

Characterization of climatic parameters in the perspective of irrigated agriculture in Uttar Kannada district of Karnataka, India

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सार – वर्षा और वाष्पोत्सर्जन - क्षमता की विशेषताएं एक साथ कृषि-मौसम क्षेत्र की स्थिति को निर्धारित करती हैं और सिंचाई के अनुप्रयोग के परिमाण और समय से संबंधित निर्णय को प्रभावित करती हैं। इस अध्ययन में, कर्नाटक के उत्तर कन्नड़ जिले से संबंधित क्षेत्र की ऐतिहासिक वर्षा और जलवायु आंकड़ों का विश्लेषण इस क्षेत्र में सिंचाई के लिए पानी की आवश्यकताओं को ध्यान में रखकर किया गया है। वर्षा के आंकड़ों के अलावा, जल संतुलन का एक महत्वपूर्ण पहलू फसल वाष्पोत्सर्जन (ET_{crop}) मॉडल है, जो उनके सिंचाई कार्यक्रम को निर्धारित करने में मुख्य कारक है। फसल वाष्पोत्सर्जन का अनुमान संदर्भित वाष्पोत्सर्जन (ET₀) और फसल गुणांक द्वारा लगाया जा सकता है। वायुमंडलीय जल की मांग को 'संभावित वाष्पीकरण' (PET) द्वारा दर्शाया जाता है और जलवायु चर से गणना की जाती है जो सिंचाई योजना के लिए महत्वपूर्ण है। यह बताया गया है कि पेनमैन-मोंटिथ विधि अन्य वाष्पोत्सर्जन (ET₀) तरीकों के लिए लगातार सही वाष्पोत्सर्जन (ET₀) अनुमान देती है। वर्षा और पीईटी दोनों के महत्व को समझते हुए, एक प्रभावी उपाय को 'नमी उपलब्धता सूचकांक' (MAI) के रूप में जाना जाता है, जिसकी गणना 75% भरोसेमंद वर्षा और संभावित वाष्पोत्सर्जन के अनुपात के रूप में की जाती है। 'नमी उपलब्धता सूचकांक' (MAI) का 1.00 मान इंगित करता है कि भरोसेमंद वर्षा संभावित वाष्पोत्सर्जन के लगभग बराबर है। फसल संवर्धन के मौसम के दौरान एक महीने के लिए 'नमी उपलब्धता सूचकांक' (MAI) का मान 0.33 या उससे कम का होना जल की कमी का संकेत माना जाता है जिससे फसल की पैदावार में कमी होती है। 'नमी उपलब्धता सूचकांक' (MAI) पर किए गए इस अध्ययन के निष्कर्षों का उपयोग फसलों की बुवाई की अवधि के चयन के लिए किया जाता है ताकि फसल की कटाई के समय पानी की किल्लत से बचा जा सके।

ABSTRACT. A rainfall and potential evapotranspiration characteristics together determine the agrometeorological regime of a region and influences decision concerning the magnitudes and timing of irrigation application. In the present study, historical rainfall and climate data pertaining to the study area, Uttar Kannada district, Karnataka, was analyzed with a view to characterizing irrigation water requirements. In addition to rainfall input, an important aspect of the water balance model is the crop evapotranspiration (ET_{crop}), which is the main factor in determining the irrigation schedule. ET_{crop} could be estimated by reference evapotranspiration (ET₀) and crop coefficient. Atmospheric demand for water is represented by 'potential evapotranspiration' (PET) and calculated from climatic variables which is crucial for irrigation planning. It has been reported that the Penman-Monteith method gives more consistently correct ET₀ estimates to other ET₀ methods. While recognizing the importance of both rainfall and PET, an effective measure is known as the 'Moisture Availability Index' (MAI), which is computed as the ratio of 75% dependable rainfall and potential evapotranspiration. An MAI value of 1.00 indicates that dependable precipitation is equal to potential evapotranspiration. An MAI value of 0.33 or less for one month during the crop growing season is considered to be a signal of water deficit resulting reduction in crop yield. The findings of this study on MAI are used to decide the selection of the sowing period of crops so as to avoid water stress during the critical harvesting period.

Key words – Rainfall, Evapotranspiration, Climate, Moisture availability index, Probability, Wet spell.

1. Introduction

Climate is the long-term average of weather in a given location, fairly a long-time period of at least 10 years (Krishnaiah, 1998). It consists of average values of meteorological or oceanographic variables, such as air

temperatures, precipitation, humidity, wind speed or ocean temperature, etc. If the climate changes over time, it can directly affect human activities by the impact on the crops that are grown, the supply of freshwater, or the mean sea level. It can also affect natural ecosystems, causing deserts to expand, wildfires to become more prevalent, or

permafrost to melt. From the irrigation point of view, important characteristics of rainfall are;

- (i) Magnitudes of rainfall with various probabilities of occurrence.
- (ii) Duration and probabilities of wet spells of rainfall.
- (iii) Duration and probabilities of dry spells of rainfall.

Standard meteorological methods have been developed for regional-scale estimation of crop and irrigation water requirements for various crops using routinely available climate, soils and crop information. Estimates of evapotranspiration flux occurring from cropped land surfaces are essential in studies relating to hydrology, climate and agricultural water management. Atmospheric demand for water represented by potential evapotranspiration (PET) and calculated from climatic variables, is crucial to irrigation planning. The procedure for estimation of ET rates from agricultural crops is well established and involves as a first step in the computation of reference crop evapotranspiration (ET_{crop}) using regular climatologically recorded data. ET_{crop} could be estimated by reference evapotranspiration (ET₀) and crop coefficient (Doorenbos and Pruitt, 1977). It has been reported that the Penman-Monteith method gives more consistently correct ET₀ estimates compared to other ET₀ methods (Nayak and Nandagiri, 2009).

1.1. Objectives of the study

The main objectives of the study are:

- (i) Evaluation of rainfall characteristics for the study area. Characteristics such as dependable rainfall magnitudes and frequency of occurrence of wet and dry spells of rainfall were quantified considering historical daily rainfall observations.
- (ii) Characterization of the frequency distribution of mean daily FAO Penman-Monteith reference evapotranspiration for each month and computation of effective precipitation.
- (iii) Demonstration of the applicability of the concept of the Moisture Availability Index (MAI) for irrigation planning in the coastal region of Uttar Kannada district.

