Journal of Agrometeorology 23 (4) : 409-415 (December 2021) : https://doi.org/10.54386/jam.v23i4.145

Analysis of rainfall characteristics and moisture availability index for crop planning in semi arid region of north Gujarat

JAYDIP J. MAKWANA*, B. S. DEORA, C. K. PATEL, B. S. PARMAR and A. K. SAINI

Centre for Natural Resources Management, S. D. Agricultural University, Sardarkrushinagar, Gujarat, India

*Corresponding author email : *makwanajaydip@gmail.com*

ABSTRACT

The rainfall, one of the most important natural input resource for dryland agricultural production system, is erratic and temporal in nature. An attempt has been made to analyze thirty years (1990-2019) of meteorological data for prediction of probable week of onset and withdrawal of monsoon and to end with crop planning in North Gujarat region (India).The highest and lowest amount of weekly rainfall was observed in 27th and 39th SMW, respectively. The probability distribution functions viz. generalized extreme value, Gumbel maximum, Gamma and Weibull were found best-fit for prediction of weekly rainfall. The analysis revealed 26th SMW (25 Jun – 01 Jul) and onwards as the most suited sowing time of *kharif* crops. There are also chances of occurrence of moisture stress during 34th and 35th SMW. The results would be useful for agricultural scientists, researchers, decision makers and policy planners in the field of agricultural crop planning and irrigation management for semi arid regions.

Key words: Rainfall, probability analysis, evapotranspiration, moisture availability index, crop planning, north Gujarat

Agriculture is the backbone of India as it feeds ever growing population and provides employment to about 58 per cent of the population. A majority of the farmers are small holders and depend on rainfed rather than irrigated agriculture. Dryland farming is a special case of rainfed agriculture practiced in arid and semiarid regions in which annual precipitation is about 20–35 per cent of potential evapotranspiration. In spite of development of several advanced techniques, the crop productivity particularly from dryland agriculture is always uncertain and largely depends on the rainfall amount, its distribution and moisture availability during the season.

Rainfall probability distributions are widely used to understand the rainfall pattern of an area for proper crop planning under changing environment. Probability analysis of rainfall data enables us to determine the expected rainfall at various chances (Deora and Singh, 2008; Deora and Singh, 2009). The selection of the best fitted distribution has always been a key interest in the study of rainfall amount. Different probability distributions (normal, lognormal, gamma, Weibull, logistic, log-logistic, smallest and largest extreme value) have been widely used for rainfall analysis (Kumar *et al.,* 2017; Rajeshkumar *et al.,* 2018). Different probability distributions have mixed results at different locations and times (Lairenjam *et al.,* 2016). Sharda and Das (2005) compared several types of distributions to fit weekly rainfall amount in Doon valley, India. Alam *et al*. (2015) has done weekly rainfall analysis using different two and three parameter statistical distributions for *kharif* crop planning in Shivalik regions of India. Jana *et al.* (2015) analysed and studied the annual extreme rainfall characteristics using probability model and predicted the changes of extreme rainfall behaviour in future climate for Doonvaley. Kumar *et al.* (2017) analyzed the statistical distribution of rainfall in Uttarakhand, India, and found that the Weibull distribution performed the best. Mandal *et al.* (2015) found that the rainfall analysis would be utilized for agricultural planning in rainfed area and mitigation of dry spells at the Daspalla region in Odisha, India. Alam *et al.* (2016) analyzed weekly rainfall data using different probability function and found that the sowing of *kharif* crops has to be done during the 27th SMW for maximum utilization of rain water.

