify these changes in the context of reported climate change.

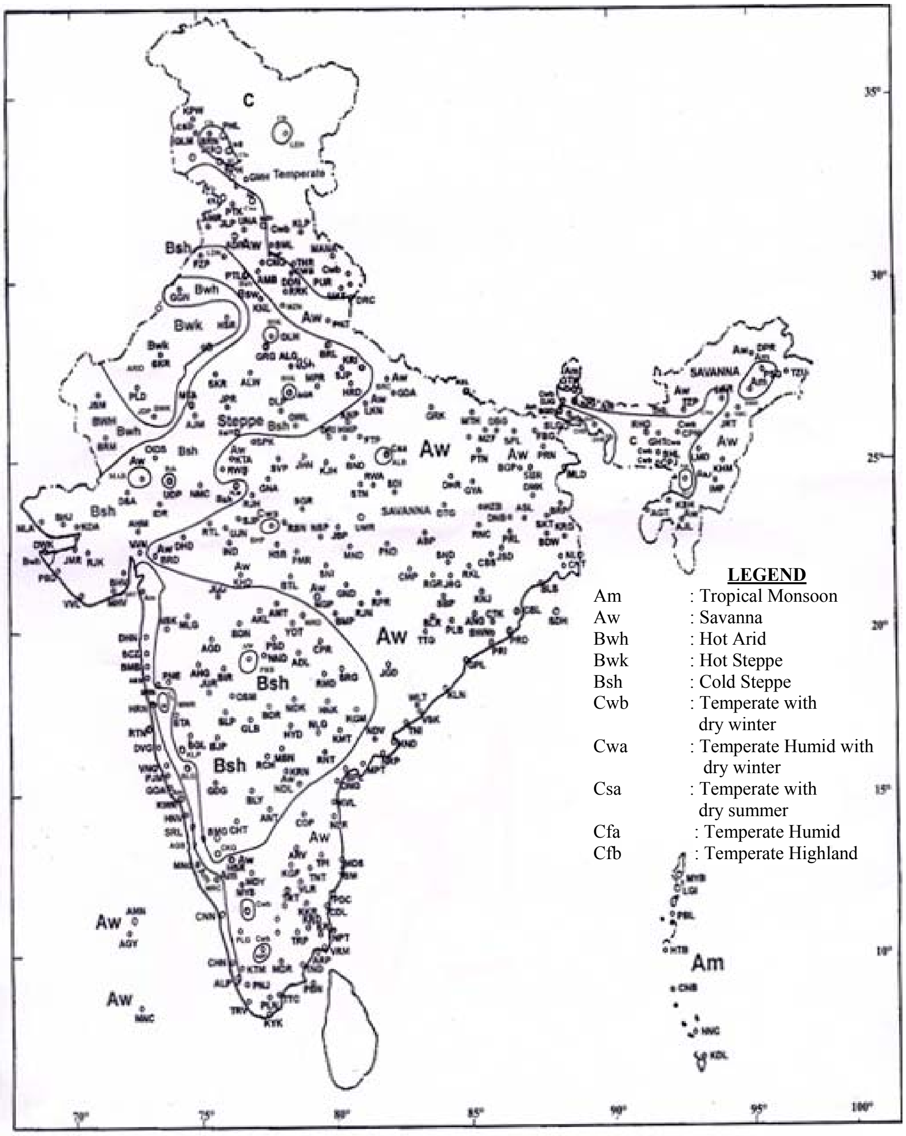


Fig. 2. Koppen Climate pattern – India

2. Materials and methodology

Modified Penman potential evapotranspiration equation (1948) employed by Rao *et al.* (1971) and Abbi *et al.* (1976) is used for estimation of potential evapotranspiration on a monthly basis for 194 stations that are well distributed over India with a 35 years of record from 1961 to 1995. Basic statistics of annual PET for the selected stations in terms of maximum, minimum, mean, standard deviation, coefficient of variation, range and trend are obtained. Annual and seasonal PET trends have been studied using linear trend analysis technique. Statistical significance test has been carried out on the results for more than 95 per cent level. Annual and seasonal rate of change of PET are obtained from the slope of the trend analysis curve.

