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Monthly climatic water balance at selected locations in India

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सार – मासिक औसत वर्षा (आर. एफ.) और वाष्पोत्सर्जन विभव (पी.ई.टी.) की गणना करने के लिए भारत में फैले सत्ताइस (27) स्टेशनों के वर्ष 1971 से 2000 तक के मौसम आँकड़ों का उपयोग किया गया है। इस शोध पत्र में एफ.ए.ओ. द्वारा अनुशंसित पेन मैन मॉनटीथ समीकरण का उपयोग करके वाष्पोत्सर्जन विभव की गणना की गई है। इस शोध पत्र में पानी की कमी/अधिकता वाले महीनों का पता लगाने का प्रयास किया गया है और मानसून अथवा खरीफ (जून से सितंबर) एवं रबी (अक्तूबर से फरवरी) दोनों ऋतुओं की फसल योजनाओं तैयार करने के संबंध में इस पर चर्चा की गई है।

पश्चिमोत्तर, पश्चिमी और मध्य क्षेत्र के खरीफ ऋतु में अनेक स्टेशनों में तथा रबी की ऋतु में सभी स्टेशनों पर पानी की कमी प्रेक्षित की गई है। इन क्षेत्रों में औसत वर्षा एवं वाष्पोत्सर्जन विभव का अनुपात 0.53 पाया गया है जिससे यह पता चलता है कि पंतनगर आधारतल (0.94) को छोड़कर फसल चयन एव योजना तैयार करना अधिक पानी की आवश्यकता वाली फसलों के लिए सहायक नही रहा है। खरीफ ऋतु के दौरान हिसार और जोधपुर को छोडकर अनेक स्टेशनों पर वर्षा/वाष्पोत्सर्जन विभव का अनुपात एक से अधिक पाया गया है जो वर्षा ऋतु के दौरान फसल लगाने के लिए बहुत अच्छा माना जाता है। पूर्व और पूर्वोत्तर क्षेत्र में खरीफ ऋतु के दौरान सभी स्टेशनों पर पानी की अधिकता देखी गई है। अधिकांश स्थानों में दिसंबर, जनवरी और फरवरी के महीनों में रबी के लिए पानी की कमी देखी गई है। खरीफ ऋतु के दौरान वर्षा/वाष्पोत्सर्जन विभव का अनुपात 1.44 और 5.93 के बीच पाया गया है जिससे पता चलता है कि फसल उगाने की अवधि के दौरान किसी भी स्टेशन पर पानी की कमी नही हुई है। दक्षिणी क्षेत्र के चयनित स्टेशनों पर जून, जुलाई और अगस्त के महीनों में खरीफ ऋतु में अनेक स्थानों पर पानी की कमी देखी गई है। जनवरी एवं फरवरी माह के दौरान रबी फसल के समय अनेक स्थानों पर पानी की कमी देखी गई है। राजामुंद्री और पट्टम्बी को छोड़कर अन्य स्थानों में खरीफ ऋतु के दौरान वर्षा/वाष्पोत्सर्जन विभव का अनुपात 1 से कम पाया गया है। इससे यह स्पष्ट होता है कि सीमित नमी में अच्छी उपज के लिए उपयुक्त फसल का चयन आवश्यक है।

ABSTRACT Meteorological data (1971-2000) for twenty seven (27) well distributed locations in India, have been utilized to compute average monthly rainfall (RF) and potential evapotranspiration (PET). In the present study, potential evapotranspiration (PET) has been calculated by using FAO recommended Penman-Monteith equation. An attempt has been made to identify the months of water deficit / surplus and these have been discussed in relation to crop planning for both seasons Monsoon or Kharif (June to September) and Rabi (October to February).