The another factor for very low and highly unstable yields in a particular region is the soil moisture stress during active growth period of the crops. The most important aspect is proper distribution of rainfall, in order to meet the combined demand of transpiration from plants and evaporation from soils. The crop production in dryland areas is very closely related to moisture availability and soil characteristics. The Moisture Availability Index (MAI) is highly uncertain since the rainfall distribution is highly erratic and uncertain both in time and space. MAI is the ratio of assured rainfall expected and potential evapotranspiration for the concerned period (Hargreaves, 1971). The Food and Agriculture Organization have recommended Penman-Monteith (FAO-56 PM) method for estimation of ET_0 (Allen *et al.,* 1998). The FAO-56 PM equation has been widely used as a benchmark method to calibrate, validate and evaluate other methods as per availability of climatic data for estimating ET_0 (Gocic *et al.,* 2015; Trajkovic *et al.,* 2020).MAI is prime factor for crop planning (cropping system, cropping pattern, *etc*.) especially in dryland agriculture. However, in such systems the monthly MAI values were not truly representative as month is a longer period for planning and cultural operation. Moreover, if there are dry spells causing crop failure, the monthly MAI may not represent the scenario. Hence, there is a need to use weekly MAI for agricultural planning.

North Gujarat is one such area where drought used to cause adversity to the agriculture and needs proper crop planning. Farming system of crops and livestock are the main occupations of the region. The region dependent on scanty and uncertain distribution of the rainfall is characterized by hard rock area with limited or inadequate ground water resources. The important aspect include onset of monsoon, distribution of monsoon length of growing period, starting and ending of rainfall periods *etc*. for proper planning and enhancing productivity. To fulfill the above mentioned aspect, studied weekly rainfall characterization and moisture availability index to suggest crops and cropping systems for North Gujarat region.

MATERIALS AND METHODS

Study area and data used

Sardarkrushinagar (Dantiwada), located in semi-arid region of North Gujarat, India, is selected for crop planning based on rainfall characteristics and moisture availability index. The study area is located at 24.32° N latitude, 72.32° E longitude with 172 m above mean sea level altitude. Daily meteorological data (maximum and minimum temperature, relative humidity, wind speed, bright sunshine hours, rainfall) for thirty years (1990-2019) were collected from Department of Agro-meteorology, CPCA, SDAU, Sardarkrushinagar, Gujrat. The daily data collected were summed up on meteorological week, year was partitioned as per meteorological calendar, starting from 1st January of each year and ending on 31st December of the same year.

Probability analysis

A large number of probability distribution methods have been applied in different regions and found to be useful for estimation of rainfall distribution. The best-fit probability distribution in the present case was evaluated using the following procedure.

Step I*:* Fitting the probability distribution: The probability distributions, viz. Normal, Lognormal, Gamma, Generalized Gamma, Weibull, Logistic, Log-logistic, Generalized extreme value, Exponential, Gumbel Maximum, Laplace, log-Pearson 3, Pearson 5, Prearson 6, were applied to find out the best-fit probability distribution. The description of various probability distribution functions regarding probability density function and range are shown in Tables 1.

Step II*:* Testing the goodness of fit: The goodness of fit tests, Chi-square test was used at 5% significance level for the selection of the best-fit distribution. The best-fitted distribution was selected based on the minimum error produced. Using O_i to "observed count" and E_i to "expected count", the Chi-square test statistic is calculated by:

$$\chi^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i}$$

Moisture availability index

Moisture Availability Index (MAI) is a measure of the adequacy of precipitation in supplying crop water need (Hargreaves, 1971). Hargreaves defined MAI as the ratio of the assured rainfall expected with probability to the estimated reference evapotranspiration for the concerned period. For calculating MAI, the probable rainfall was taken from best fitted distribution based on Chi-square test value. The FAO-56 Penman-Monteith (PM) standard method was used for estimation of ET_0, which is recommended by the Food and Agricultural Organization (FAO) (Allen *et al.,* 1998). The PM FAO-56 model equation is as follow:

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

Where, ET_0 is reference evapotranspiration (mm day^{-1}), R_n is net radiation at the crop surface (MJ m^{-2} day^{-1}), G is soil heat flux density (MJ m^{-2} day^{-1}), T is mean daily air temperature at 2 m height (°C), u_2 is wind speed at 2 m

Table 1: Probability density functions of different distributions used to fit the rainfall data