3. Results and discussion

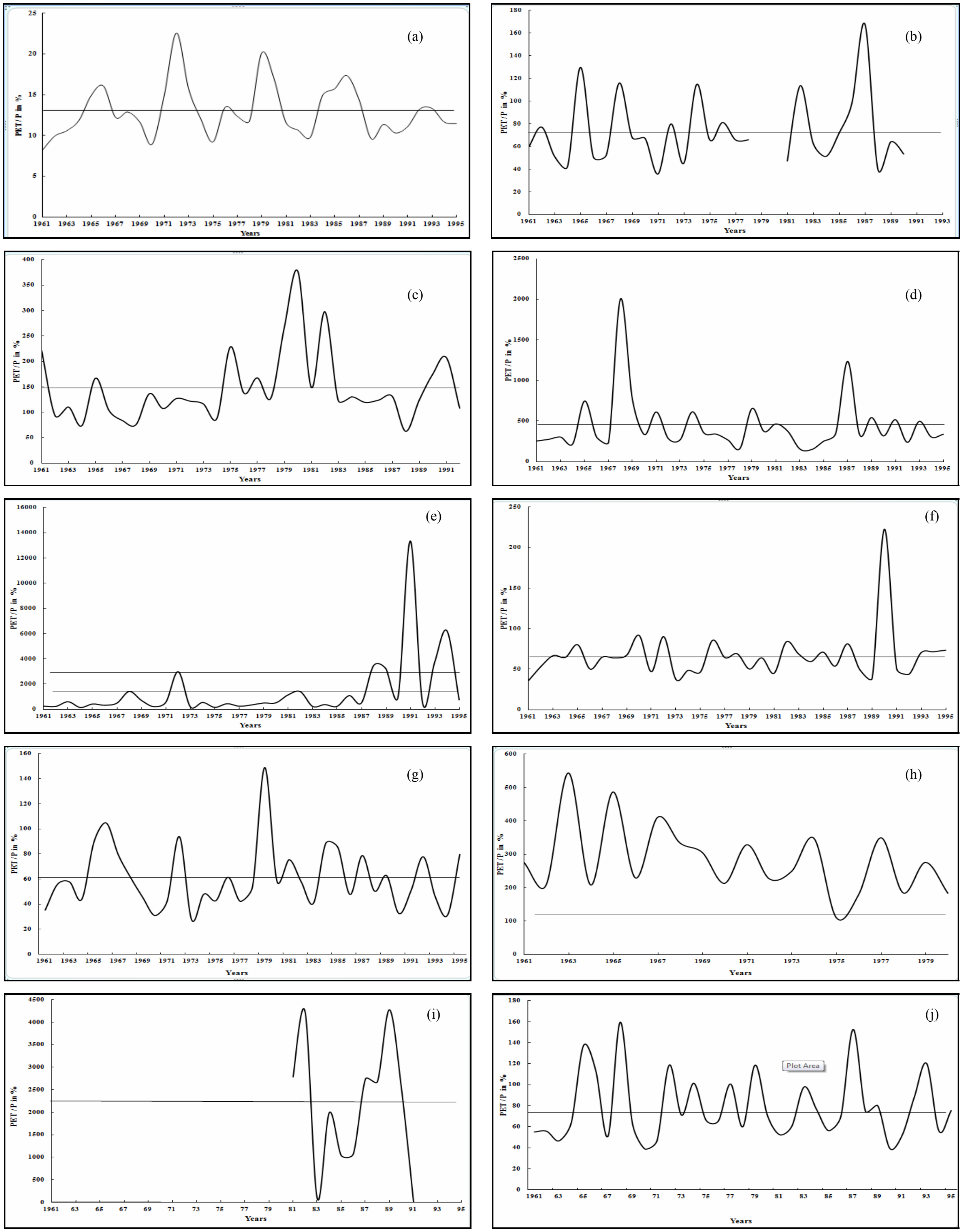
3.1. *Spatial distribution of PET*

The annual pattern of potential evapotranspiration is shown in Fig. 1. Highest annual potential evapotranspiration (PET) values of exceeding 1800 mm are observed over Saurashtra and Kutch and adjoining Gujarat Region, western parts of West Rajasthan, Marathwada and adjoining places, Rayalaseema and extreme southern parts of Tamilnadu subdivisions. Lowest values of PET are found over the northern parts of the country comprising of parts of Jammu and Kashmir, Uttaranchal, Himachal Pradesh, Punjab and Haryana and parts of northeast India. Most of the hill stations, the elevated places, *like*, Jagadalpur, remaining parts of north east India, southern parts of west coast and Andaman and Nicobar Islands are experiencing the potential evapotranspiration that varies from 1000-1400 mm. The remaining areas including Lakshadweep islands are recording the moderate PET values of 1400 to 1800 mm.

3.2. *Koppen climate system of India - PET*

Koppen system of main and sub climate types over India were reported by Subrahmanyam *et al.* (1965) but the pattern in Fig. 2. is based on record of 1951-1980. The conspicuous deviation that is observed in the present pattern from the earlier one is that the Svanna climate types have occupied as most extensive and continuous belt by replacing the Steppe and Temperate climatic zones over different parts of the country indicating thereby warm and more moist India during the period 1951 to 1980 compared to the first half of the 20^{th} century. The second feature was that the Steppe climatic zone is compressed. Steppe climatic types over parts of East Madhya Pradesh (Chattisgarh) and adjoining western parts of Orissa and eastern parts of Vidarbha are replaced by Savanna type and the Steppe was narrowed around Baroda and Dohad stations of Gujarat and adjoining areas due to the expansion of Savanna. The Temperate climate type that prevailed over parts of East and West Uttar Pradesh, Bihar, Punjab, Haryana northeast Madhya Pradesh and small region in Chattisgarh subdivisions are replaced with Savanna type. The Boreal climate type (D) of extreme north India is replaced with temperate climate type. Similarly, the Tropical monsoon and Savanna climate types of southern parts and the Steppe climate type of northern parts of Assam & Meghalaya subdivision were occupied by Temperate and Savanna types respectively.

The magnitude of PET of the selected stations from each of the zone of Koppen climate system is varied approximately from 1000-1400 mm over Tropical monsoon climatic region (Am) to 1400-1600 mm, in general, in the Tropical Wet and Dry or Savanna climates (Aw). However there are pockets exceeding 1800 mm and below 1400 mm in this climate zone. It is found that the values are high over south compared to north Indian region. The PET values in the Desert and Steppe sub groups of Dry climate types (BWk, BWh and BSh) are found to be highest among all the climate groups with an exceedence over 2100 mm at some locations of these climate types. Moderate PET values are observed over temperate climatic province (Cwa, Cwb, Csa, Cfa and Cfb) with lowest mean annual value of PET (800-1000 mm) witnessed over Srinagar (Cfa) and Leh (Cfb) (Fig. 1). Koppen climatic classification is mainly based on the magnitude of precipitation and temperature and their distribution through the year over a region influence the PET. Therefore a study of a ratio between PET and precipitation serve not only as a better tool in understanding the climate potentialities of a region but also in characterizing the various Koppen climate types of India in terms of PET/P ratio to appreciate the extent to which the precipitation meets the water need in these climatic provinces along with the inter seasonal march [Figs. 3(a-j)]. However from the Tropical Monsoon Climate (Am) zone is characterized by more than 1000 mm of annual monsoon rainfall with a more than 18 °C mean monthly temperature throughout the year recorded a mean seasonal PET/P ratio of 13% [Fig. 3(a)]. The ratio varied from a maximum of 23% to a minimum of 08%. One observes as one marches from the Tropical Wet and Dry or Savanna (Aw) one notices that the rainfall is less than 1000 mm for Roorkee and for which the mean seasonal PET/P ratio is increased to 73%. The range is of order of 132% [Fig. 3(b)] and might be due to higher temperatures associated with low rainfall (less rainy days), relatively more bright sunshine hours, less relative humidity and with less cloudiness that eventually lead to higher PET and therefore higher PET/P values. Further the dry climates from the western side of north-west of India is characterized with a precipitation amount that is less than potential evapotranspiration and the stations that represent the climate types Bsh, Bwh and Bwk are Karnal, Ganganagar and Phalodi respectively and for which the mean seasonal PET/P ratio is increased to 239%, 440% and 1402% [Figs. 3(c-e)]. The relatively low annual temperatures (< 18 °C) coupled with a low annual rainfall (< 320 mm) characterize the Bwk climate compared to Bsh and Bwh climates and this might be responsible for the highest mean seasonal PET/P ratio from this zone. The range of variation is also found to be very high of the order of 1854% and 13186% for Ganganagar and Phalodi respectively indicating there by the thermohygric regime of the stations is subjected to rapid fluctuations. The prevalence of temperate climate of Cwa, Cfa, Cwb , Cfb and Csa is conspicuous all along the Himalayan region and as isolated pockets in certain ghat sections of south India The seasonal mean PET/P ratio is found to be approximately 30 to 60 % in Cwb and Cwa types represented by Udagamandalam [Fig. 3(f)] and Bhopal [Fig. 3(g)]. Also a comparison of the mean seasonal PET/P ratio of Cwa and Cwb types of C group with other climate types show that these are fit in between the Tropical monsoon and savanna climate types. It appears that the southwest monsoon supports for wet summers when Siberian high pressure system harboring dry winters in these climate strips. The seasonal PET / P ratio is higher in Cfa and Cfb types represented by Srinagar and Leh stations [Figs. 3(h-i)] which are not only