In northwest, west and central zone, water deficit is observed at several stations in Kharif and all stations in Rabi. The average RF/PET ratio in this zone is 0.53 indicating that except in Pantnagar and Adhartal (0.94), crop selection and planning do not favour crops requiring more water. During Kharif season RF/PET ratio of several stations, except Hissar and Jodhpur, is more than 1, suggesting successful cropping with rainfall. In east and northeast zone, water surplus is observed at all the stations in Kharif. Water deficit in Rabi occurred at most of the places during December, January and February. RF/PET ratio during Kharif season ranges between 1.44 and 5.93 suggesting none of the stations undergo water deficit during the crop growing period. For the stations selected in south zone, water deficit in Kharif occurred at many places in the months of June, July and August. Water deficit in Rabi occurred at many places during January and February. During Kharif RF/PET ratio is less than 1 except for Rajamundry and Pattambi. This emphasizes the need for proper crop selection for successful cropping with limited moisture.

Key words – Monthly climatic water balance, Water deficit, Water surplus, Potential evapotranspiration.

1. Introduction

The two most important requirements for the growth and development of crops are heat and moisture. In a tropical country like India, the limiting factor for successful agriculture is moisture, as there is no dearth of thermal energy. Rainfall becomes a major limiting factor for crop production as it is not uniformly and evenly

TABLE 1

Location, Soil type and Water holding Capacity (WHC) of different stations

S. No.	Station	Lat. (deg N)		Long. (deg E)		Data (years)	Soil type	WHC (mm)
1.	Adhartal	23	09	79	58	29	Sandy loam	150
2.	Agartala	23	53	91	15	22	Clay loam	200
3.	Akola	20	42	77	00	25	Clay loam	230
4.	Anand	22	35	72	55	20	Loam	180
5.	Guwahati	26	06	91	35	28	Clay loam	200
6.	Hissar	29	10	75	46	26	Loam	180
7.	Jhansi	25	27	78	35	20	Clay loam	210
8.	Jodhpur	26	18	73	00	18	Sandy loam	140
9.	Kolhapur	17	00	74	00	18	Clay loam	200
10.	Kolkata	22	32	88	20	23	Silty clay	220
11.	Pantnagar	29	00	79	30	29	Sandy loam	140
12.	Pune	18	32	73	51	29	Clay loam	230
13.	Udaipur	24	35	73	42	18	Sandy loam	125
14.	Bhubaneshwar	20	15	85	50	29	Sandy loam	160
15.	Bikramganj	25	10	84	15	17	Clay loam	200
16.	Buralikson	26	35	93	50	17	Clay loam	220
17.	Canning	22	15	88	40	28	Clay	250
18.	Karimganj	24	50	92	20	30	Clay	250
19.	Annamalainagar	11	24	79	44	18	Clay loam	190
20.	Bellary	15	09	76	51	29	Clay loam	190
21.	Coimbatore	11	00	77	00	18	Clay loam	180
22.	Dharwar	15	26	75	07	19	Clay loam	250
23.	Hebbal	13	00	77	38	25	Sandy loam	130
24.	Hyderabad	17	32	78	16	23	Sandy loam	100
25.	Kovilpatti	9	12	77	53	28	Clay	250
26.	Pattambi	10	48	76	12	29	Sandy loam	110
27.	Rajamundry	17	00	81	46	30	Clay	220

spread in space and time (Soman and Kumar, 1990). The uneven distribution of rainfall leads to situations in which, crop suffer from deficient rainfall on some occasions and excess rainfall at other occasions. Under these circumstances, it is difficult to effectively utilize the rainfall for maximum crop production. Study of climatic water balance is one of the important disciplines of applied climatology, hydrology and agriculture. The change of state of water from solid or liquid to vapour and its diffusion into the atmosphere is referred to as evaporation. In evapotranspiration, two processes occur simultaneously; evaporation from the soil and transpiration from canopy of the crop. Potential evapotranspiration (PET) is the maximum possible amount of water vapour loss, under a given climate from an extensive surface of green, well-watered grass canopy of uniform height, which is actively growing and completely shading the ground. (FAO, 1998). PET plays a major role in the redistribution of energy between the soil-plant continuum and the atmosphere and is an essential part of the hydrological cycle. Potential evapotranspiration (PET) is a parameter widely used by scientific community for solving many practical oriented problems related to water balance, irrigation assessment, agro-meteorology and hydrology. As such, there is great demand from various users across the country for this important parameter.