Distribution	Probability density function	Range
Normal	$f(x)=\dfrac{\exp\left(-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right)}{\sigma\sqrt{2\pi}}$	$-\infty < x < +\infty$
Lognormal	$f(x)=\dfrac{\exp\left(-\frac{1}{2}\left(\frac{\ln x-\mu}{\sigma}\right)^2\right)}{x\sigma\sqrt{2\pi}}$	$\gamma < x < +\infty$
Gamma	$f(x)=\dfrac{x^{\alpha-1}}{\beta^{\alpha}\Gamma(\alpha)}\exp(-x/\beta)$	$\gamma \le x < +\infty$
Weibull	$f(x)=\dfrac{\alpha}{\beta}\left(\dfrac{x}{\beta}\right)^{\alpha-1}\exp\left(-\left(\dfrac{x}{\beta}\right)^{\alpha}\right)$	$\gamma \le x < +\infty$
Logistic	$f(x)=\dfrac{\exp(-z)}{\sigma(1+\exp(-z))^2}$	$-\infty < x < +\infty$
log-logistic	$f(x)=\dfrac{\alpha}{\beta}\left(\dfrac{x}{\beta}\right)^{\alpha-1}\left(1+\left(\dfrac{x}{\beta}\right)^{\alpha}\right)^{-2}$	$\gamma \le x < +\infty$
Generalized extreme value	$f(x)=\begin{cases}\frac{1}{\sigma}\exp\left(-(1+kz)^{-1/k}\right)(1+kz)^{-1-1/k} & k\neq 0\\ \frac{1}{\sigma}\exp(-z-\exp(-z)) & k=0\end{cases}$	$1+k\dfrac{(x-\mu)}{\sigma}>0 \quad for \quad k\neq 0$ $-\infty < x < +\infty \quad for \quad k=0$
Exponential	$f(x)=\lambda\exp(-\lambda x)$	$\gamma \le x < +\infty$
Gen. Gamma	$f(x)=\dfrac{kx^{k\alpha-1}}{\beta^{k\alpha}\Gamma(\alpha)}\exp\left(-(x/\beta)^k\right)$	$\gamma \le x < +\infty$
Gumbel Max	$f(x)=\dfrac{1}{\sigma}\exp(-z-\exp(-z))$	$-\infty < x < +\infty$
Laplace	$f(x)=\dfrac{\lambda}{2}\exp\left(-\lambda\lvert x-\mu\rvert\right)$	$-\infty < x < +\infty$
Pearson 5	$f(x)=\dfrac{\exp\left(-\beta/x\right)}{\beta\Gamma(\alpha)\,(x/\beta)^{\alpha+1}}$	$\gamma < x < +\infty$
Pearson 6	$f(x)=\dfrac{\left(x/\beta\right)^{\alpha_1-1}}{\beta B(\alpha_1,\alpha_2)\,(1+x/\beta)^{\alpha_1+\alpha_2}}$	$\gamma \le x < +\infty$

Where, σ = Continuous scale parameter, μ = Continuous location parameter, α = Continuous shape parameter, β = Continuous scale parameter, k = Continuous shape parameter, λ = continuous inverse scale parameter, α_1 = Continuous shape parameter, α_2 = Continuous shape parameter.