Figs. 3(a-j). March of PET to P ratio in Koppen Climatic zones, (a) Honavar - Tropical monsoon (Am), (b) Roorkee - Savanna (Aw), (c) Karnal - Hot Arid (Bwh), (d) Ganganagar - Cold Steppe (Bsh), (e) Phalodi - Hot Steppe (Bwk), (f) Uthagamandalam - Temperate with dry winter (Cwb), (g) Bhopal - Temperate Humid with dry winter (Cwa), (h) Srinagar - Temperate Humid (Cfa), (i) Leh- Temperate Highland (Cfb) and (j) Allahabad - Temperate with dry summer (Csa)

TABLE 1

Statistical Parameters of annual PET (1961-95) of selected stations

S. No.	Station	Maximum	Minimum	Range	S.D.	Mean	C.V.(%)	Trend
1.	Ambikapur	1489.0	1237.8	251.1	65.3	1376.7	4.7	Decreasing
2.	Bhopal	1786.7	1366.2	420.4	104.8	1659.0	6.3	Decreasing
3.	Beetul	1395.3	1271.7	123.7	33.7	1351.2	2.5	Insignificant
4.	Indore	1905.4	1546.0	359.4	83.8	1707.4	4.9	Decreasing
5.	Jabalpur	1540.8	1332.3	208.4	42.2	1420.1	3.0	Insignificant
6.	Khandwa	1894.7	1531.2	363.5	83.0	1712.5	4.8	Decreasing
7.	Seoni	1601.0	1331.3	269.7	57.7	1470.1	3.9	Increasing
8.	Umeria	1441.1	1241.2	199.9	47.2	1359.3	3.5	Insignificant
9.	Aurangabad	1910.5	1628.6	282.0	54.3	1761.1	3.1	Insignificant
10.	Akola	1819.9	1588.5	231.4	58.5	1715.8	3.4	Insignificant
11.	Buldana	1716.0	1521.8	194.2	53.1	1621.7	3.3	Decreasing
12.	Chandrapur	1894.2	1520.3	374.0	79.8	1696.3	4.7	Increasing
13.	Kalingapatnam	2181.1	1542.4	638.7	108.6	1663.1	6.5	Decreasing
14.	Kolahpur	1766.7	1355.2	411.5	105.6	1533.6	6.9	Decreasing
15.	Nagpur	1826.2	1516.2	310.0	68.7	1670.8	4.1	Decreasing
16.	Parbhani	1766.9	1533.9	233.0	59.5	1654.1	3.6	Decreasing
17.	Visakhapatnam	1814.1	1486.2	328.0	84.0	1675.0	5.0	Decreasing
18.	Agra	1592.9	1373.1	219.8	58.4	1477.0	4.0	Decreasing
19.	Aligarh	1662.3	1255.9	406.4	81.0	1460.0	5.6	Decreasing
20.	Ambala	1697.4	1277.6	419.7	117.4	1460.2	8.0	Decreasing
21.	Barelley	1605.9	1359.0	246.9	39.8	1501.9	2.6	Insignificant
22.	Chandigarh	1535.2	1293.8	241.4	44.2	1421.9	3.1	Insignificant
23.	Jhansi	1622.6	1367.8	254.8	52.4	1512.1	3.5	Insignificant
24.	Mainpuri	1757.3	1343.9	413.4	90.0	1554.3	5.8	Insignificant
25.	Meerut	1716.4	1541.1	175.3	34.8	1623.6	2.1	Insignificant
26.	Roorkee	1422.8	1195.5	227.3	52.2	1311.0	4.0	Decreasing
27.	Ahmadnagar	1759.7	1392.3	367.4	76.9	1604.6	4.8	Insignificant
28.	Baramati	1947.5	1668.1	279.4	67.6	1775.4	3.8	Decreasing
29.	Devgarh	1840.8	1552.3	288.5	59.8	1701.1	3.5	Insignificant
30.	Goa	1748.2	1494.0	254.2	68.4	1612.9	4.2	Decreasing
31.	Jalegaon	2087.2	1742.4	344.8	76.1	1939.8	3.9	Decreasing
32.	Malegaon	1925.4	1296.2	629.2	167.8	1594.9	10.5	Decreasing
33.	Pune	1644.5	1401.3	243.2	66.9	1509.6	4.4	Decreasing
34.	Ratnagiri	1659.0	1470.0	189.0	52.6	1564.2	3.4	Insignificant
35.	Solapur	1937.9	1551.9	386.0	74.6	1743.8	4.3	Decreasing
36.	Ahmedabad	1948.6	1590.0	358.6	70.4	1676.3	4.2	Insignificant
37.	Baroda	1949.1	1564.1	384.9	98.8	1753.8	5.6	Decreasing
38.	Dohad	2212.8	1698.7	514.1	143.3	1944.2	7.4	Increasing
39.	Deesa	1875.0	1508.0	367.0	88.7	1677.7	5.3	Decreasing
40.	Jagadalpur	1477.6	1251.5	226.1	55.0	1368.2	4.0	Decreasing
41.	Kanker	1603.5	1342.8	260.8	43.0	1508.2	2.9	Insignificant
42.	Nalia	1901.9	1533.0	368.9	91.7	1682.3	5.4	Insignificant
43.	Pendra	1530.8	1282.5	248.3	60.8	1379.9	4.4	Decreasing
44.	Raipur	1659.1	1391.7	267.4	61.9	1534.9	4.0	Insignificant
45.	Ajmeer	1819.5	1331.9	487.6	118.3	1572.3	7.5	Insignificant
46.	Guna	1658.0	1386.9	271.1	63.8	1531.6	4.2	Decreasing
47.	Gwalior	1734.4	1361.1	373.3	74.7	1532.4	4.9	Decreasing
48.	Jhalwar	1732.4	1532.1	200.3	44.8	1650.2	2.7	Insignificant
49.	Kota	1900.2	1510.8	389.4	92.0	1728.4	5.3	Insignificant
50.	Neemach	1752.8	1491.0	261.8	61.0	1596.7	3.8	Decreasing
51.	Nowgang	1528.0	1331.0	197.1	54.5	1423.4	3.8	Insignificant
52.	Sagar	1768.6	1356.2	412.4	89.5	1521.0	5.9	Decreasing

TABLE 1 (*Contd.*)