The estimates of soil water balance and water balance indices (humidity index, aridity index and moisture index) at a given location provides useful information on soil moisture storage, period of water deficit and water surplus. Knowledge of moisture deficit facilitates the understanding of economic feasibility of irrigation and that of the water surplus provides information on scope of recharge and conservation for future utilization. The estimates of soil water balance can be used as guides for estimating probable length of growing season, irrigation needs, leaching of soils for salts, fluctuations in water table, drought hazards, soil water availability in different regions and judging the agricultural potential of the region. The quantitative results obtained may also be utilized for Agromet. Advisory service bulletins.

The climatic water balance of Thornthwaite and Mather (1957) is useful over wide range of soil and vegetation conditions. Research studies relating to Potential evapotranspiration (PET), soil water balance, water balance indices and its application to agriculture as well as hydrology have been carried out by many researchers (Adhikari *et al*., 2004; Allen, *et al*., 1998; Arora, 2002; Debnath, 1996; Ghadekar, 2003; Hulme *et al*., 1992; Jat, *et al*., 2004; Kingra *et al*., 2004; Lenka, D., 1998; Mehta *et al*., 2006; Pascua, D. D., 2000; Rukmini *et al*., 1996; Singh *et al*., 2004; Singh and Ramakrishna, 1992; Subramaniam and Kesava Rao, 1984; Varshneya and Pillai , 2004; WMO, 1997).

2. Data and methodology

In the present study, meteorological data (1971-2000) on maximum and minimum temperature, morning and afternoon relative humidity, wind speed, bright sunshine hours and rainfall for twenty seven (27) selected stations in India have been utilized to compute average monthly potential evapotranspiration (PET) and monthly rainfall (RF). The data were obtained from National Data Center (NDC), India Meteorological Department, Pune. The Location, data availability, Soil type and Water holding Capacity (WHC) information of 27 well distributed stations in India is given in Table 1.

In the present study, potential evapotranspiration (PET) has been calculated by using FAO recommended Penman-Monteith equation (FAO, 1998). This method provides a standard to which evapotranspiration in different periods of the year or in other regions can be compared and to which the evapotranspiration from other crops can be related. The FAO Penman-Monteith method requires radiation, air temperature, air humidity and wind speed data to compute the potential evapotranspiration as given in equation :

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\dfrac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

where,

ET_0 = potential / reference evapotranspiration [mm day^{-1}],

R_n = net radiation at the crop surface [MJ m^{-2} day^{-1}],

G = soil heat flux density [MJ m^{-2} day^{-1}],

T = air temperature at 2 m height [°C],

u_2 = wind speed at 2 m height [ms^{-1}],

e_s = saturation vapour pressure [kPa],

e_a = actual vapour pressure [kPa],

e_s - e_a = saturation vapour pressure deficit [kPa],

Δ = slope of the saturation vapour pressure-temperature curve [kPa °C^{-1}],

γ = psychrometric constant [kPa °C^{-1}].

Climatic water balance for all months of the year have been worked out utilizing water budgeting procedure based on the method of Thornthwaite and Mather (1955). Crops require a certain fixed amount of water, during a particular growth stage for its optimum growth. When crops receive deficient rainfall than required by the crop, supplementary irrigation needs to be given for successfully raising the crop. Deficient rainfall causes soil moisture stress which adversely affects plant growth resulting in poor yield. However, when crops receive excess rainfall than required by the crop, then excess water needs to be drained out, in order to avoid water logging conditions and poor aeration, particularly crops such as maize, millets etc. (Venkatraman and Krishnan, 1992). In this paper, an attempt has been made to identify the months of water deficit / surplus and these have been discussed in relation to crop planning for both seasons Monsoon or Kharif (June to September) and Rabi (October to February).