Table 2: Week wise first ranked probability distribution using Chi-Squared

Dates	SMW	Distribution	Parameters	Chi-Squared value	Rainfall (mm) at 50% Probability level
28 May – 03 Jun	22	Gen. Extreme Value	k=0.91368 σ=0.29537 μ=0.05271	19.194	0.19
04 Jun – 10 Jun	23	Gumbel Max	σ=5.1049 μ=0.63671	7.217	2.50
11 Jun – 17 Jun	24	Gen. Extreme Value	k=0.52806 σ=9.6898 μ=4.1646	1.825	8.00
18 Jun – 24 Jun	25	Gen. Extreme Value	k=0.70838 σ=4.2771 μ=1.2127	8.937	3.00
25 Jun – 01 Jul	26	Gumbel Max	σ=68.63 μ=-0.5444	3.516	26.00
02 Jul – 08 Jul	27	Gumbel Max	σ=53.839 μ=5.92	3.683	26.00
09 Jul – 15 Jul	28	Gumbel Max	σ=83.291 μ=33.623	3.888	65.00
16 Jul – 22 Jul	29	Gen. Extreme Value	k=0.31466 σ=30.156 μ=18.181	1.879	30.00
23 Jul – 29 Jul	30	Gen. Extreme Value	k=0.65287 σ=45.903 μ=24.237	0.060	44.00
30 Jul – 05 Aug	31	Gamma	α=0.63824 β=93.596	0.971	33.00
06 Aug – 12 Aug	32	Gen. Extreme Value	k=0.21456 σ=33.858 μ=19.526	2.681	33.00
13 Aug – 19 Aug	33	Gen. Extreme Value	k=0.42399 σ=27.154 μ=13.569	4.725	25.00
20 Aug – 26 Aug	34	Gamma	α=0.30628 β=115.81	1.498	9.00
27 Aug – 02 Sep	35	Weibull	α=0.17008 β=15.601	1.449	2.00
03 Sep – 09 Sep	36	Gumbel Max	σ=95.326 μ=1.413	3.762	37.00
10 Sep – 16 Sep	37	Gumbel Max	σ=37.969 μ=6.0935	2.854	20.00
17 Sep – 23 Sep	38	Gen. Extreme Value	k=0.74827 σ=4.7268 μ=1.4806	4.376	3.50
24 Sep – 30 Sep	39	Gen. Extreme Value	k=0.91678 σ=1.5589 μ=0.36182	9.816	1.00
01 Oct – 07 Oct	40	Gen. Extreme Value	k=0.75158 σ=2.6992 μ=0.73949	8.674	1.90
08 Oct – 14 Oct	41	Gen. Extreme Value	k=0.86784 σ=0.58814 μ=0.11503	19.869	0.37
15 Oct – 21 Oct	42	Gen. Extreme Value	k=0.95748 σ=0.35551 μ=0.06071	18.893	0.22

height (m s^{-1}), e_s is saturation vapour pressure (kPa), e_a is actual vapour pressure (kPa), $(e_s - e_a)$ is saturation vapour pressure deficit (kPa), Δ is slope vapour pressure curve (kPa °C^{-1}), and γ is psychrometric constant (kPa °C^{-1}).

RESULTS AND DISCUSSION

Rainfall characteristics and probabilities

Analysis of thirty years (1990-2019) weekly rainfall data indicated that the monsoon starts effectively from 24th SMW (11th-17th June) and remains active up to 39th SMW (24th-30th September). Therefore, mean length of rainy season was found to be 16 weeks (112 days) and rest of the period with no effective rainfall. The mean weekly rainfall was found to be > 40 mm during 28th-36th SMW and found to be < 40 mm during 24th-27th, 34th and 37th-39th SMW. The weekly contribution of average annual rainfall was found >70% and >85% during 28th–36th and 26th-37th SMW, respectively. In 30th SMW two major peak events were occurred with rainfall amount of 836.5 and 1198.4mm in year 2015 and 2017, respectively. The most probable period for rain water harvesting 28thto 37th SMW (July to September). Properly harvested and stored rainwater during these weeks be reused as supplemental irrigation during mid season/terminal drought period or during *rabi* season. The average pre-monsoon rainfall varies from 3.30 to 20.30 mm during 22nd to 25th SMW, for ploughing, seed bed preparation and other pre-sowing agricultural operations. During *kharif* season, it is desirable to complete the sowing operation 12-15 days before the onset of monsoon. However, in rainfed areas, the sowing time should coincide with onset of monsoon.