S. No.	Station	Maximum	Minimum	Range	SD	Mean	C.V (%)	Trend
53.	Udaipur	1586.9	1258.2	328.7	65.0	1402.3	4.6	Increasing
54.	Allahabad	1922.6	1323.7	598.9	104.4	1495.2	7.0	Insignificant
55.	Dehradun	1177.0	1002.0	175.0	40.6	1097.1	3.7	Decreasing
56.	Fatehpur	1706.7	1237.1	469.5	95.7	1500.2	6.4	Insignificant
57.	Faziabad	1416.2	1212.6	203.5	36.1	1353.5	2.7	Insignificant
58.	Gorakpur	1683.5	1313.8	369.6	60.0	1505.9	4.0	Insignificant
59.	Kanpur	1858.8	1419.4	439.4	102.8	1626.4	6.3	Decreasing
60.	Lucknow	1658.0	1288.9	369.0	71.1	1451.6	4.9	Insignificant
61.	Sultanapur	1557.2	1303.7	253.5	42.8	1444.8	3.0	Insignificant
62.	Varanasi	1680.7	1403.7	277.0	65.9	1566.7	4.2	Decreasing
63.	Allepey	1666.6	1397.1	269.5	71.5	1542.4	4.6	Insignificant
64.	Amini	1779.3	1404.3	374.9	78.1	1622.7	4.8	Insignificant
65.	Dalhousie	971.5	812.0	159.5	31.5	886.1	3.6	Decreasing
66.	Dharmasala	1073.3	917.7	155.6	34.0	997.5	3.4	Insignificant
67.	Joshimat	1005.0	833.7	171.3	43.0	927.0	4.6	Insignificant
68.	Simla	896.9	755.7	141.2	30.3	808.9	3.7	Increasing
69.	Minicoy	1664.0	1438.5	225.4	49.4	1551.3	3.2	Insignificant
70.	Tiruvananthahpuram	1559.3	1350.6	208.7	48.4	1452.0	3.3	Decreasing
71.	Amrutsar	1534.7	1205.8	328.9	69.0	1376.9	5.0	Decreasing
72.	New Delhi	1762.4	1441.2	321.2	73.9	1606.9	4.6	Decreasing
73.	Ferozpur	1434.2	1237.6	196.6	40.0	1351.8	3.0	Decreasing
74.	Karnal	1630.5	1323.2	307.3	62.4	1488.1	4.2	Decreasing
75.	Ludiana	1473.6	1321.2	152.3	30.9	1391.0	2.2	Insignificant
76.	Leh	1038.1	943.0	95.1	13.0	990.0	1.3	Insignificant
77.	Patiala	1549.6	1286.6	262.9	71.2	1416.8	5.0	Decreasing
78.	Hissar	1643.6	1434.6	209.0	52.6	1536.9	3.4	Decreasing
79.	Srinagar	892.6	766.6	126.0	25.3	828.6	3.1	Insignificant
80.	Anantapur	1971.9	1727.0	244.9	61.2	1847.4	3.3	Decreasing
81.	Cuddallore	1766.3	1523.5	242.8	59.7	1645.4	3.6	Insignificant
82.	Cuddapah	2066.8	1672.8	394.0	93.9	1871.9	5.0	Increasing
83.	Coimbattore	1938.7	1570.2	368.5	98.5	1760.3	5.6	Decreasing
84.	Khammam	1895.2	1503.5	391.7	97.4	1703.3	5.7	Increasing
85.	Kurnool	1914.3	1582.5	331.9	86.9	1732.9	5.0	Decreasing
86.	Mahabubnagar	1901.8	1558.1	343.6	83.5	1709.3	4.9	Insignificant
87.	Madurai	1991.9	1561.2	430.7	74.5	1806.9	4.1	Insignificant
88.	Madras	1745.7	1503.8	241.9	54.6	1668.3	3.3	Insignificant
89.	Bidar	2071.1	1575.4	495.8	90.4	1734.0	5.2	Insignificant
90.	Bijapur	1720.2	1457.7	262.5	59.9	1584.4	3.8	Insignificant
91.	Gulbarga	1913.7	1447.2	466.5	92.6	1713.7	5.4	Decreasing
92.	Karwar	1860.1	1415.2	444.9	108.7	1580.6	6.9	Insignificant
93.	Mangalore	1539.5	1387.5	152.1	34.8	1480.8	2.3	Insignificant
94.	Honawar	1705.5	1381.5	324.0	88.3	1540.5	5.7	Insignificant
95.	Pamban	1918.2	1578.7	339.5	88.3	1779.5	5.0	Increasing
96.	Pallankotaai	2011.1	1520.2	490.9	129.7	1822.5	7.1	Decreasing
97.	Tuticorn	2163.0	1722.8	440.3	116.8	1943.7	6.0	Decreasing
98.	Burdwan	1803.1	1230.5	572.6	103.0	1600.6	6.4	Insignificant
99.	Baghdogra	1323.3	1079.0	244.3	46.0	1201.5	3.8	Insignificant
100.	Berhampur	1547.9	1130.0	417.9	98.6	1369.5	7.2	Increasing
101.	Kolkatta	1574.1	1320.5	253.6	51.7	1409.9	3.7	Insignificant
102.	Coochbehar	1285.5	1026.1	259.4	45.9	1171.4	3.9	Insignificant
103.	Imphal	1128.0	942.0	186.0	38.3	1028.8	3.7	Insignificant
104.	Jalpaiguri	1392.2	1120.5	271.7	55.0	1247.7	4.4	Decreasing
105.	Krishnanagar	1791.7	1423.5	368.2	95.5	1587.8	6.0	Increasing
106.	Midnapore	1625.2	1250.9	374.4	98.7	1434.2	6.9	Decreasing

TABLE 1 (*Contd.*)