TABLE 2

Climatic water balance for stations in north-west, west and central zone

Stations	Elements	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Adhartal	PET	69.6	87.5	132.9	173.3	217.7	180.7	115.6	102.9	111.3	108.1	77.1	62.1	1438.8
Adhartal	RF	20.6	26.0	12.0	5.2	8.5	168.5	360.4	477.7	200.7	41.4	15.4	16.5	1352.9
Adhartal	WD	35.9	50.1	108.5	161.3	206.7	12.1	0.0	0.0	0.0	12.9	29.2	28.9	645.6
Adhartal	WS	0.0	0.0	0.0	0.0	0.0	0.0	95.5	374.8	89.4	0.0	0.0	0.0	559.7
Akola	PET	113.6	135.1	199.4	249.5	317.8	226.4	145.1	127.7	141.1	136.3	112.3	101.1	2005.4
Akola	RF	10.6	10.9	10.4	3.4	9.1	155.0	230.2	201.2	109.9	48.4	22.6	11.3	823.0
Akola	WD	80.3	107.5	175.9	239.3	306.1	71.2	0.0	0.0	0.0	24.1	45.5	59.8	1109.7
Akola	WS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Anand	PET	91.1	105.0	150.0	177.1	213.1	186.3	125.5	111.4	131.0	129.7	98.3	85.1	1603.6
Anand	RF	2.2	0.0	0.6	2.0	9.3	106.9	282.7	239.7	109.6	27.7	15.7	1.5	797.9
Anand	WD	74.9	95.3	142.4	171.8	202.5	79.1	0.0	0.0	1.2	32.9	49.2	62.3	911.6
Anand	WS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	105.9	0.0	0.0	0.0	0.0	105.9
Hissar	PET	55.1	75.3	123.2	181.2	241.5	232.1	174.9	157.8	146.7	115.4	71.2	51.9	1626.3
Hissar	RF	11.4	15.9	10.9	12.9	27.3	57.9	162.2	128.2	53.8	10.0	2.8	4.4	497.7
Hissar	WD	43.1	58.7	111.6	167.7	159.7	140.2	11.3	26.6	86.3	101.1	66.6	46.7	1019.6
Hissar	WS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jhansi	PET	57.9	81.9	133.5	174.4	230.7	211.2	139.3	114.6	120.0	105.3	69.8	51.7	1490.3
Jhansi	RF	11.3	13.8	6.1	4.9	14.4	78.7	266.3	293.7	168.0	36.6	4.5	9.6	907.9
Jhansi	WD	28.5	48.0	103.5	153.6	208.1	130.3	0.0	0.0	0.0	10.1	24.8	22.0	728.9
Jhansi	WS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	179.1	48.0	0.0	0.0	0.0	227.1
Jodhpur	PET	99.4	115.1	172.3	216.4	271.2	253.1	190.3	163.6	165.4	137.3	101.1	90.3	1975.5
Jodhpur	RF	4.2	4.1	2.1	12.5	16.5	45.1	136.4	129.3	45.9	8.0	2.8	1.0	407.9
Jodhpur	WD	95.2	110.9	170.2	203.9	232.0	190.4	52.3	33.5	118.0	128.6	98.0	89.2	1522.2
Jodhpur	WS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kolhapur	PET	125.0	140.0	208.5	202.5	209.0	138.5	100.0	96.5	107.0	120.0	107.5	103.0	1657.5
Kolhapur	RF	4.4	1.3	2.4	14.3	53.4	168.6	292.4	194.0	108.0	143.6	17.8	8.6	1008.8
Kolhapur	WD	84.5	116.9	192.1	183.4	154.0	0.0	0.0	0.0	0.0	0.0	17.4	46.4	794.7
Kolhapur	WS	0.0	0.0	0.0	0.0	0.0	0.0	23.9	0.0	0.0	23.6	0.0	0.0	47.5
Pantnagar	PET	54.3	73.4	124.4	187.1	227.4	186.7	137.9	125.4	115.8	103.3	68.4	53.1	1457.2
Pantnagar	RF	26.1	31.0	18.6	16.8	56.0	183.1	449.3	416.9	232.2	51.4	5.6	20.3	1507.3
Pantnagar	WD	19.3	32.0	90.1	160.6	168.5	3.6	0.0	0.0	0.0	8.5	27.9	19.9	530.4
Pantnagar	WS	0.0	0.0	0.0	0.0	0.0	0.0	172.6	291.5	116.4	0.0	0.0	0.0	580.5
Pune	PET	102.3	121.0	167.9	203.0	233.6	157.3	117.6	108.4	119.6	123.7	104.4	94.8	1653.6
Pune	RF	0.9	1.7	1.6	10.5	32.1	158.5	168.2	123.6	137.4	81.6	28.4	5.5	750.0
Pune	WD	68.2	95.0	147.9	182.6	197.1	0.0	0.0	0.0	0.0	0.0	22.1	45.0	757.9
Pune	WS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Udaipur	PET	70.9	90.0	140.4	181.7	228.0	195.5	130.1	119.3	123.1	114.9	78.2	63.5	1535.6
Udaipur	RF	5.7	6.8	0.7	6.6	10.8	73.8	205.2	174.5	86.7	26.0	7.9	2.0	606.7
Udaipur	WD	58.7	78.6	136.4	173.9	216.9	121.6	0.0	0.0	4.8	41.4	50.5	51.4	934.2
Udaipur	WS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.3	0.0	0.0	0.0	0.0	5.3