1.2. Evapotranspiration (ET₀) and Penman-Monteith (PM) Equation

As per the classification of the agro-climatic zone in Karnataka, the study area falls under Zone-10 (coastal region) which receives an annual rainfall of more

than 3500 mm. Since all the climatic information required for computation of ET is not available in the area under study, climatic data of neighboring stations have been used in this study. This is permissible in areas where the same weather extends over long distances (Doorenbos and Pruitt, 1977). An IMD climate station located at Brahmapur (12° 59' N and 74° 54' E) provided historical records of daily average climatic variables required for estimation of daily mean FAO-56 Penman-Monteith reference crop evapotranspiration (ET₀). The recent version of the internationally accepted United Nations Food and Agriculture Organization (FAO) methodology for estimation of crop water requirement (Allen *et al.*, 1998) recommends the sole use of the PM equation for ET₀ computations. The standard form of the Penman-Monteith equation is:

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

where, ET₀ is reference crop ET(mm/d), R_n is net radiation at crop surface (MJ/m²/day), G is soil heat flux density (MJ/m²/day), T_m is mean air temperature (°C) at 2 m height, u₂ is wind speed (m/s) at 2 m height, e_s is saturation vapour pressure(kpa), e_a is actual vapour pressure (kpa),

(e_s - e_a) is saturation vapour pressure deficit (vpd) (kpa), Δ is slope of vapour pressure versus temperature curve at temperature T (kpa/ °C) and γ is the psychrometric constant (kpa/°C).

It is common practice to use mean climatic data for computing ET₀. However, due to weather changes, ET_{crop} will vary from year to year and for each period within the year (Patle *et al.*, 2013).

1.3. Crop Evapotranspiration (ET_{crop})

Paddy (rice) is one of the most common crops grown by farmers in the Uttar Kannada district in the coastal plains. Paddy cultivation is divided into two distinct periods - the wet season crop that is planted to coincide with the onset of the monsoon (May/June) and harvested by the end of the monsoon (September/October) and the dry season crop during December/January to March/April. Since the Uttar Kannada region experiences over 3500 mm of rainfall during the monsoon season, providing supplemental irrigation for the wet season crop is not necessary. Appropriate land preparation and providing field bunds ensure the capture and storage of rainfall for optimal crop growth (Nayak and Nandagiri, 2010). The dry season paddy crop receives no contribution from

TABLE 1
K_c values for paddy crop

Crop	Initial	Development	Mid-season	Last 4 weeks	Total period
Rice	1.1-1.15	1.1-1.15	1.1-1.3	0.95-1.05	1.05-1.2

rainfall and therefore providing supplemental irrigation is crucial for crop growth during this period.

Crop evapotranspiration (ET_{crop}) is equivalent to crop water requirement and is computed by using the following equation.

$$ET_{crop} = ET_0 * K_c$$

$$\text{where, } K_c = \text{crop coefficient} \quad (2)$$

Crop coefficient K_c incorporates crop characteristics and averaged effects of evaporation from the soil. For normal irrigation planning and management purposes, for the development of basic irrigation schedules and for most of the hydrologic water balance studies, average crop coefficients are relevant and more convenient than the K_c computed on a daily basis.

(Doorenbos and Pruitt, 1977) specified K_c values for paddy for different geographic locations and seasons (Table 1). Wind conditions and during the dry season, the relative humidity may be important; whereas during the dry season when the relative humidity is more than 70%, the K_c values given for the wet season should be used. There are differences in the growing season according to variety; therefore, the length of the mid-season growth period will need adjustment. Local information on the length of the growing season will have to be procured from the agriculture department. K_c needs to be reduced by 15-20% during initial crop stages (Doorenbos and Pruitt, 1977). Seasonal K_c value of 1.15 upland (wet) and 1.2 for pluvial (dry) rice is adopted in the present study for computing total irrigation requirements in further analysis.

1.4. Effective precipitation

While determining net irrigation requirements, the amount of rain that enters the soil and becomes available for crop water use must be considered. The precipitation used by the plants depends upon the rainfall intensity, soil conditions and field management practices. Several methods of estimating effective rainfall for irrigation schedules are in practice in different countries. They are based on long experience and have been found to work quite satisfactorily in the specific conditions under which they were developed (Yemenu, 2013). In the present study

effective precipitation was computed using US Bureau Reclamation, Potential Evapotranspiration/Precipitation ratio method for India and USDA, SCS methods.

1.5. Total irrigation requirements

Total Irrigation Requirements (IWR) includes

- (i) Potential crop evapotranspiration ($ET_0 * K_c$)
- (ii) Excess water required for leaching
- (iii) Efficiency of project operation.

(Hargreaves, 1985) assumed 60% efficiency for surface irrigation and 1000 mm of water depth for percolation, soaking and filling for rice fields. Effective precipitation (P_e) was computed using USDA, SCS method as it appeared to be a reasonable value (based on mean monthly rainfall and mean monthly consumptive use). Groundwater contribution in meeting crop water requirement was not considered.

1.6. Moisture Availability Index (MAI)

(Hargreaves, 1975) found a high degree of correlation between annual surface runoff and annual sums of monthly positive values of precipitation (P) minus ET_0 .

$$MAI = (75\% \text{ probability of assured precipitation}) / (ET_0) \quad (3)$$

In the Uttar Kannada district, there is abundant rainfall in monsoon season. Hence there is no as such shortage of water for paddy crops during this period. However, dry season crop cultivated between November to March requires proper irrigation. Farmers should get prior information about starting their field preparations to avoid water stress in the later stages. Analysis of rainfall and concept of MAI gives probable weekly dates of field preparations at local level depending on climate, soil conditions and availability of water (Subhash *et al.*, 2011). The ET_0 can be used to estimate monthly values of stream flow at a 75% probability for ungauged watersheds. A value of MAI exceeding 1.33 is an indication of the need for good, natural surface drainage (Hargreaves *et al.*, 1985).

2. Methodology

2.1. Rainfall analysis

It is very difficult to arrive at decisions in crop planning on the basis of monthly rainfall data since a month is a too long period. Therefore, it is ideal to analyze the rainfall data for a shorter period like a week, which