S. No.	Station	Maximum	Minimum	Range	SD	Mean	C.V (%)	Trend
107.	Bikaner	2024.4	1480.0	544.4	121.5	1721.2	7.1	Decreasing
108.	Barmer	1911.7	1541.3	370.4	90.9	1764.3	5.1	Decreasing
109.	Ganganagar	1627.2	1315.4	311.9	63.2	1505.6	4.2	Insignificant
110.	Judhpore	1982.2	1528.4	453.8	102.5	1750.9	5.9	Decreasing
111.	Jaipur	1687.0	1372.4	314.6	68.3	1521.1	4.5	Insignificant
112.	Jaisalmer	2187.3	1761.4	425.8	95.0	1989.1	4.8	Insignificant
113.	Pilani	1926.3	1399.1	527.2	139.7	1617.6	8.6	Decreasing
114.	Phalodi	2137.1	1548.8	588.3	180.2	1834.0	9.8	Decreasing
115.	Sikkar	1753.7	1428.9	324.9	76.6	1542.5	5.0	Insignificant
116.	Belgaum	1581.0	1329.9	251.1	53.8	1404.4	3.8	Insignificant
117.	Bangalore	1561.0	1351.2	209.8	47.2	1431.5	3.3	Decreasing
118.	Kochi	1529.3	1180.9	348.3	83.2	1387.1	6.0	Increasing
119.	Chitradurga	1835.5	1498.3	337.2	89.7	1681.2	5.3	Insignificant
120.	Kozhikode	1696.8	1491.6	205.3	50.2	1605.3	3.1	Increasing
121.	Gadag	1815.3	1444.4	371.0	85.5	1673.9	5.1	Increasing
122.	Mysore	1715.6	1458.1	257.5	60.1	1599.1	3.8	Decreasing
123.	Palghat	1934.2	1540.3	393.9	111.0	1695.2	6.5	Increasing
124.	Raichur	2034.8	1600.4	434.4	96.3	1832.6	5.3	Insignificant
125.	Balasore	1999.5	1320.7	678.7	137.4	1486.0	9.2	Insignificant
126.	Bhubaneswar	1904.9	1461.7	443.2	88.6	1642.4	5.4	Decreasing
127.	Chandbali	1703.8	1327.7	376.1	80.7	1489.6	5.4	Decreasing
128.	Contai	1651.2	1275.6	375.6	101.3	1434.0	7.1	Decreasing
129.	Jharsguda	1613.0	1385.4	227.6	55.6	1516.3	3.7	Insignificant
130.	Sambalpur	1929.1	1367.9	561.2	121.8	1550.4	7.9	Decreasing
131.	Sandheads	1931.5	1451.6	479.9	79.3	1622.1	4.9	Decreasing
132.	Sagarislands	1584.1	1359.6	224.5	59.9	1479.4	4.0	Decreasing
133.	Titlagarh	1889.7	1422.9	466.8	100.6	1604.0	6.3	Insignificant
134.	Bombay	1720.9	1546.0	174.9	42.1	1632.3	2.6	Decreasing
135.	Dahanu	1826.1	1520.3	305.9	66.0	1661.6	4.0	Insignificant
136.	Dwaraka	2047.5	1519.3	528.2	118.4	1540.9	7.7	Insignificant
137.	Kandla	1971.0	1648.6	322.4	72.4	1810.8	4.0	Insignificant
138.	Jamnagar	2202.4	1703.8	498.6	108.0	2012.3	5.4	Decreasing
139.	Porbandar	2012.9	1708.7	304.2	66.6	1853.0	3.6	Insignificant
140.	Rajkot	2421.9	1925.1	496.8	143.7	2102.8	6.8	Decreasing
141.	Harnai	1943.9	1502.8	441.1	98.4	1689.4	5.8	Insignificant
142.	Veeraval	1890.7	1498.4	392.3	95.7	1722.1	5.6	Decreasing
143.	Bahraich	1526.4	1264.2	262.3	50.9	1414.7	3.6	Decreasing
144.	Darbanga	1608.2	1350.2	258.0	56.3	1460.2	3.9	Insignificant
145.	Gondia	1621.5	1284.0	337.5	54.7	1504.9	3.6	Insignificant
146.	Gaya	1717.1	1269.0	448.1	117.9	1516.1	7.8	Decreasing
147.	Muzzafarpur	1508.2	1320.6	187.6	38.6	1408.3	2.7	Insignificant
148.	Nautanwa	1511.1	1301.2	209.9	36.0	1452.0	2.5	Insignificant
149.	Purnea	1427.2	1144.0	283.2	58.5	1317.3	4.4	Insignificant
150.	Patna	1625.5	1274.8	350.7	59.9	1456.3	4.1	Insignificant
151.	Sabaur	1495.4	1131.9	363.5	76.6	1378.5	5.6	Increasing
152.	Car Nicobar	1557.2	1167.5	389.6	83.2	1374.8	6.0	Insignificant
153.	Dibrugarh	1184.3	974.1	210.3	37.6	1089.7	3.5	Increasing
154.	Dhubri	1272.0	1130.3	141.8	29.8	1198.8	2.5	Insignificant
155.	Guwahati	1223.3	1085.1	138.2	32.3	1148.0	2.8	Insignificant
156.	Kondul	1504.4	1056.6	447.9	89.5	1341.5	6.7	Insignificant
157.	PortBlair	1534.2	1204.1	330.1	76.7	1364.6	5.6	Decreasing
158.	Pasighat	1282.5	1084.7	197.8	47.0	1178.2	4.0	Insignificant
159.	Tura	1202.0	673.5	528.5	109.5	1002.9	10.9	Insignificant
160.	Tezpur	1540.1	1144.0	396.1	73.8	1288.8	5.7	Insignificant

TABLE 1 (*Contd.*)

S. No.	Station	Maximum	Minimum	Range	SD	Mean	C.V (%)	Trend
161.	Dumka	2008.5	1322.5	686.0	130.2	1564.5	8.3	Insignificant
162.	Dhanbad	1932.2	1143.8	788.4	125.8	1426.8	8.8	Insignificant
163.	Daltonganj	1751.2	1298.8	452.3	99.0	1461.5	6.8	Insignificant
164.	Gopalpur	1583.9	1422.3	161.7	44.7	1500.3	3.0	Insignificant
165.	Jemshedpur	1594.9	1415.0	179.8	41.9	1502.7	2.8	Insignificant
166.	Korapur	1779.8	1358.8	421.0	69.3	1577.6	4.4	Insignificant
167.	Mothihari	1485.9	1185.0	301.0	66.8	1366.8	4.9	Insignificant
168.	Puri	1921.7	1334.7	587.0	102.4	1586.5	6.5	Insignificant
169.	Hazarabagh	1592.5	1157.3	435.2	93.9	1369.0	6.9	Insignificant
170.	Mount Abu	1418.3	985.4	432.9	91.1	1190.4	7.7	Decreasing
171.	Chirapunji	1043.3	831.4	211.9	45.0	916.4	4.9	Insignificant
172.	Darjeeling	1070.6	559.7	510.9	83.6	671.5	12.5	Insignificant
173.	Kohima	1065.8	759.3	306.5	68.0	900.2	7.6	Insignificant
174.	Kalipong	1363.8	633.6	730.2	136.9	1020.4	13.4	Decreasing
175.	Mukteswar	1172.3	793.9	378.3	94.0	962.8	9.8	Decreasing
176.	Mussorie	963.7	789.9	173.8	40.7	868.4	4.7	Insignificant
177.	Naintal	1040.8	872.1	168.7	38.3	962.1	4.0	Insignificant
178.	Shillong	1128.2	781.2	347.0	51.1	895.7	5.7	Insignificant
179.	Aijal	1252.5	1040.9	211.6	39.8	1149.1	3.5	Increasing
180.	Coonoor	1221.4	1054.9	166.5	27.9	1155.4	2.4	Insignificant
181.	Mahabaleswar	1490.2	1193.4	296.8	66.7	1354.3	4.9	Insignificant
182.	Mercara	1401.6	1100.2	301.3	58.1	1250.0	4.7	Insignificant
183.	Uthagamandalam	1073.2	955.3	117.9	27.6	1015.4	2.7	Insignificant
184.	Pachmarhi	1293.9	962.9	331.0	103.3	1210.9	8.5	Decreasing
185.	Kakinada	1896.5	1521.5	375.0	78.2	1651.9	4.7	Decreasing
186.	Machilipatnam	1900.7	1379.8	520.9	135.4	1606.5	8.4	Increasing
187.	Hanumakonda	2035.6	1610.5	425.1	91.5	1807.6	5.1	Insignificant
188.	Nellore	1886.3	1548.6	337.6	87.7	1775.8	4.9	Increasing
189.	Nizamabad	1782.5	1430.8	351.7	86.8	1615.8	5.4	Decreasing
190.	Oogole	2152.4	1564.6	587.7	141.6	1798.0	7.9	Insignificant
191.	Ramagundam	1788.8	1507.2	281.5	86.1	1669.7	5.2	Decreasing
192.	Rentichintala	2042.3	1584.2	458.1	100.4	1757.2	5.7	Insignificant
193.	Hyderabad	1842.6	1612.2	230.4	48.0	1722.5	2.8	Insignificant
194.	Satna	1568.3	1347.3	221.03	48.557	1476.5	3.2	Decreasing

less influenced by southwest monsoon but also the high altitude location that might be the causal factor for higher ratio. The mean seasonal PET / P ratio is found to be 80% at Allahabad [Fig. 3(j)] from dry summer climate group of India. A comparison of maximum, minimum and seasonal average PET/P ratio of the station with its Cwa and Cwb counterparts reveal that the characteristics are similar. This may be due to the relatively less influence of southwest monsoon system compared to the sub- tropical systems over this landscape.