(PET- Potential evapotranspiration, RF- Rainfall, WD- Water Deficit, WS- Water Surplus)

TABLE 3

Climatic water balance for stations in north-east zone

Stations	Elements	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Agartala	PET	67.4	85.2	132.4	147.6	139.3	114.0	115.5	120.0	105.2	102.1	81.3	65.1	1275.2
Agartala	RF	42.2	20.7	60.9	187.5	367.6	380.5	328.9	271.7	231.4	147.5	36.9	20.0	2095.9
Agartala	WD	10.0	33.4	46.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6	12.7	107.7
Agartala	WS	0.0	0.0	0.0	0.0	125.4	266.5	213.4	151.6	126.2	45.4	0.0	0.0	928.4
Bhubaneshwar	PET	96.8	117.2	166.7	193.9	210.9	150.2	119.7	117.2	116.5	118.9	100.7	92.1	1600.8
Bhubaneshwar	RF	8.4	22.0	26.0	29.3	96.2	199.9	301.4	363.5	236.4	143.9	44.0	5.3	1476.3
Bhubaneshwar	WD	60.7	78.3	128.6	159.1	113.1	0.0	0.0	0.0	0.0	0.0	9.0	39.8	588.6
Bhubaneshwar	WS	0.0	0.0	0.0	0.0	0.0	0.0	72.9	246.3	119.9	25.0	0.0	0.0	464.1
Bikramganj	PET	65.9	83.2	137.6	193.9	220.3	181.8	128.4	127.6	117.1	103.7	72.9	62.2	1494.6
Bikramganj	RF	18.2	19.8	9.8	8.3	21.4	176.6	340.7	286.7	232.1	40.0	10.3	10.4	1174.3
Bikramganj	WD	30.3	45.8	105.6	170.5	192.7	5.1	0.0	0.0	0.0	9.1	23.6	27.5	610.2
Bikramganj	WS	0.0	0.0	0.0	0.0	0.0	0.0	15.8	159.1	115.0	0.0	0.0	0.0	289.9
Buralikson	PET	53.4	67.1	97.9	108.7	120.1	111.5	112.7	116.1	97.5	93.0	69.1	53.7	1100.8
Buralikson	RF	17.0	43.8	56.6	183.6	207.4	307.9	367.1	257.1	273.3	136.5	22.5	15.1	1887.9
Buralikson	WD	13.6	10.6	21.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6	10.0	60.6
Buralikson	WS	0.0	0.0	0.0	0.0	36.6	196.4	254.4	141.0	175.8	43.5	0.0	0.0	847.7
Canning	PET	81.5	100.8	160.8	187.8	194.6	145.8	129.5	123.8	117.6	121.5	90.9	76.1	1530.7
Canning	RF	14.3	24.9	43.4	84.0	143.0	309.9	343.2	340.1	300.8	144.5	53.8	8.5	1810.4
Canning	WD	28.4	43.0	82.6	84.1	44.5	0.0	0.0	0.0	0.0	0.0	2.6	16.6	301.8
Canning	WS	0.0	0.0	0.0	0.0	0.0	0.0	213.7	216.3	183.2	23.0	0.0	0.0	636.2
Guwahati	PET	58.3	74.7	114.3	130.5	132.3	114.5	114.5	118.2	101.7	97.2	74.9	58.2	1189.1
Guwahati	RF	8.4	22.9	47.2	159.5	232.4	303.4	353.6	255.8	202.0	105.1	19.3	10.7	1720.3
Guwahati	WD	23.5	30.5	46.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0	15.5	123.2
Guwahati	WS	0.0	0.0	0.0	0.0	0.0	169.4	239.2	137.6	100.3	7.9	0.0	0.0	654.4
Karimganj	PET	64.2	76.6	110.6	118.1	116.1	103.9	100.3	107.0	96.5	99.0	76.7	62.8	1131.8
Karimganj	RF	5.1	46.8	128.9	471.2	581.2	845.7	668.1	499.9	404.4	230.8	43.6	13.2	3938.9
Karimganj	WD	21.3	13.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	10.2	47.4
Karimganj	WS	0.0	0.0	0.0	353.1	465.2	741.8	567.8	392.9	307.9	131.8	0.0	0.0	2960.5
Kolkata	PET	74.1	92.4	139.5	164.9	165.7	122.3	111.1	109.1	103.6	104.6	84.9	70.4	1342.4
Kolkata	RF	11.5	28.1	26.0	52.3	141.7	306.6	373.0	340.7	308.5	160.5	34.7	11.1	1794.5
Kolkata	WD	29.5	38.8	83.2	94.7	21.2	0.0	0.0	0.0	0.0	0.0	5.3	17.9	290.6
Kolkata	WS	0.0	0.0	0.0	0.0	0.0	0.0	250.3	231.6	204.9	55.9	0.0	0.0	742.7