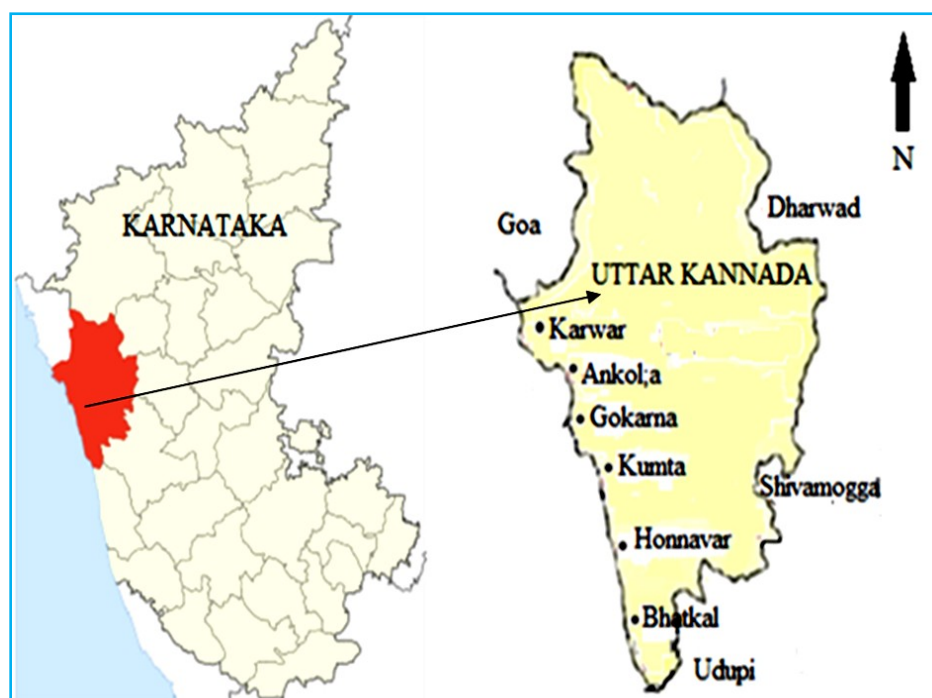


Fig. 1. Location of study area

will be extremely useful for crop management (Nayak and Nandagiri, 2010). Weekly totals of rainfall are computed for Bhatkal, Kumta, Gokarna, Karwar, Ankola and Honnavar station of the Uttara Kannada district from the daily rainfall data based on the standard meteorological weeks followed by Indian Meteorological Department (Fig. 1). The co-ordinates of all the selected stations are shown in (Table 2). Historical rainfall records for all the six stations were collected for the period of ten years from 2005 to 2015 to analyze various rainfall characteristics such as,

- (i) Mean weekly rainfall
- (ii) Coefficient of variation of weekly rainfall
- (iii) The probabilities for the weekly rainfall to exceed 1, 5, 10, 20 and 30 cm using probability analysis. (Weibull distribution was found to be the best fit for all the regions).

3. Results and discussion

3.1. Frequency distribution of mean daily ET_0

ET_0 values are highest in March and the lowest in July/August months. From year to year, the monthly values show greater variation. In areas having a distinct dry and wet season, the transition month shows significant differences from year to year depending on the arrival of rains. In selecting ET_{crop} for project planning and design,

TABLE 2

Latitude and departure for the selected stations in the study area

Area	Latitude	Longitude
Bhatkal	13° 59' 52" N	74° 32' 26" E
Kumta	14° 25' 40" N	74° 25' 08" E
Gokarna	14° 32' 52" N	74° 19' 08" E
Karwar	14° 48' 48" N	74° 07' 46" E
Ankola	14° 39' 55" N	74° 18' 00" E
Honnavar	14° 16' 47" N	74° 26' 38" E

the information should be available on level and frequency at which high demands for water can be expected, particularly in the months of peak water use (Sharna *et al.*, 2010). Table 4 shows 25%, 50% and 75% probability values of ET_0 for Bhatkal station. The values of ET_{crop} selected for the design can be based on a probability of 75 or 80% or the highest ET_{crop} value out of 4 or 5-years. 50% ET_0 values match with average ET_0 values (Table 3). The variation of ET_0 during different weeks is shown in Fig. 2. Using frequency analysis, frequency distribution curves for mean daily ET_0 for different months are developed for Bhatkal and shown in (Fig. 3). For planning and design purposes for January month, an average ET_0 of 4.55 mm/day would be considered (Table 3). The frequency distribution of mean ET_0 for Bhatkal station has been shown in Fig. 3.

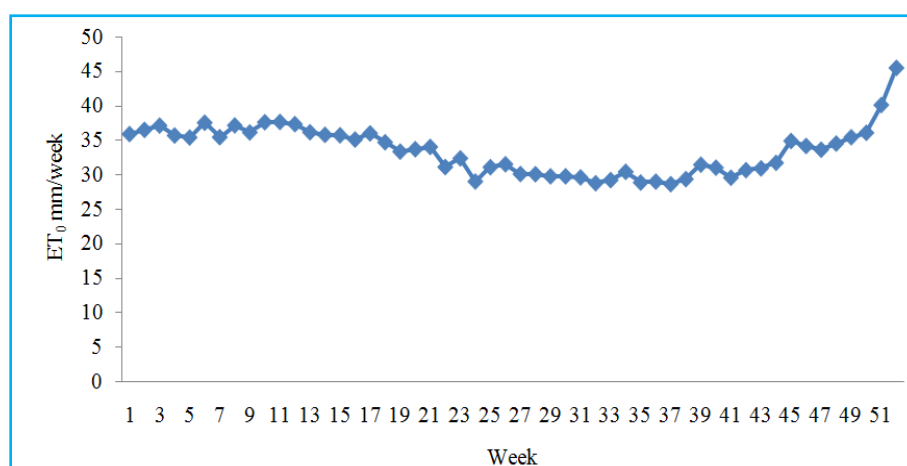


Fig. 2. Variation of ET_0 during different weeks

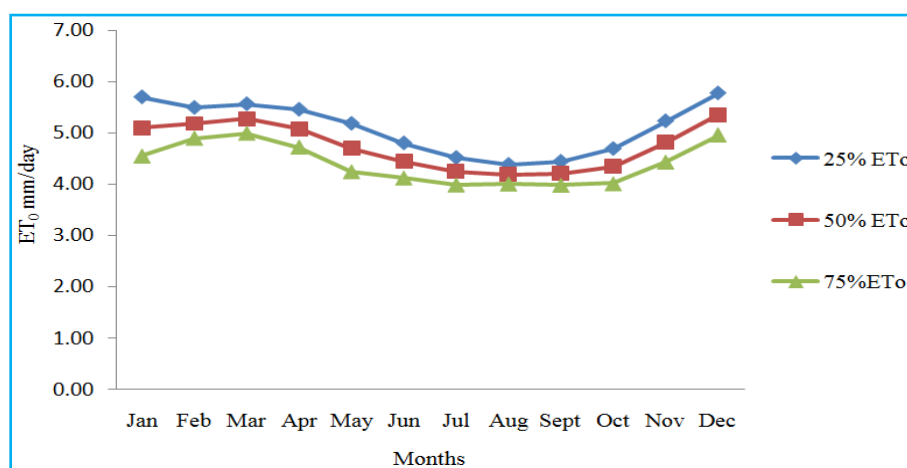


Fig. 3. Frequency Distribution of mean ET_0 for different months at Bhatkal

TABLE 3

Average ET_0 for Bhatkal

Month	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Monthly average ET_0 (mm/day)	5.15	5.20	5.29	5.10	4.73	4.47	4.26	4.20	4.22	4.36	4.85	5.38