The selected distribution's, parameters and Chi-Square test value are presented for relevance with rainy season (22nd-42nd SMW) (Table 1). The results revealed that there was 50 per cent chances that the onset and cessation of rainy season occured during 26th and 37th SMW respectively. Sowing short duration crops like groundnut, pearl millet, pulses, maize and sorghum can be planned during 26th SMW or one week prior to ensure effective utilization of rainwater then after

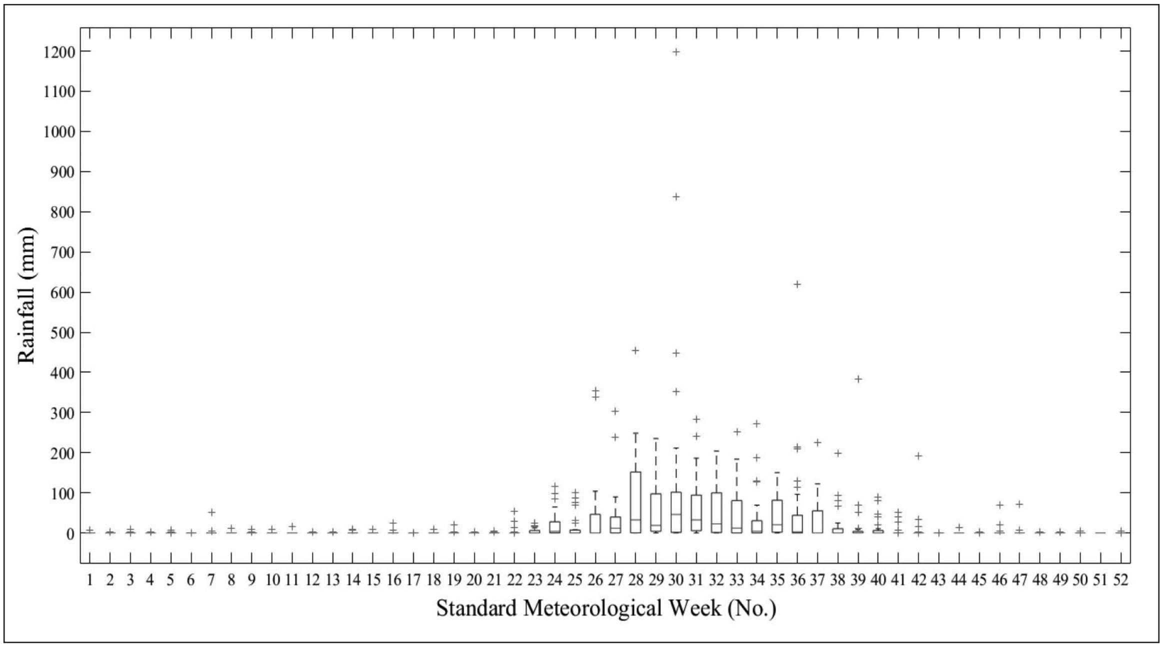

Fig. 1: Week wise rainfall distribution for Sardarkrushinagar

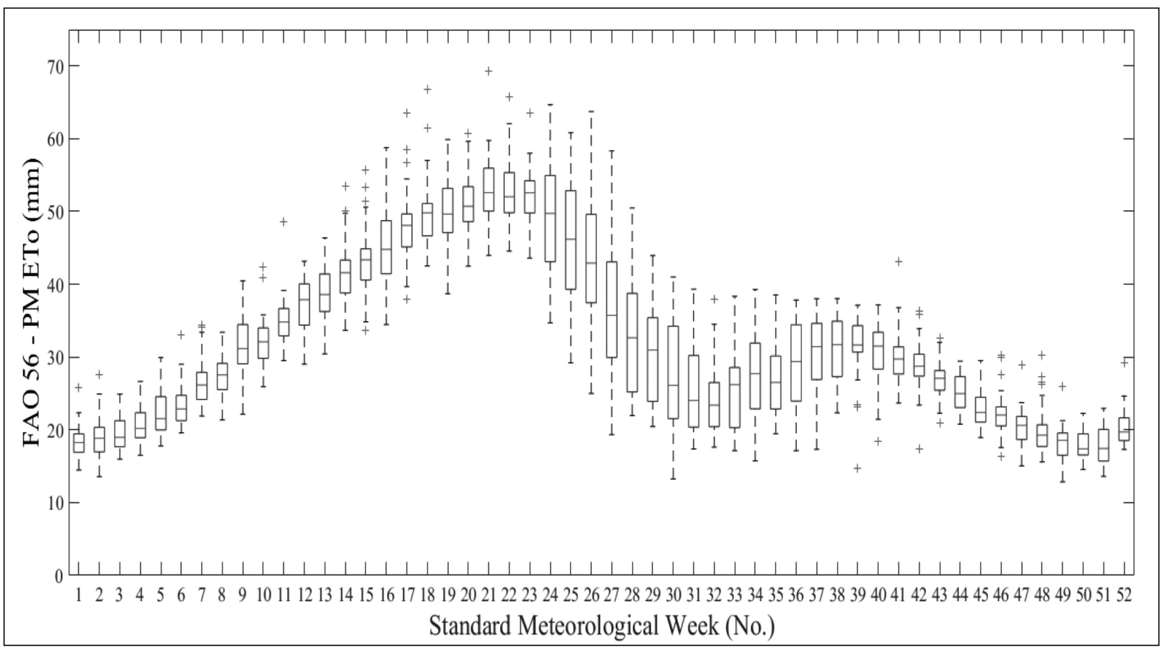

Fig. 2: Weekly reference evapotranspiration for Sardarkrushinagar

runoff increase gradually, which may be harvested and be provided as lifesaving irrigation at critical growth stages of crop growth during lean period. The analysis revealed that total assured rainfall of 350 mm at 50 per cent probability levels was received during the crop-growing period (26-37th SMW). The long-term arithmetic average rainfall of 660 mm was received during crop growing period indicated hardly needs of irrigation water. For delay in onset of monsoon, short duration with low water consumption crops may be grown during *kharif* season. Short duration crops *viz.,* pulses and oil seeds may grow during first week of July and harvested by the mid September. *Rabi* crops like dilseed, mustard, chickpea etc. may be sown from 37th SMW onwards as the average weekly rainfall varies from 18.2 to 4.3 mm from 37th to 42nd SMW and harvested rainwater use as supplemental irrigation. Post monsoon rainfall highly uncertain and it is risky for growing crops without supplementary irrigation.