(PET- Potential evapotranspiration, RF- Rainfall, WD- Water Deficit, WS- Water Surplus)

3. Results and discussions

3.1. *Climatic water balance for stations in Northwest, west and central zone*

Climatic water balance for stations in Northwest, west and central zone of India is given in Table 2. It may be seen, surplus water is available at Adhartal, Anand, Pantnagar and Jhansi during Kharif. Surplus water is mainly seen in the month of August. Water deficit is observed at several stations in Kharif and all stations in Rabi. The highest annual PET value of 2005 mm is recorded in Akola and the lowest PET of 1439 mm in Adhartal. The highest rainfall of 1507 mm is observed in

TABLE 4

Climatic water balance for stations in south zone

Stations	Elements	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Annamalainagar	PET	116.8	125.8	157.5	171.6	203.3	197.5	178.1	167.6	150.6	123.1	99.1	104.8	1795.8
Annamalainagar	RF	15.6	14.1	5.8	13.5	33.8	57.4	58.1	95.4	101.1	275.9	400.3	280.7	1351.7
Annamalainagar	WD	22.7	62.2	117.6	142.3	162.4	137.5	118.9	71.8	49.3	0.0	0.0	0.0	884.7
Annamalainagar	WS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	301.2	175.9	477.1
Bellary	PET	130.7	154.9	203.4	226.1	260.9	222.2	199.6	186.0	162.6	137.6	114.1	111.0	2109.1
Bellary	RF	7.3	2.0	3.2	15.3	51.9	64.0	44.5	52.5	125.4	108.2	36.5	9.0	519.8
Bellary	WD	123.2	152.7	200.1	148.2	167.3	146.4	150.0	131.5	36.8	29.2	77.1	101.6	1464.1
Bellary	WS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coimbatore	PET	123.1	138.7	182.0	173.2	178.0	176.3	170.4	167.3	151.8	123.5	102.9	109.8	1797.0
Coimbatore	RF	14.6	6.7	15.9	57.3	52.2	36.2	44.9	29.6	72.2	154.6	113.8	46.4	644.4
Coimbatore	WD	51.2	96.0	146.0	109.6	122.4	138.2	124.7	137.3	79.4	0.0	0.0	0.0	1004.8
Coimbatore	WS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dharwar	PET	112.6	127.4	174.9	197.8	202.4	132.9	103.8	103.9	112.2	115.2	108.3	105.9	1597.3
Dharwar	RF	2.3	0.1	8.0	41.1	69.1	118.4	138.9	86.9	102.5	110.2	32.7	9.0	719.2
Dharwar	WD	70.9	98.9	146.1	146.5	128.5	14.1	0.0	0.0	0.8	0.5	18.2	44.6	669.1
Dharwar	WS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hebbal	PET	118.8	129.5	169.1	173.9	180.9	147.6	136.2	127.9	123.3	114.8	100.8	103.1	1625.9
Hebbal	RF	2.9	7.1	9.9	26.3	87.1	74.4	89.1	106.1	200.6	132.5	58.3	12.2	806.5
Hebbal	WD	88.4	110.8	153.9	146.1	93.4	73.1	47.0	21.8	0.0	0.0	41.2	43.8	819.5
Hebbal	WS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hyderabad	PET	105.4	125.1	168.9	186.8	221.5	187.6	154.3	140.6	129.0	120.8	101.6	94.7	1736.3