3.3. *Variation and trend in annual and seasonal PET*

The statistic of annual PET in terms of maximum, minimum, mean, range, coefficient of variation, standard deviation and the trend significant at ≥ 95 % level for all the 194 stations are presented in Table 1. The PET varied from 893 mm to 2422 mm and the highest annual PET is found at Rajkot in the year 1969 while the lowest is found over Srinagar in the year 1970. The minimum annual of 1925 mm is noticed at Rajkot in the year 1983 but the lowest minimum value of 560 mm is seen at Darjeeling in the year 1972. It is clear from the above as well as from distribution of mean annual PET that the higher and highest values have prevailed over dry climates while the lower values and the lowest minimum ones occurred in savanna and temperate climate regions of India. In general, it can be inferred that lower values of PET may be mainly due to the amount of precipitation (higher rainy days) associate with the higher relative humidity along with the lower number of bright sunshine hours coupled with lower temperatures that characterize the wet climates while the dry climates of steppe and desert prevail with

TABLE 2

Seasonal rate of change in PET of selected stations (significant ≥ 95%)

S. No.	Station	Winter	Pre-monsoon	Monsoon	Post-monsoon
1.	Philodi	**-1.03**	**-4.90**	**-5.96**	**-1.57**
2.	Malegaon	**-1.41**	**-4.90**	**-4.40**	**-2.10**
3.	Pilani	**-1.15**	**-3.34**	**-5.19**	**-1.25**
4.	Kolapur	**-1.41**	**-3.20**	**-2.60**	**-1.86**
5.	Ambala	**-0.49**	**-2.13**	**-4.80**	**-1.38**
6.	Kalipong	-0.52	**-3.65**	**-3.40**	-0.51
7.	Mount Abu	**-1.10**	**-2.60**	**-1.86**	**-1.54**
8.	Gaya	**-1.04**	**-3.30**	**-2.26**	-0.47
9.	Bikaner	-0.21	**-1.90**	**-4.34**	-0.37
10.	Midnapore	**-0.41**	**-2.70**	**-3.26**	**-0.50**
11.	Ramagundam	**-0.80**	**-2.71**	**-1.99**	**-1.10**
12.	Tuticorn	-0.85	-0.98	**-3.39**	**-1.31**
13.	Rajkot	**-0.82**	-1.10	**-2.97**	**-1.26**
14.	Indore	**-0.85**	**-3.00**	-1.30	**-0.72**
15.	Contai	**-0.31**	**-2.80**	**-2.37**	-0.39
16.	Mukteswar	**-0.67**	**-2.71**	**-1.56**	**-0.91**
17.	Kakinada	-0.34	**-1.98**	**-2.91**	**-0.55**
18.	Jodhpur	**-0.70**	**-1.90**	-2.00	**-1.15**
19.	Kanpur	-0.35	**-2.00**	**-1.99**	**-1.38**
20.	Coimbattore	-0.51	**-1.70**	**-2.92**	-0.53
21.	Deesa	**-0.94**	**-1.92**	**-1.90**	**-0.72**
22.	Visakhapatnam	**-0.56**	**-2.28**	**-1.50**	**-0.84**
23.	Kurnaool	**-0.59**	**-1.30**	**-2.89**	-0.38
24.	Khandwa	**-1.05**	**-2.50**	-0.45	**-0.97**
25.	Veeraval	**-0.86**	**-1.10**	**-1.95**	**-0.99**
26.	Barmer	**-0.41**	**-1.34**	-1.59	**-1.17**
27.	Bubaneswar	-0.40	**-3.00**	-0.70	**-0.36**
28.	Sambalpur	-0.19	**-1.99**	-1.90	**-0.21**
29.	Nizamabad	**-0.74**	**-1.85**	1.52	**-3.30**
30.	JMR	**-0.78**	**-1.40**	-0.46	**-1.05**
31.	Nagpur	**-0.72**	**-1.61**	-1.10	**-0.61**
32.	Goa	**-0.60**	**-1.51**	**-1.01**	**-0.95**
33.	Parbhani	**-0.42**	**-1.25**	**-1.60**	**-0.79**
34.	Kalingapatnam	-0.26	**1.57**	-1.50	**-3.85**
35.	Bhopal	**-0.71**	**-1.50**	-1.20	-0.46
36.	Gulbarga	**-0.66**	**-1.60**	-0.69	**-0.85**
37.	Baroda	**-0.88**	**-1.51**	-0.67	-0.68
38.	Pendra	**-0.76**	**-1.85**	-0.62	**-0.43**
39.	Ambikapur	**-0.41**	**-1.50**	**-1.39**	-0.21
40.	Pune	**-0.44**	**-1.34**	**-1.30**	**-0.53**
41.	Gwalior	**-0.41**	**-1.69**	-1.06	**-0.26**
42.	Sagar	**-0.45**	**-1.75**	-0.65	-0.56
43.	Sandheads	**-0.78**	**-1.49**	0.17	-1.25
44.	Patiala	**-0.70**	**-1.19**	-0.69	**-0.69**
45.	Baramati	**-0.79**	**-1.10**	1.69	**-2.95**
46.	Chandbali	-0.25	**-1.70**	-0.65	**-0.55**
47.	Roorkee	**-0.24**	**-1.10**	**-1.65**	-0.07
48.	Mysore	**-0.42**	**-0.73**	**-1.21**	**-0.67**
49.	Solapur	**-1.08**	**-0.98**	**2.10**	**-2.92**
50.	Sagarislands	**-0.33**	**-1.80**	-0.60	-0.08
51.	PortBlair	**-0.89**	-0.63	-0.66	-0.64
52.	Buldana	**-0.68**	**-1.34**	-0.37	-0.29

TABLE 2 (*Contd.*)