TABLE 4

Evaluation of 25%, 50% and 75% probability values of ET_0 for Bhatkal station (mm/day)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
25% ET_0	5.7	5.5	5.57	5.46	5.19	4.80	4.52	4.39	4.44	4.69	5.23	5.78
50% ET_0	5.1	5.19	5.27	5.08	4.70	4.45	4.25	4.19	4.21	4.34	4.82	5.36
75% ET_0	4.55	4.89	4.99	4.72	4.25	4.12	3.99	4.04	3.98	4.01	4.43	4.96

TABLE 5
Distribution of weekly rainfall at Bhatkal

Week No.	Month & date	Mean rainfall (mm)	SD (mm)	CV (%)	Probability for the weekly rainfall to exceed (%)				
					10 mm	50 mm	100 mm	200 mm	300 mm
10	5-11 Mar	0	0	0	0	0	0	0	0
11	12-18 Mar	0	0	0	0	0	0	0	0
12	19-25 Mar	0	0	0	0	0	0	0	0
13	26 Mar-1 Apr	0.29	0.92	316.23	0	0	0	0	0
14	2-8 Apr	1.93	6.10	316.23	4	1	0	0	0
15	9-15 Apr	0.32	1.01	316.23	0	0	0	0	0
16	16-22 Apr	1.47	3.10	210.97	3	0	0	0	0
17	23-29 Apr	8.28	15.67	189.31	21	3	1	0	0
18	30 Apr-6 May	17.85	28.33	158.70	41	9	3	0	0
19	7-13 May	13.87	43.86	316.23	15	5	3	1	1
20	14-20 May	2.67	7.03	263.47	6	1	0	0	0
21	21-27 May	10.35	13.91	134.41	32	3	0	0	0
22	28 May-3 Jun	130.07	236.74	182.01	69	43	30	17	12
23	4-10 Jun	142.83	126.67	88.68	96	75	53	25	11
24	11-17 Jun	245.45	158.46	64.56	100	94	82	55	31
25	18-24 Jun	233.15	249.91	107.19	95	78	62	41	27
26	25 Jun-1 Jul	212.41	144.08	67.83	99	91	76	46	24
27	2-8 Jul	262.91	209.60	79.72	99	90	77	53	34
28	9-15 Jul	269.22	151.47	56.26	100	97	88	63	38
29	16-22 Jul	278.19	211.11	75.89	99	92	80	57	37
30	23-29 Jul	258.21	243.43	94.27	97	84	70	48	32
31	30 Jul-5 Aug	208.47	163.01	78.19	98	87	71	43	24
32	6-12 Aug	171.83	150.36	87.50	97	80	60	33	17
33	13-19 Aug	140.87	95.94	68.11	98	84	60	23	7
34	20-26 Aug	115.34	80.96	70.19	98	78	50	14	3
35	27 Aug-2 Sep	192.89	184.07	95.43	96	79	61	36	21
36	3-9 Sep	161.70	131.60	81.38	97	81	61	30	14
37	10-16 Sep	133.74	113.97	85.22	96	75	52	22	9
38	17-23 Sep	93.93	63.72	67.84	97	72	39	7	1
39	24-30 Sep	81.28	122.91	151.22	72	40	24	11	6
40	1-7 Oct	80.81	102.82	127.23	80	46	26	10	4
41	8-14 Oct	29.81	31.37	105.24	69	19	4	0	0
42	15-21 Oct	22.91	31.55	137.69	52	13	4	0	0
43	22-28 Oct	19.45	37.04	190.45	36	10	4	1	0
44	29 Oct-4 Nov	24.29	26.04	107.21	63	13	2	0	0
45	5-11 Nov	20.20	33.22	164.48	42	11	4	1	0
46	12-18 Nov	5.91	13.96	236.24	13	2	1	0	0
47	19-24 Nov	2.46	4.47	181.63	5	0	0	0	0
48	25 Nov-2 Dec	0.02	0.06	316.23	0	0	0	0	0
49	3-9 Dec	2.60	5.43	208.81	6.05	0.31	0.04	0	0
50	10-16 Dec	1.77	5.60	316.23	3	0	0	0	0
51	17-23 Dec	2.35	7.43	316.23	4.29	0.68	0.23	0.06	0.02
52	24-31 Dec	0.75	2.37	316.23	1.27	0.10	0.02	0	0

TABLE 6

Frequency of wet spells occurrence of different lengths at Bhatkal station

Month	Frequency of occurrence of wet spell (>2.5 mm/day)					Avg. length of wet spell days	Avg. no. of wet days	Prob. of occ. of wet days (%)
	1-2 days	2-5 days	6-10 days	11-20 days	21-31 days			
March	1	-	-	-	-	0.11	0.11	0
April	9	-	-	-	-	0.472	1.222	4
May	17	4	-	-	-	1.322	3.778	12
June	17	3	10	5	1	5.81	21.44	71
July	1	3	9	2	5	12.77	29.11	94
August	5	8	10	6	1	7.48	25.77	83
September	8	3	7	3	2	9.918	19.66	66
October	14	6	1	1	-	3	7.33	24
November	19	4	1	-	-	1.436	4.44	15
December	3	-	-	-	-	0.22	0.44	1

TABLE 7

Frequency of wet spells occurrence of different lengths at Kumta station

Month	Frequency of occurrence of wet spell (>2.5 mm/day)					Avg. length of wet spell days	Avg. no. of wet days	Prob. of occ. of wet days (%)
	1-2 days	2-5 days	6-10 days	11-20 days	21-31 days			
March	6	1	-	-	-	0.425	0.9	3
April	17	-	-	-	-	0.825	1.2	6
May	23	1	-	-	-	1.103	2.7	11
June	13	7	4	5	1	6.144	21.8	72
July	1	7	5	3	7	12.449	29.11	94
August	12	6	6	17	1	7.984	23.6	81
September	19	4	6	3	-	4.905	17.2	60
October	18	4	4	-	-	2.82	7.1	22
November	14	3	-	-	-	1.766	1.7	9
December	2	-	-	-	-	0.2	0.2	1

ET₀ values are lower between 24th to 41st weeks. Hence, irrigation requirements will also be lower during this period. Weekly ET₀ values are also used in subsequent parts for the computation of MAI (Moisture Availability Index).

3.2. Analysis of rainfall data

Analysis of average weekly rainfall data for all six stations has been carried out by collecting rainfall data from the period of 2005 to 2015. The typical distribution of weekly rainfall at Bhatkal station has been depicted in Table 5. A similar kind of analysis has been carried out for the other stations of the study region.