Hyderabad	RF	4.1	5.0	12.2	18.4	35.9	110.0	153.6	154.9	132.5	92.9	31.6	3.2	754.3
Hyderabad	WD	91.8	116.2	155.4	168.2	185.5	77.6	0.7	0.0	0.0	0.0	31.9	68.9	896.2
Hyderabad	WS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kovilpatti	PET	124.7	140.0	174.5	168.7	191.7	209.8	209.4	210.2	179.3	142.2	107.4	106.4	1964.3
Kovilpatti	RF	20.2	14.4	19.1	56.5	67.3	19.1	21.4	31.5	80.4	184.5	158.4	65.0	737.8
Kovilpatti	WD	32.2	70.5	116.3	95.8	113.1	181.3	183.7	176.7	98.3	0.0	0.0	0.0	1067.9
Kovilpatti	WS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pattambi	PET	143.4	144.6	168.4	159.0	144.6	94.7	90.2	103.7	117.6	114.7	113.0	130.5	1524.4
Pattambi	RF	4.1	3.6	11.6	72.3	159.7	682.9	685.5	378.6	203.1	270.0	146.7	21.1	2639.2
Pattambi	WD	110.1	132.7	154.4	86.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	40.1	523.5
Pattambi	WS	0.0	0.0	0.0	0.0	0.0	588.2	595.4	274.9	85.5	155.3	33.7	0.0	1733.0
Rajamundry	PET	103.6	116.6	156.1	176.5	195.1	158.8	127.3	120.9	118.1	119.0	110.5	100.9	1603.4
Rajamundry	RF	12.6	12.6	8.2	29.2	58.7	147.1	199.2	242.5	144.2	172.1	57.7	5.4	1089.5
Rajamundry	WD	53.0	76.1	125.3	135.8	130.8	11.4	0.0	0.0	0.0	0.0	0.0	34.5	566.9
Rajamundry	WS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.7	0.0	0.0	0.0	5.7

(PET- Potential evapotranspiration, RF- Rainfall, WD- Water Deficit, WS- Water Surplus)

Pantnagar and the lowest rainfall of 408 mm in Jodhpur. On an average, the annual PET and rainfall for the stations selected in this zone are 1644 and 866 mm, respectively, indicating severe water deficit and risk in crop planning and management.

Annual RF/PET ratio of stations in this zone range from 0.21 in Jodhpur to 1.03 in Pantnagar. The average RF/PET ratio in this zone is 0.53. This indicates that except in Pantnagar and Adhartal (0.94), crop selection and planning do not favour crops requiring more water. However, during southwest monsoon season RF/PET ratio of several stations (except Hissar and Jodhpur) is more than 1, suggesting successful cropping with rainfall. In some stations, RF/PET ratio is more than 2, suggesting multiple cropping systems like inter cropping. In many of the stations rainfall is more or less equal to PET in June itself indicating crop sowing at the start of monsoon. Groundnut, cotton, maize, bajra and pulses like green gram and red gram are grown during kharif and wheat, gram, mustard and peas are grown during rabi season. Rabi crops in this zone are mainly grown with residual soil moisture. The crops are also grown with supplementary irrigation if soil moisture does not support during growing period.