S. No.	Station	Winter	Pre-monsoon	Monsoon	Post-monsoon
53.	Palankottai	-0.74	-0.77	-0.91	-0.12
54.	Delhi	**-0.52**	**-1.50**	-0.28	**-0.38**
55.	Karnal	**-0.44**	-0.32	**-1.70**	-0.11
56.	Hissar	-0.07	**-0.97**	-1.10	**-0.46**
57.	Jalegaon	**-0.75**	-0.59	-0.89	-0.33
58.	Aligarh	**-0.65**	**-1.37**	-0.19	-0.33
59.	Anantapur	-0.26	**-0.80**	-1.20	-0.27
60.	Bangalore	-0.33	-0.89	**-1.22**	-0.02
61.	Varanasi	-0.10	-1.10	-1.10	-0.11
62.	Neemach	**-0.57**	-0.75	-0.65	-0.30
63.	Guna	**-0.32**	-1.47	-0.29	-0.12
64.	Amrutsar	-0.27	-0.62	-1.10	-0.18
65.	Jalpaiguri	0.04	**-1.36**	**-0.71**	-0.13
66.	Satna	**-0.22**	**-0.84**	-0.99	0.09
67.	Agra	**-0.28**	**-1.54**	-0.06	-0.09
68.	Jagadalpur	-0.22	-0.74	-0.69	-0.19
69.	Bahraich	**-0.32**	**-1.30**	-0.20	0.08
70.	Tiruvananthapuram	-0.38	-0.37	**-1.10**	0.04
71.	Dehradun	**-0.32**	**-0.85**	-0.15	-0.22
72.	Ferozpur	**-0.29**	-0.43	-0.71	-0.08
73.	Bombay	-0.16	**-0.72**	-0.42	-0.19
74.	Dalhousie	-0.21	**-0.55**	-0.13	**-0.41**
75.	Pachmarhi	**-0.23**	0.21	-0.02	-0.11
76.	Simla	**0.15**	0.22	0.46	**0.19**
77.	Dibrugarh	0.13	0.23	**0.87**	**0.41**
78.	Aijal	0.05	0.36	**0.96**	**0.34**
79.	Calicut	0.26	0.59	0.51	0.41
80.	Seoni	-0.39	**0.69**	**1.70**	0.13
81.	Sabaur	**-0.34**	0.53	**2.05**	**0.52**
82.	Chandrapur	0.16	0.72	1.33	0.59
83.	Parbhani	**0.75**	0.80	0.68	0.69
84.	Udaipur	-0.03	**0.88**	**1.44**	0.46
85.	Khammam	0.11	0.50	**2.73**	0.71
86.	Palghat	0.49	**1.50**	**1.86**	0.50
87.	Gadag	**0.68**	**1.29**	**1.58**	**1.21**
88.	Nellore	**0.88**	**1.10**	1.72	1.20
89.	Berhampur	0.13	0.24	**4.00**	**0.75**
90.	Krishnanagar	0.20	0.70	**3.81**	0.52
91.	Chennai	**0.68**	**2.00**	**1.86**	**1.11**
92.	Cuddapah	**1.07**	**2.00**	**1.86**	**1.34**
93.	Dohad	0.16	1.29	**6.09**	0.31
94.	Masulipatnam	**0.88**	**3.40**	**3.94**	**1.47**
	Average	**-0.38**	**-1.07**	**-0.68**	**-0.45**

higher number of bright sunshine hours, low relative humidity accompanied by high temperature along with the prevailing circulation pattern and the latitudinal position of the station or region that play a crucial role in climate system in ascertaining the PET. The annual range in PET is varied from 95 mm at Leh (cold arid station) to 788 mm for Dhanbad while the mean varied from 671 to 2103 mm. The highest annual PET (2103 mm) is observed over Rajkot and the lowest (671 mm) is witnessed by Darjeeling. The mean annual PET for the country as a whole is 1499 mm and the coefficient of variation [C.V = (SD /Mean) *100] is varied from 1.3 over Leh to 13.4 for Kalimpong. The standard deviation (SD) of annual PET of Kalipong and Darjeeling are found to be high compared to Leh and Srinagar. It is to be noted here that the SD of annual PET values of hill stations of

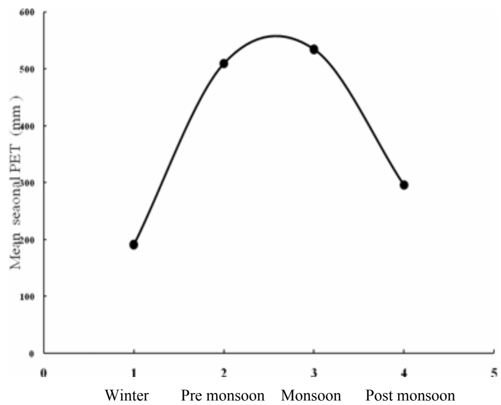


Fig. 4. Variation in PET through seasons-India

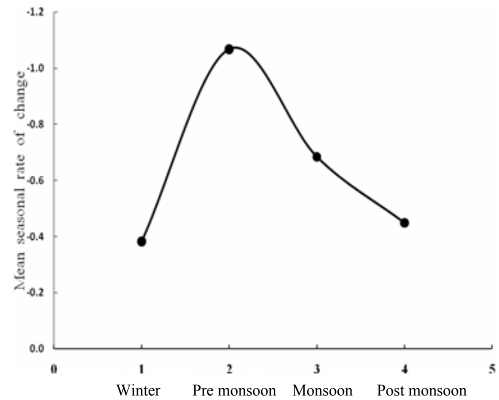


Fig. 5. Rate of change of PET through seasons-India

central and northeast India are higher than their counter parts of north most India and southeast peninsula. It is very interesting to note that the monsoon is not influencing to the required degree for northern most of India and southeast peninsula but for the central and northeast India it is not only imparting copious moisture flux but also subjecting with vagaries and anomalies in circulation pattern that lead to interannual variation in PET and high SD with the consequent C.V. Mean seasonal PET values for the four meteorological seasons, *i.e.*, winter (January- February), pre-monsoon (March-May), monsoon (June-September) and post- monsoon (October- December) for the country as a whole are diagrammed in Fig. 4. The seasonal PET values varied from 191.3 mm to 534.6 mm (Fig. 4). Highest seasonal PET is observed in monsoon season (534.6 mm) followed by pre-monsoon (509.4 mm), post- monsoon (296.1 mm) with the least in winter season (191.3 mm).