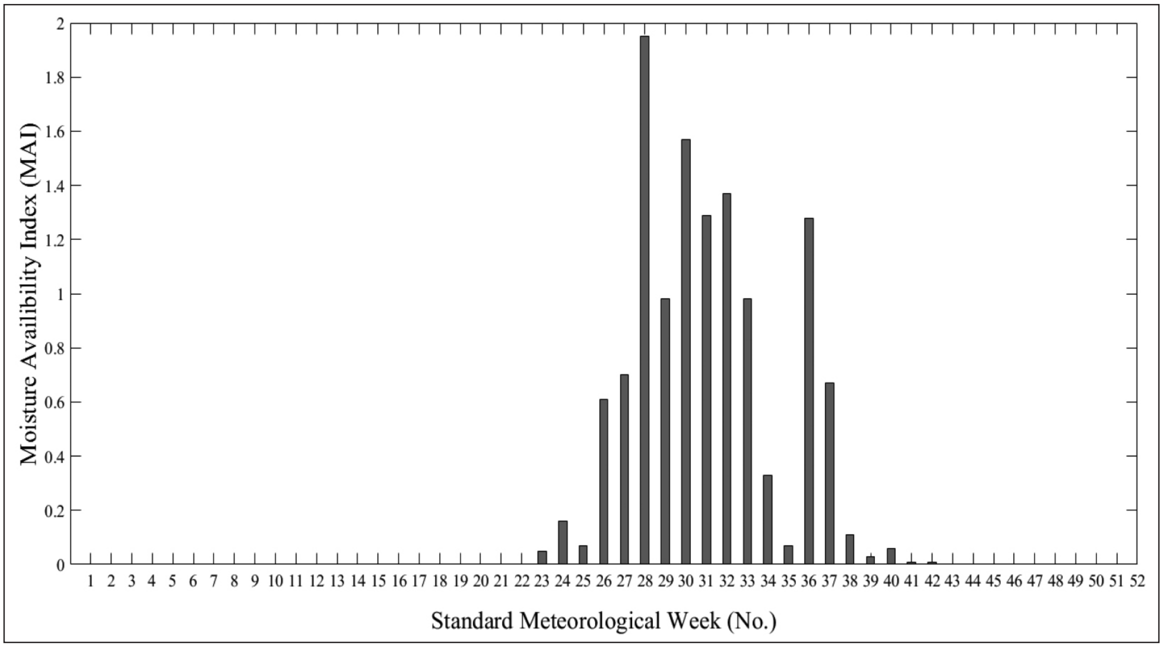

Fig. 3: Weekly moisture availability index for Sardarkrushinagar

Reference evapotranspiration

Weekly reference evapotranspiration (ET_0) was estimated for the 30 years (1990-2019) of dataset using the FAO-56 PM method. It is observed from the Fig.2 that weekly ET_0 values showed increasing trend from 1st to 21st SMW and it reached maximum (52.96 mm) in 21st SMW. Subsequently, it starts decreasing and reached minimum (17.65 mm) during 50th SMW. The higher (>50 mm) and lower (<20 mm) ET_0 value observed from 18th to 23rd and 49th to 52nd; 1st to 3rd SMW, respectively (Fig. 2). According to change in ET_0 values over the weeks, the coefficient of variation (CV) was less than 0.15 for 1stto 24th and 38th to 52nd SMW, which showed that the sequence of weekly ET_0 in these weeks had a relatively small variation. However, the CV was relatively larger as 0.15 for 25th to 37th SMW, showed that weekly ET_0 was relatively dispersive. The standard deviation varies from a 2.03 to 10.64 mm during 50th and 27th SMW, respectively. Fig. 2 clearly shows that low standard deviation, indicates that the values is closer to the mean during the winter, whereas the high deviation during monsoon.

Moisture availability index

The crop growth periods was considered as the period during which the MAI >0.5 at the time of sowing and active vegetative growth period, and > 0.3 at the time of maturity. In present study, MAI >0.5 observed from 26th to 33rd SMW, indicates the earlier sowing of *kharif* crops facieses water stressed for growing. The analysis revealed 26th SMW (25 June – 01 July) and onwards as the most suited sowing time of *kharif* crops. There are also chances of occurrence of moisture stress during 34th and 35th SMW to meet crop water requirement, during that period supplemental irrigation or conservation practices *viz.,* mulching, anti-traspirants, interculturing, weeds control, adequate plant stands are helps in better crop production and to mitigate the effect the moisture stress during active growth period. The probable time of sowing of *rabi* crops are assumed to be the week when the soil moisture storage is sufficient to meet the full evaporation demand.

The adoption of Good Agricultural Practices (GAP) such as minimum tillage, integrated fertilizer, insect, pest, diseases and weed management, crop rotation, inter and relay cropping in conjunction with new cultivars has the potential to increase the productivity and rainwater use efficiency of dryland crops. Saudagar (2002) suggested crop planning based on MAI and moisture availability period at 50 and 70 % probability levels of assured rainfall for plain zone of Maharashtra. Gupta *et al.* (1975) revealed that 50% probability level is the maximum limit for taking risk and can be effectively used to determine the moisture availability period for crop planning.

CONCLUSIONS

The semi arid region of North Gujarat, depends on scanty and uncertain distribution of rainfall and characterized by limited or inadequate ground water resources. Thus to cope up with these issues, weekly rainfall probability, evapotranspiration and MAI were analyzed using thirty year (1990-2019) of meteorological data. Weekly rainfall series fitted by different probability distribution and compared using goodness of fit Chi squared tests. The weekly contribution of average annual rainfall was found >70 and >85 per cent during 28th–36th and 26th-37th SMW, respectively. The analysis revealed that total assured rainfall of 350 mm at 50 per cent probability levels was received during the crop-growing period (26-37th SMW). The analysis revealed 26th SMW (25 June – 01 July) and onwards as the most suited sowing time of *kharif* crops. The results would be useful for agricultural scientists, researchers, decision makers and policy planners in the field of agricultural crop planning and irrigation management for semi arid regions. "Suggestive measures for improving rain water-use efficiency in dryland farming:

ACKNOELEDGEMENT

The authors are thankful for the pain staking efforts of Technical Officers involved in collection and compilation of meteorological data.