Predominant rainfall was observed in Bhatkal from 18th to 45th weeks. The coefficients of variation and standard deviation in these weeks were 158% to 164 %, and 28.3 mm to 33.22 mm respectively. The active rainy

season starts from 22nd week (Bhatkal) and the probability for the weekly rainfall to exceed 50mm is more than 40%. Rainfall is highest during 2nd to 37th week. The rainfall is dependable (>25mm) up to 41st week. From here onwards, rainfall decreases considerably and is not dependable. The major paddy crop requires about 1000 mm of water for soaking, filling and percolation (Hargreaves, 1993). The analyses of rainfall data indicate that; this initial filling is met in Bhatkal in the 26th week. This period was slightly varying in other stations *i.e.*, it was occurring in 22nd week at Kumta, 22nd week at Gokarna, 23rd week at Karwar, 22nd week at Ankola and 23rd week at Honnavar station.

3.3. Wet spells

As suggested by IMD, a wet day is a day with rainfall not less than 2.5 mm and a wet spell is the

TABLE 8

Frequency of wet spells occurrence of different lengths at Gokarna

Month	Frequency of occurrence of wet spell (>2.5 mm/day)					Avg. length of wet spell days	Avg. no. of wet days	Prob. of occ. of wet days (%)
	1-2 days	2-5 days	6-10 days	11-20 days	21-31 days			
March	4	1	1	-	-	0.65	0.9	3
April	8	-	-	-	-	0.533	1.2	4
May	18	2	-	-	-	1.23	2.7	9
June	25	9	3	5	1	5.11	21.8	73
July	11	9	7	3	2	8.134	26.1	84
August	16	10	9	4	-	7.481	23.6	76
September	17	5	4	5	2	5.88	17.2	57
October	26	5	1	-	-	2.34	7.1	23
November	8	1	-	-	-	0.95	1.7	6
December	2	-	-	-	-	0.2	0.2	1

TABLE 9

Frequency of wet spells occurrence of different lengths at Karwar station

Month	Frequency of occurrence of wet spell (>2.5 mm/day)					Avg. length of wet spell days	Avg. no. of wet days	Prob. of occ. of wet days (%)
	1-2 days	2-5 days	6-10 days	11-20 days	21-31 days			
March	1	-	-	-	-	0.11	0.222	0
April	11	-	-	-	-	0.592	1.333	4
May	11	1	1	-	-	1.944	3.222	10
June	18	2	3	5	2	8.194	22.22	74
July	7	4	2	5	5	13.889	28.667	93
August	14	8	7	6	1	6.002	24.889	80
September	27	8	8	3	-	4.407	18.667	62
October	21	6	3	-	-	2.842	7.667	25
November	10	4	-	-	-	1.241	2.667	9
December	2	-	-	-	-	0.222	0.333	1

sequence of wet days preceded and followed by dry days. The frequency of occurrence of wet spells of different lengths during the months from March to December is computed based on 2005 to 2015 data for all the six selected stations. The frequency of occurrence of wet spells of at least 1-2, 3-5, 6-10, 11-20- and 21-31-days duration for all the six stations are given in (Tables 6-11). The average length of a wet spell and the probability of getting wet days in percent are also given as additional information.

From (Table 13), it is seen that the average length of the wet spell is maximum at Ankola (15.203 days) and minimum at Gokarna (8.31 days) during the month of July. The average number of wet days is highest at Bhatkal and Kumta (29.11 days) and is lowest at Ankola (25.44 days) during July shown in (Table 12). The results also show that the probability of getting wet days is above

70% from June to August and below 15% during November to May. The probability of occurrence of wet days is maximum during the month of July and found to be, 92%, 82% and 89% respectively in Karwar, Ankola and Honnavar stations and 94%, 94% and 84% respectively in Bhatkal, Kumta and Gokarna stations (Table 14). It is the lowest during the month of January to March. Farmers in this region face a shortage of water if harvesting is advanced beyond the middle of March (Figs. 4-6).

3.4. Dry weather periods

Dry weather periods occur during the rainy season as a result of a break or temporary withdrawal of the monsoon. Crops are likely to experience moisture stress during the dry weather periods, if adequate moisture is not available in the soil (Majumdar, 2002). Any week receiving a rainfall less than 10 mm

TABLE 10
Frequency of wet spells occurrence of different lengths at Ankola station

Month	Frequency of occurrence of wet spell (>2.5 mm/day)					Avg. length of wet spell days	Avg. no. of wet days	Prob. of occ. of wet days (%)
	1-2 days	2-5 days	6-10 days	11-20 days	21-31 days			
March	3	-	-	-	-	0.333	0.333	1
April	9	-	-	-	-	0.722	1.111	4
May	14	2	-	-	-	0.934	2.778	9
June	15	9	6	5	1	5.10	21.44	72
July	7	1	6	2	6	15.203	25.44	82
August	10	6	4	8	3	9.150	26.556	86
September	20	5	5	6	-	6.389	19.44	65
October	23	7	3	-	-	1.592	8.22	27
November	10	3	1	-	-	1.517	3.111	10
December	1	-	-	-	-	0.11	0	0

TABLE 11
Frequency of wet spells occurrence of different lengths at Honnavar

Month	Frequency of occurrence of wet spell (>2.5 mm/day)					Avg. length of wet spell days	Avg. no. of wet days	Prob. of occ. of wet days (%)
	1-2 days	2-5 days	6-10 days	11-20 days	21-31 days			
March	2	-	-	-	-	0.222	0.333	1
April	10	-	-	-	-	0.7963	1.667	6
May	15	2	1	-	-	1.50	3.667	12
June	20	7	11	2	1	4.069	20.44	68
July	3	5	6	4	5	13.229	27.67	89
August	11	3	4	6	4	13.573	26.89	87
September	17	12	5	5	-	3.910	18.67	62
October	24	7	2	-	-	3.054	8.44	27
November	19	2	-	-	-	1.229	3.22	11
December	4	-	-	-	-	0.444	0.44	2

TABLE 12
Average number of wet spell days at different stations

S. No.	Months	Bhatkal	Kumta	Gokarna	Karwar	Ankola	Honnavar
1.	March	0.11	0.425	0.65	0.11	0.333	0.222
2.	April	0.4722	0.825	0.533	0.592	0.722	0.796
3.	May	1.322	1.103	1.23	1.944	0.934	1.50
4.	June	5.81	6.144	5.11	8.194	5.10	4.069
5.	July	12.77	12.449	8.134	13.889	15.203	13.229
6.	August	7.48	7.984	7.481	6.002	9.150	13.573
7.	September	9.918	4.905	5.88	4.407	6.389	3.910
8.	October	3	2.82	2.34	2.842	1.592	3.054
9.	November	1.436	1.766	0.95	1.241	1.517	1.229
10.	December	0.22	0.2	0.2	0.222	0.11	0.444

