**International Journal of Science and Research (IJSR)**
**ISSN (Online): 2319-7064**
**Index Copernicus Value (2016): 79.57 | Impact Factor (2017): 7.296**

# Study on the Pattern of Rainfall Distribution using Some Competing Probability Distribution in Cooch Behar District of West Bengal

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## 1. Introduction

The agriculture land in our country amounts to 143.8 million hectare out of which 67% is dry land and rain fed. The dry land agriculture contributes 44% of our national food grain production. In West Bengal, nearly 72% of the population lives in rural areas. Agriculture is the predominant occupation in the state. The total reporting area of the state is 86.84 lakh ha. of which 52.96 lakh ha that is nearly 61% is the net sown area. The grossed cropped area is 97.52 lakh ha with a cropping intensity of 84%. The climate of the state is tropical and humid except in northern Himalayans.

The climate of the Cooch Behar district of west Bengal, in general, is sub-tropical per humid to tropical humid in nature with distinctive characteristics of high rainfall, high relative humidity and low temperature. About 70% of the annual rainfall is received during the southwest monsoon season, June being the rainiest month. On an average there are about 102 rainy days with records of more than 400 mm rainfall in 24 hours. During monsoons, starting from June, Cooch Behar experiences heavy rainfall. The average annual rainfall is about 3201mm in Cooch Behar district of West Bengal. The numbers of rainy days in Cooch Behar district is recorded to be the highest in the months of June and July. In Cooch Behar district, the number of rainy days often crossed 20 in a month during the months of June and July followed by 15-20 in August and September. Which during April, May and October is varies maintaining a central tendency towards 10 in each month. Also the above mentioned information is based on rainfall data of 1971-1981. An early onset of pre- monsoon shower and occurrence of a low quantum of precipitation during the month of March and April with occasional short dry spells are the other distinctive characteristics for the district of Cooch Behar.

The primary objectives of this research are to estimate and evaluate distribution parameters that may be used to describe the probability of monthly rainfall accumulation for a location. More specifically, probability distribution parameters are estimated from monthly model derived historical rainfall values with a spatial resolution compatible with current agro climatic models, and the goodness-of-fit of the parameters assessed. Direct interpretation of these parameter estimates results in a broad technique for the description of general rainfall regimes for the entire continent. The result of this research is a new portrayal of African rainfall utilizing these probability distribution parameters. In addition to the interpretation of these parameters, description of potential uses of the parameters in hydrologic resource modeling is introduced. Probabilistic information can be utilized to dynamically evaluate rainfall accumulations as well as test different scenarios that can be used as input into other models.

## 2. Material and methods

Daily rainfall data were collected from Gramin Krishi Mausam Seva Project, AMFU-Pundbari, Cooch Behar for the rain gauge station at AMFU-Pundbari from the year 1995 to 2015 (20 years). Rainfall was measured with IMD specified manual and automatic rain gauge.

To study the characteristics of the rainfall the individual year will be grouped according to the weeks of commencement of rainy season. The data will then, be processed to identify the maximum rainfall received on any one day (24 hours duration), in any week (7days), in a month (4 weeks), in a monsoon season (4 months), in a year (365 days period).Also we calculate total rainfall for all years, the mean, mode and median date, standard deviation and coefficient of variation regarding onset withdrawal and duration of south west monsoon.

**Methods of estimating rainfall probabilities:**

In estimating probability, two different methods may be tried. Viz.,

1) Past frequencies are directly taken to delimit future expectations and
2) A theoretical distribution may be fitted to available data and probable frequency may be found out from such a distribution.

Frequency distribution of weekly rainfall is highly skew and includes a number of zero values also. Thom(1966) suggested the fitting of Gamma distribution to data like rainfall having zero lower bound. Mooley (1973) studied Asian summer monsoon rainfall by fitting Gamma distribution on monthly rainfall total. In the present study rainfall probabilities are computed by fitting mixed Gamma distribution to weekly totals. It is given by: G(X) = q + p F(X ) where ,F(X) is the Gamma distribution function, q is the probability of zero precipitation and p=1-q.The distribution function F(X) of the two-parameter Gamma distribution is: F(X)=$\int_0^\infty \frac{x^{\alpha-1}e^{-(\frac{x}{\beta})}}{\beta^\alpha\Gamma\alpha}$α& β are shape and scale parameters respectively of the distribution and $\Gamma(\alpha)$ is the Gamma function of $\alpha$. The distribution is bounded at the left side by zero. G(X) is the cumulative probabilityofrain<X.To obtains the rainfall probabilities the two parameters$\alpha$ and $\beta$ of the Gamma distribution have to be estimated from the

observed data. Thom (1958) has shown that the maximum likelihood estimates are efficient consistent and jointly sufficient.Wehave used this method.