Conflict of Interest Statement: The author(s) declare(s) that there is no conflict of interest.

***Disclaimer*:** The contents, opinions, and views expressed in the research article published in the Journal of Agrometeorology are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

Publisher's Note: The periodical remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

REFERENCES

Alam, N.M., Ranjan, R., Adhikary, P.P., Kumar, A., Jana, C., Panwar, S., Mishra, P.K. and Sharma, N.K. (2016). Statistical modelling of weekly rainfall data for crop planning in Bundelkhand region of central India. *Ind. J. Soil Conser*., 44(3):336-342.

Alam, N.M., Jana, C., Panwar, P., Kumar, G., Mishra, P.K., Sharma, N.K. and Tiwari, A.K. (2015). Weekly rainfall analysis for crop planning in rainfed Shiwalik Himalayas of India. *J. Agrometeorol.*, 17(2): 234-240.

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. FAO Irrigation and Drainage paper no. 56, Pub. - FAO, pp:300.

Deora, B.S. and Singh, R.V. (2008). Frequency analysis of water deficit for crop planning in Gujarat. *J. Agrometeorol.*, 10(2):184-187.

Deora, B.S. and Singh, R.V. (2009). Stochastic modelling of water deficit. *J. Agrometeorol.*, 11(1):19-28.

Gocic, M., Motamedi, S., Shamshirband, S., Petkovic, D., Ch, S., Hashim, R. and Arif, M. (2015). Soft computing approaches for forecasting reference evapotranspiration. *Comp. Electro. Agri*., 113:164-173.

Gupta, S.K., Babu, Ram and Tejwani, K.G. (1975). Weekly rainfall of India for planning cropping programme. *Soil Cons. Digest*., 3(1):31-36.

Hargreaves, G.H. (1971). Precipitation dependability and potential for agricultural production in Northeast Brazil. Pub. No. 74-D- 159, EMBRANA and Utah State Univ. (USB), 123 p.

Jana, C., Alam, N.M., Sharimali, S.S., Kumar, G., Ghos, B.N. and Mishra, P.K. (2015). Rainfall extremity in Doon valley of Uttarakhand – reorienting agricultural management. *Int. J. Agri. Stat. Sci*., 11(2):425-431.

Kumar, V., Shanu, Jahangeer. (2017). Statistical distribution of rainfall in Uttarakhand, India. *Appl. Water Sci*., 7:4765-4776.

Lairenjam, C., Huidrom, S., Bandyopadhyay, A. and Bhadra, A. (2016). Assessment of probability distribution of rainfall of North East Region (NER) of India. *J. Res. Environ. Earth Sci*., 2(9):12-18.

Mandal, K.G., Padhi, J., Kumar, A., Ghosh, S., Panda, D.K., Mohanty, R.K. and Raychaudhuri, M. (2015). Analyses of rainfall using probability distribution and Markov chain models for crop planning in Daspalla region in Odisha, India. *Theor. Appl.Climato*., 121:517-528.

Rajeshkumar, N.K., Balakrishnan, P., Srinivas Reddy, G.V., PoliseGowdar, B.S. and Satishkumar, U. (2018). Rainfall Probability Distribution Analysis in Selected Lateral Command Area of Upper Krishna Project (Karnataka), India. *Hydro.Model*., 3-12.

Sharda, V.N. and Das, P.K. (2005). Modelling Weekly rainfall data for crop planning in a sub-humid climate of India. *Agr. Water Manage*., 76:120-138.

Trajkovic, S., Gocic, M., Pongracz, R., Bartholy, J. and Milanovic, M. (2020). Assessment of reference evapotranspiration by regionally calibrated temperature based equations. *KSCE J. Civil Engg*., 24:1020-1027.

Received : October 2020 : Accepted : August 2021