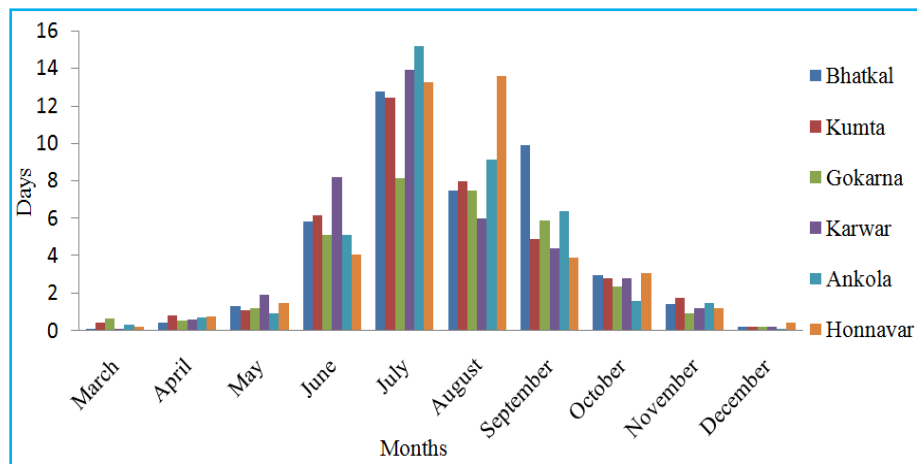


Fig. 4. Variation of average length of wet spell (days) at different stations

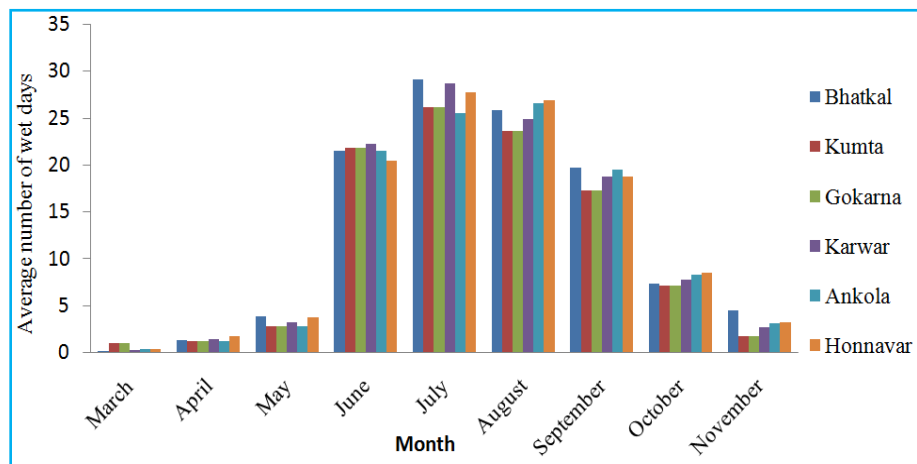


Fig. 5. Variation of average no. of wet days at different stations

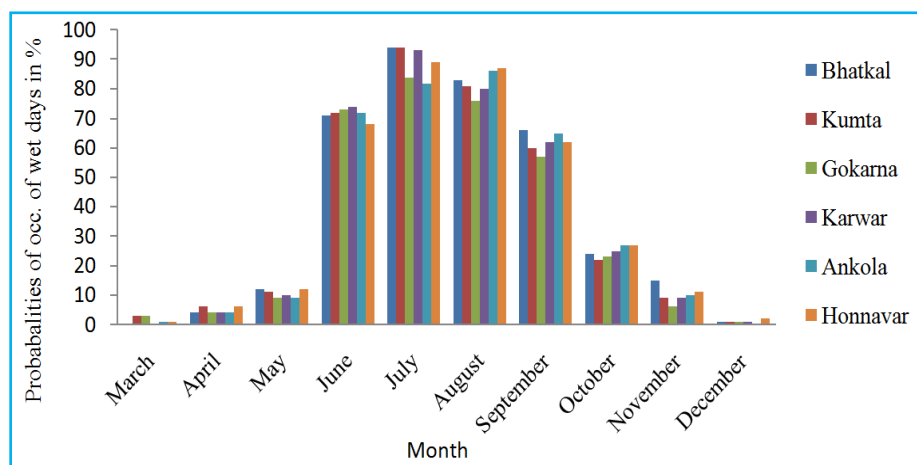


Fig. 6. Variation of Prob. of occurrence of wet days (%) at different stations

is considered as a dry week (Tammets, 2010). The probabilities of occurrence of 1, 2, 3 and 4 consecutive dry weeks from 10th week (5th March) to 52nd week (31st December) have been worked out from weekly rainfall

data. Table 14, shows the probabilities of the occurrence of dry weeks at Bhatkal station during the period (2005-2015). A similar kind of analysis has been carried out for all other study stations.

TABLE 13

Average length of wet days at different stations

S. No.	Months	Bhatkal	Kumta	Gokarna	Karwar	Ankola	Honnavar
1.	March	0.11	0.9	0.9	0.222	0.333	0.333
2.	April	1.222	1.2	1.2	1.333	1.111	1.667
3.	May	3.778	2.7	2.7	3.222	2.778	3.667
4.	June	21.44	21.8	21.8	22.22	21.44	20.44
5.	July	29.11	26.1	26.1	28.667	25.44	27.67
6.	August	25.77	23.6	23.6	24.889	26.556	26.89
7.	September	19.66	17.2	17.2	18.667	19.44	18.67
8.	October	7.33	7.1	7.1	7.667	8.22	8.44
9.	November	4.44	1.7	1.7	2.667	3.111	3.22
10.	December	0.44	0.2	0.2	0.333	0	0.44

TABLE 14

Probability of occurrence of wet days in % at different stations

S. No.	Months	Bhatkal	Kumta	Gokarna	Karwar	Ankola	Honnavar
1.	March	0	3	3	0	1	1
2.	April	4	6	4	4	4	6
3.	May	12	11	9	10	9	12
4.	June	71	72	73	74	72	68
5.	July	94	94	84	93	82	89
6.	August	83	81	76	80	86	87
7.	September	66	60	57	62	65	62
8.	October	24	22	23	25	27	27
9.	November	15	9	6	9	10	11
10.	December	1	1	1	1	0	2

In Bhatkal and Karwar station probability of getting 2 to 3 consecutive dry weeks is greater than 50% from the 48th week. Hence irrigation may be needed from the 48th week onwards (2 December) for the crops of this region. Similarly, for the other stations (Kumta, Gokarna, Ankola and Honnavar) irrigation may be required from 47th, 46th, 46th and 47th week onwards respectively. The irrigation has to be continued up to 19th to 22nd week depending upon the rainfall. However, it was observed that farmers face shortage of water for the ripening stage at the end of March in most of the areas in study regions which necessitates to start early sowing in November.