3.2. *Climatic water balance for stations in East and Northeast zone*

Climatic water balance for stations in East and Northeast zone is given in Table 3. Water surplus is observed at all the stations in Kharif and all stations except Bikramganj in Rabi. Water deficit is observed at all the stations in Rabi season. Water deficit in Rabi occurred at most of the places during December, January and February. In this zone, there is potential of assured cropping with multiple crops due to the fact that many of the stations, selected have annual rainfall more than PET. The highest rainfall of 3939 mm is observed in Karimganj and the lowest is 904 mm in Lucknow. Bhubaneshwar and Buralikson have the highest and lowest PET of 1601 and 1101 mm, respectively. The average annual rainfall and PET for the stations selected in this zone are 1798 and 1360 mm respectively, indicating successful cropping and potential for improved farming systems.

Several stations in this zone have Annual RF/PET ratio of more than 1, suggesting assured continuous moisture availability even beyond growing period. RF/PET ratio during southwest monsoon season ranges between 1.44 and 5.93 suggesting none of the stations undergo water deficit during the crop growing period. This assures not only kharif cropping but also growing of rabi crops with residual moisture. In this zone, several stations have rainfall ≥ PET even before start of monsoon. For example, Karimganj and Buralikson receive rainfall equal to PET in the months March-April. This indicates advance crop selection and sowing. Owing to assured moisture supply, more water requiring crops like paddy etc. are also grown during kharif season in addition to millets and pulses. Similarly, rabi crops like wheat, mustard, gram are grown with water deficit.

3.3. *Climatic water balance for stations in South zone*

Climatic water balance for stations in south zone is given in Table 4. Water surplus in both the seasons, *i.e.*, Kharif and Rabi is observed at Pattambi. Water surplus during the Rabi season is observed at Annamalainagar. Water deficit is observed at most of the stations in Kharif and all the stations in Rabi season. Water deficit in Kharif occurred at many places in the months of June, July and August. Water deficit in Rabi occurred at most of the places during January and February.

The highest annual rainfall of 2639 mm rain is observed in Pattambi and the lowest 520 mm in Bellary. On the contrary, the highest and lowest PET values of 2109 and 1524 mm are observed in Bellary and Pattambi, respectively. The average annual PET and rainfall of 1748 and 1038 mm, respectively for the stations selected in this zone, indicates crop growing under severe water deficit conditions.

Annual RF/PET ratio for all stations in this zone (except Pattambi) is less than 1. The average RF/PET ratio in this zone is 0.59 indicating crop selections and planning do not favour crops requiring more water. During southwest monsoon RF/PET ratio is less than 1 (except for Rajamundry and Pattambi). This emphasizes the need for proper crop selection for successful cropping with limited moisture. In several stations rainfall is significantly less than PET even after start of monsoon. Considering the limited availability of moisture during southwest monsoon, crops having low water requirement like maize, jowar and pulses are grown. During rabi mustard and gram are grown with limited residual moisture. There is also need of supplementary irrigation during rabi season at critical stages.

4. Conclusions

For the stations selected in Northwest, west and central zone, Water deficit is observed at several stations in Kharif and all stations in Rabi. The average RF/PET ratio in this zone is 0.53 indicating that except in Pantnagar and Adhartal (0.94), crop selection and planning do not favour crops requiring more water. During Kharif season RF/PET ratio of several stations, except Hissar and Jodhpur, is more than 1, suggesting successful cropping with rainfall. For the stations selected in East and Northeast zone, Water surplus is observed at all the stations in Kharif. Water deficit in Rabi occurred at most of the places during December, January and February. RF/PET ratio during Kharif season ranges between 1.44 and 5.93 suggesting none of the stations undergo water deficit during the crop growing period. For the stations selected in south zone, Water deficit in Kharif occurred at many places in the months of June, July and August. Water deficit in Rabi occurred at many places during January and February. During Kharif RF/PET ratio is less than 1 except for Rajamundry and Pattambi. This emphasizes the need for proper crop selection for successful cropping with limited moisture.

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