Annual PET trend is tested for statistical significance and presented in Table 2. Among a total of 194 stations, the significant decreasing trend in annual PET is observed for 75 locations and the significant increasing trend is for 19 stations only and for the remaining 100 stations the trend is not significant (Table 2). The annual rate of change of PET is varied from -13.5 mm/ year at Phalodi to +9.7 mm/year at Machilipatnam. It is to be noted here that Verma *et al*. (2008) reported that the trend in PET varied from +3.0 mm/year at Karimganj to -20.0 mm at Jodhpur with a mean annual rate of change of PET over India as -9.36 mm/year and in confirming this negative trend they analyzed the trend in meteorological elements and found significant increasing trend in relative humidity, deceasing trend in wind speed, decreasing trend in duration of bright sunshine hours with no trend in maximum and minimum temperatures. In the present investigation the annual rate of change of PET for the country as a whole is -2.6 mm/year but the paradox is that this decrease is at a time when mean surface temperature over the globe including Indian region is on an increase as reported by several workers (Parker 1989, Jones 1988, Hansen and Lebedeff 1987, Hingane *et al*., 1985, Groisman and Kovyneva 1989, Srivastava *et al*., 1992) due to the anthropogenic activities and which in turn triggered the global climate change. The contradiction of this decrease trend in annual PET as against increase of temperature globally may be due to the reported over all effects of cooling and warming trends in surface air temperature of the north and south Indian stations as reported by Srivastava *et al*. (1992) in addition to the effects of cooling aerosols of sulphate and nitrate. Srivastava *et al*. (1992) reported the cooling and warming trend of all the stations north of 23° N and south of 23° N respectively with a rising at the rate of 0.2 to 0.4 °C/100 years for the country as a whole. The study further confirmed that the cooling, warming and rising trend was in agreement with global and hemispheric cooling of about 0.5 °C North of 23 to 90° N between 1940 to mid 1970 as reported (Hansen *et al*., 1981, Wigley and Jones, 1981 and Borzenkova *et al*., 1976), with a warming of 0.3 to 0.4 °C south of 23° N to 90° S and a rising of mean global surface air temperature by about 0.4 °C during the past century as reported by Hansen *et al.* (1981) respectively. Trend in annual PET has been analyzed in the context of cooling and warming over north and south India respectively with the associated climate change. Among a total of 75 stations with a significant negative trend is noticed for a total of 49 of stations that lie north of 23° N (including 9 in border region of 23° N) and the estimated decreasing trend in annual PET of these stations is therefore in conformity with the cooling trend in surface temperature reported both in global and regional studies. Similarly the increasing trend at 14 stations (includes 02 in border region of 23° N) out of 19 stations that are south of 23° N, is also in accordance with the reported warming trend in surface temperature south of 23° N. Decreasing trend in annual PET for the country as a whole as well as in the north India stations is also in accordance with the witnessed decreasing trend in station level pressure by 2 hPa/100 years that associated with climate change (Srivastava *et al.*, 1992). The contradiction in decreasing/ increasing trend in annual PET observed at relatively less number of stations (26 north / 05 south India) as well as decreasing trend in annual PET for the country as a whole, with the reported cooling / warming trends in surface air temperature may be attributed to the difference in the number of stations, length of period of study and also needs further investigation.

The seasonal rate of change of PET from the linear trend is presented in Table 2 for the four seasons and for the 94 stations whose annual PET trend is statistically significant at 95% level. It is conspicuous from Table 2 that there is variation in seasonal rates of change of PET among four seasons (Fig. 5). The maximum variation is observed over Dohad (5.93 mm/year) while the least is found over Pamban (0.12 mm/year). It is also seen that trend is not significant in all the four seasons at a station, albeit the trend of annual PET at the corresponding station is significant and the number of seasons in which trend is significant varied from station to station. Seasons in which the trend is statistically significant are indicated in higher and bold font. Again among the 94 stations only for 21 stations, the trend is significant in all the four seasons. The significant trend is observed for 62 stations for winter while for pre-monsoon, monsoon and post-monsoon seasons, the trend was significant for 71, 47 and 49 stations respectively. The contribution of various seasons for annual rate of change of PET for the country as whole is - 0.38 for winter, - 1.07 for pre-monsoon, - 0.68 for monsoon and -0.45 for post monsoon season. The magnitude of PET and its rate of change at a location/ region are essential prerequisite apraiari in understanding not only the climate potentialities in introducing the crop variety but also for irrigation schedule. A second order polynomial fit for the rate of change of PET (Fig. 5) yields the following non linear equation and is used to derive the seasonal rate of change of PET over India.

$$y = 0.2301x^2 - 1.132\,x + 0.4584$$

$$(R = 0.86)$$

where, y = Mean seasonal rate of change of PET for the country (mm/year), x for different seasons. The correlation coefficient for the annual and seasonal rate of PET is 0.86 and is substantial.

3.5. *Anomalies in PET*

Anomalies of mean annual and seasonal PET for 160 stations in the two epochs of 1931-1960 (base period) and 1961-1995 are analyzed. The mean annual PET for the country as a whole is increased by 47.2 mm in 1961-1995 period compared to 1931-1960. The contribution of winter, pre-monsoon, monsoon and post-monsoon seasons for this change is 4.6 mm, 27.3 mm, 19.0 mm and -3.7 mm respectively and obviously the higher contribution is from pre monsoon and monsoon season and which is in agreement with the observed change in surface air temperature which is higher than the grand mean of 1931-60. It is also to be noted here that in spite of a decrease trend in PET at the rate of 2.6 mm/year for the country as whole during 1961-95, the PET was still above the 1931-60 period. Again among the 160 stations, there are 82 stations that displayed statistically significant trend in annual PET with 64 stations decreasing and 18 increasing trend. The Station wise study of annual and seasonal PET anomalies, has revealed that a total of 95 stations recorded positive annual PET anomalies that include 49 stations with a significant decreasing and 07 stations for an increasing trend while the remaining 65 stations recorded negative anomalies that include 15 stations with significant decreasing and 11 stations for an increasing trend. The number of stations that recorded positive (negative) anomalies for winter, pre monsoon, monsoon and post monsoon seasons are 109 (51), 114 (46), 78 (82) and 65 (95) respectively.

4. Conclusion

(*i*) In general higher annual potential evapotranspiration (PET) exceeding 1800 mm is observed over arid and steppe climate regions of the country while the lowest prevailed over the savanna and temperate climate regions of the country. The annual PET has been found to be highest at Rajkot (2422 mm) and the lowest is for Darjeeling (560 mm).

(*ii*) Seasonal PET values are increased over many locations of India during pre-monsoon, monsoon and winter seasons with a marginal decrease during post-monsoon season in the period of 1961-95 compared to 1931- 60. Annual PET is increased by 47.2 mm for the country as a whole during 1961-95 period compared to the 1931-60 period and is in conformity with the reported increase in surface temperature during 1961-95 periods over that of the period 1931-60.

(*iii*) There are seventy five stations that recorded significant decreasing trend while at nineteen locations significant increasing trend is noticed. The trend is found to be statistically not significant for 100 stations.

(*iv*) Mean seasonal PET for the country as a whole is found to be highest (534.6 mm) for monsoon season followed by pre-monsoon (509.4 mm), post-monsoon (296.1 mm) and with the least in winter (191.3 mm).

Similarly highest contribution has been observed from pre-monsoon season (-1.07) toward the annual rate of change of PET for the country as a whole followed by monsoon (-0.68), post monsoon (-0.45) and winter (-0.38) seasons.

(*v*) Annual rate of change of PET for the country as a whole was found to -2.6 mm/year. Stations from north India (north of 23° N) are found to be registered decreasing trend, which is in agreement with the reported cooling trend north of 23° N.

(*vi*) Potential evapotranspiration to precipitation ratio is increased gradually from tropical monsoon climate type to dry climates through temperate and Savanna.

(*vii*) Steppe climatic type shrank while Savanna climate enlarged over India during 1951-1980.

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