3.5. Effective precipitation

Even though coastal Uttar Kannada district receives heavy rainfall of about 3500 mm annually, this is confined to four rainy months (June-September). Temporal variability and spatial heterogeneity make a situation of variation in the amount of water provided which definitely

affects the critical crop growth stages in the later stage. These variations make the empirical estimation of effective precipitation very incorrect (Hargreaves, 1993). For purposes of calculating water requirements and agricultural benefits, a 50% probability was used after checking the ranking using gamma distributions (Hargreaves *et al.*, 1985). Table 16, compares mean, actual (the 50% probability) and dependable (the 75% probability of assured rainfall) for the June-October rainy season at Bhatkal station for the recent 10-year record (2005-2015). 75% probable rainfall values are less than mean rainfall and can be used for computations. Moreover, the USBR method gives 362 mm effective precipitation for 9 months (September-May) whereas the ratio method and USDA method yields 561 mm and 311 mm respectively (excluding percolation loss in case of rice crop). For purposes of calculating water requirements, 311 mm (USDA, SCS) is used since this method gives more accurate values of effective precipitation and also recommended for soils of high infiltration (Dastane, 1975).

TABLE 15
Probability of dry week at Bhatkal

Ending week	Probability of occurrence of dry weeks consecutively for (%)				
	Month & Date	1 week	2 weeks	3 weeks	4 weeks
10	5-11 Mar	100	100	100	100
11	12-18 Mar	100	100	100	100
12	19-25 Mar	100	100	100	100
13	26 Mar-1 Apr	100	100	100	100
14	2-8 Apr	89	89	89	89
15	9-15 Apr	100	89	89	89
16	16-22 Apr	100	100	89	89
17	23-29 Apr	67	67	67	67
18	30 Apr-6 May	56	33	33	33
19	7-13 May	89	56	33	33
20	14-20 May	89	78	44	33
21	21-27 May	56	56	44	33
22	28 May-3 Jun	33	33	33	22
23	4-10 Jun	0	0	0	0
24	11-17 Jun	0	0	0	0
25	18-24 Jun	0	0	0	0
26	25 Jun – 1 Jul	0	0	0	0
27	2-8 Jul	0	0	0	0
28	9-15 Jul	0	0	0	0
29	16-22 Jul	0	0	0	0
30	23-29 Jul	0	0	0	0
31	30 Jul - 5 Aug	11	0	0	0
32	6-12 Aug	11	11	0	0
33	13-19 Aug	11	11	11	0
34	20-26 Aug	11	11	11	11
35	27 Aug - 2 Sep	78	11	11	11
36	3-9 Sep	11	11	11	11
37	10-16 Sep	22	11	11	11
38	17-23 Sep	11	11	11	11
39	24-30 Sep	56	11	11	11
40	1-7 Oct	56	44	11	11
41	8-14 Oct	44	22	11	11
42	15-21 Oct	56	44	22	11
43	22-28 Oct	56	44	33	22
44	29 Oct - 4 Nov	56	56	44	33
45	5-11 Nov	56	33	33	22
46	12-18 Nov	78	56	33	22
47	19-24 Nov	89	67	44	33
48	25 Nov – 2 Dec	100	89	78	56
49	3-9 Dec	78	67	67	44
50	10-16 Dec	89	67	67	67
51	17-23 Dec	89	89	67	56
52	24-31 Dec	100	89	89	67

TABLE 16

Mean actual, dependable and effective precipitation (mm) in Bhatkal taluk

Month	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Mean	383	207	12.3	10	1.54	0	0	0	710
Actual 50% prob.	350	189	-	-	-	-	-	-	66
Dependable 75% prob.	245	105	-	-	-	-	-	-	5
Eff. Precipitation (USDA, SCS)	82	114	-	-	-	-	-	-	115

TABLE 17

Crop water requirements for rice crops (mm/month) at Bhatkal

Variables	Upland (pluvial/wet)	Medium (phreatic/dry)
Monthly ET_0	-	-
November	-	-
December	-	153
January	-	140
February	-	137
March	-	154
April	-	-
May	131	-
June	127	-
July	123	-
August	124	-
September	119	-
October	124	-
Seasonal ET_0	748	584
Seasonal Kc	1.15	1.2
ETcrop	860	700
P_e	392 #	0
I	1468*	1700*

Based on USDA, SCS method and exclusive of percolation loss for the rice crop, percolation loss of about 3mm/day ($183 \times 3 = 549$ mm)

*Includes 1000mm of water for soaking, filling and percolation losses

3.6. Total irrigation requirements

The crop water requirements for rice crop (mm/month) in the rice-cropping pattern for Bhatkal station is shown in Table 17. In the coastal region, rainwater is abundant in three months (June-August) and makes a contribution to upland irrigation (pluvial system) only. Farmers are having small landholdings (less than 1 ha of an area) for cultivation. Total irrigation water requirement for dry season crop is found to be 1700 mm and for the wet season, it is less. There is a significant contribution of rainfall to the crop water supply in the wet period.

Fig. 7 depicts the variation of 75% probable assured precipitation at different stations of the study area from 17th to 44th week leaving zero rainfall in other weeks. Higher values of precipitation were observed from 23rd to 40th week. These values were significant up to 44th week indicating that irrigation is not required up to this period. It also highlights a unimodal trend in the rainfall pattern at all the observed stations. Net ($ET_0 - P_{75}$) gives an indication of the required depth of irrigation necessary to achieve optimum production. For June, July and August months $P_{75} > ET_0$, signifying potential surface runoff. But in other months $ET_0 > P_{75}$, indicating water was required for full production in these months.

TABLE 18
MAI values for all six regions on weekly basis

Week No	Bhatkal	Kumta	Gokarna	Karwar	Ankola	Honnavar
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0.36	0.0021	0
11	0	0	0	0	0	0
12	0	0	0	0	0.00013	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0.0006	0.02
16	0.001	0	0.001	0	0.0320	0.02
17	0.009	0	0.013	0.01	0.0775	0.02
18	0.044	0	0.016	0.01	0.0025	0.01
19	0	0	0	0	0.0076	0.01
20	0	0	0.004	0	0.0036	0.13
21	0.045	0	0.019	0	0.0304	0.23
22	0.208	0.240	0.030	0.05	0.0840	2.02
23	1.558	1.613	0.257	0.49	1.7279	6.72
24	4.393	5.514	2.273	2.51	4.9936	4.18
25	1.901	4.510	4.972	4.75	4.6112	4.46
26	3.321	3.742	4.862	4.99	4.5632	3.88
27	3.574	3.973	4.046	2.58	4.2595	4.27
28	5.201	3.176	2.959	3.55	3.9917	3.86
29	4.072	4.374	3.120	3.02	4.0022	4.90
30	2.775	4.955	4.102	3.52	5.7818	4.25
31	2.953	3.665	4.588	4.50	3.7052	5.04
32	2.149	4.845	3.464	3.11	3.5069	4.38
33	2.365	2.913	4.270	3.34	2.7349	2.15
34	1.802	1.995	2.595	2.55	1.2390	2.48
35	2.091	1.958	2.154	1.80	1.6222	2.47
36	2.221	1.668	2.152	2.00	0.2136	2.25
37	1.747	2.461	1.746	1.46	1.6292	1.07
38	1.575	1.578	2.553	1.03	1.7048	0.26
39	0.262	0.371	1.052	0.51	0.3513	0.99
40	0.442	1.145	0.360	0.42	0.8394	0.06
41	0.268	0.177	1.505	0.06	0.1401	0.09
42	0.102	0.057	0.205	0.01	0.1158	0.16
43	0.025	0.148	0.017	0.05	0.0797	0.15
44	0.194	0.139	0.170	0.04	0.0601	0.05
45	0.043	0	0.015	0.01	0.0257	0.01
46	0.002	0	0.001	0.01	0.0031	0
47	0.004	0	0.001	0	0	0
48	0	0	0	0	0	0
49	0	0	0	0	0	0
50	0	0	0	0	0	0
51	0	0	0	0	0	0
52	0	0	0	0	0	0

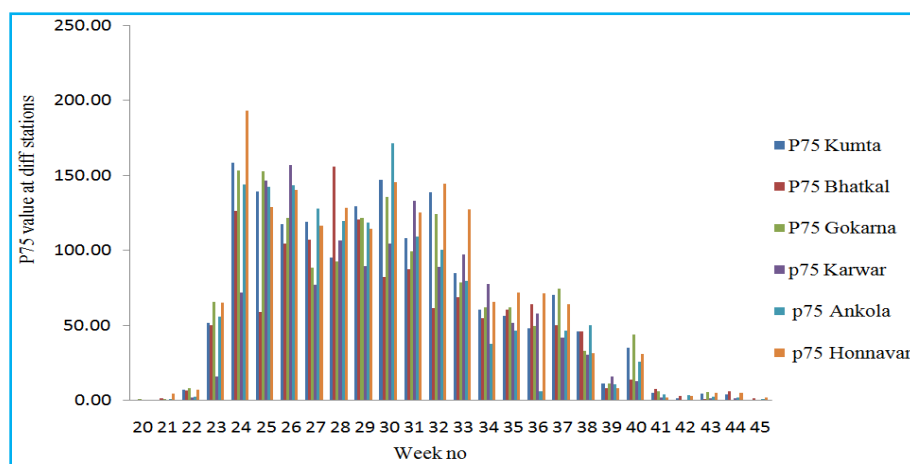


Fig. 7. Variation of 75% probability assured precipitation at all six station (20th - 45th week)

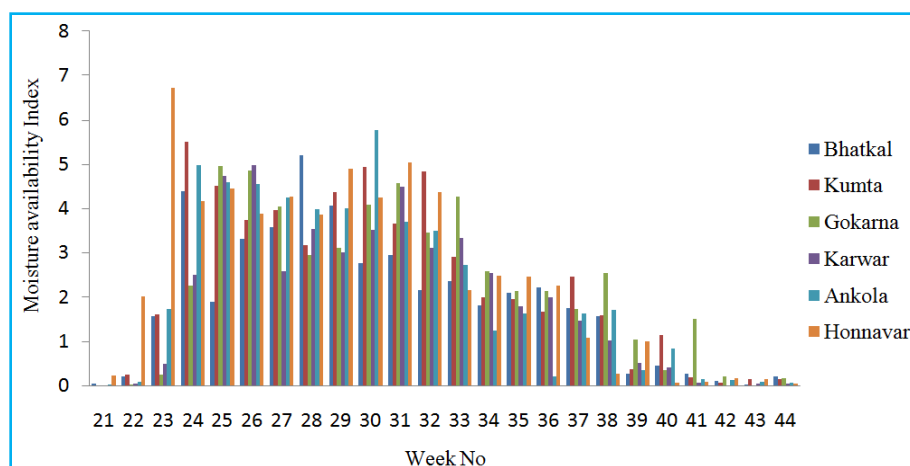


Fig. 8. MAI values versus weeks at all six stations (21st - 43rd week)

3.7. Moisture Availability Index (MAI) and Application in paddy Irrigation

Table 18 shows MAI values for all the six regions of the study area computed using Eqn. 3 on a weekly basis (Fig. 8). The highest value of MAI (Max 5.210 and Min 3.176) at all the stations was in the 28th week (9-15 July). MAI value of 0.33 is considered as the threshold value to demarcate dry and moderate wet periods (Hargreaves *et al.*, 1985). This index was significant up to 40th week (except at Honnavar station)

4. Conclusions

The Agrometeorological regime of an area is governed by rainfall characteristics and potential evapotranspiration, which further influences the magnitude and frequency of irrigation application. Analysis of rainfall shows that higher values of

precipitation were observed from 22nd to 40th weeks at all the stations of the study regions. These values were significant up to 43rd week indicating that irrigation is not required during this period. For June, July and August months $P75 > ET_0$, signifying potential surface runoff. However, during the remaining months $ET_0 > P75$, indicating the necessity of additional water for full production in these months.

MAI (Moisture availability Index) values in stations under consideration are more than 1.33 from 23rd to 38th week indicating there is no shortage of water for agricultural activities during this period. Moreover, the shortage of water for the ripening stage in the second half of March in most of the areas in coastal regions faced by the farmers was noted. These necessities to start early sowing for paddy in the month of November. Advancing the sowing date by two to three weeks is found to be necessary, which will help the farmer to save irrigation

water in the ripening stage. This preserved water can be utilized for other needs to avoid water stress in critical dry periods in April and May.

The present study also indicates that the probability of getting two to three consecutive dry weeks is greater than 50% from 47th week onwards at all the selected stations. Hence irrigation is found to be very essential from 47th week onwards (24 November) for the paddy crops of this region. Continuing Irrigation from 19th to 22nd week depending upon the beginning of monsoon rainfall is also need of the hour.

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