The following equation has been solved on the computer by iteration process for X when $P_{z=}$ 0.10, 0.20,………..0.90 respectively utilising the procedure given in detail by Mooley(1973), where, Z = x/$\beta$

$$P_Z = 1 - \left( q + p \int_0^z \frac{z^{\hat{\alpha}-1} e^{-z}}{\sqrt{\hat{\alpha}}} dz \right)$$

The amounts calculated at 10% to 90% probability levels are designated as assumed rainfall(AR) here onwards. For each station, graphs have been prepared showing for each week, the AR values for the nine probability levels,viz.,10%, 20%,…………90%.An examination of these figures for different stations shows that there are one or more high peaks in AR. On the basis of the amplitudes of the maxima and the positions of the peaks in the rainfall march of time, the patterns are classified. Similar rainfall patterns can be grouped together to form homogenous rainfall pattern zones.

Potential evapotranspiration (PET) was that calculated from U.S. class 'A' pan evaporimetervalues multiplied by 0.7 (pan coefficient) (Banik, 1996).

Moisture availability index (MAI) has been calculated and it is defined as the ratio of weekly rainfall at different confidence levels to PET of the corresponding period (Hargreaves, 1971). The MAI was, however, worked out for 30, 50 and 70 percent probability levels. Depending on the threshold values of MAI the agricultural operations for rice cultivation can be recommended (Banik, 1996).

| Threshold values of MAI | Agricultural operations |
|---|---|
| <0.3 | No. agricultural operations can be done |
| 0.3-0.5 | Land preparation |
| 0.5-0.75 | Direct sowing of rice can be done |
| 0.76-1 | transplanting |
| >1 | Without any risk |

**Gamma Distribution**

The time taken for a number $\beta$of events to occur in a Poisson process is described by the gamma distribution, which is the distribution of a sum of $\beta$ independent and identical exponentially distributed random variables. The gamma distribution has a smoothly varying form like the typical probability density function and is useful for describing skewed hydrologic variables without the need for log transformation. It has been applied to describe the distribution of depth of precipitation in storms. The p.d.f. of one parameter gamma distribution is given by $f(x)$ = $\frac{1}{\Gamma(\beta)} u^{\beta-1} e^{-u}$, x≥0, β≥0. The gamma distribution involves the gamma function $\Gamma(\beta)$, which is given by $\Gamma(\beta)$=$(\beta-1)!$ = $(\beta-1)$ $(\beta-2)$..........2.1. $\Gamma(\beta)$ = $\int_0^{\infty} u^{\beta-1} e^{-u} du$. The two-parameter gamma distribution (parameters $\beta$and λ) has a lower bound at zero, which is a disadvantage for application to meteorological variables that has a lower bound larger than zero. Maximum intensity values used in IDF analyses have a lower bound larger than zero and hence the gamma distribution has a limitation in IDF analyses.

**M.L.E estimation of Gamma:** The equations used for computation of minimum assured rainfall are mixed continuous distributions. As for example for Gamma distribution; G(X) = $q$ + $p$ F(X) where F(X) is the Gamma distribution function and $q$ is the probability of zero precipitation and $p$=1-$q$. The distribution function F(X) of the two parameter Gamma Distribution is:

F(X) = $\int_0^x \frac{x^{\alpha-1} e^{-x/\beta}}{\beta^{\alpha} \Gamma_{\alpha}} dx$ where x,$\alpha, \beta > 0$

= 0 when$x \leq 0$

$\alpha, \beta$are shape and scale parameters respectively of the distribution. Γ(α) is the Gamma Function of α =$\int_0^{\infty} x^{\alpha-1} e^{-x} dx$. In the above notation G(X) is the probability of rain$< X$.

L = -n.$\alpha$.log$\beta$ – n log $\Gamma(\alpha)$+$(\alpha-1)\sum logx$ - $\frac{1}{\beta}\sum x$

Where the summation is over the n sample values. Differentiating as indicated in equations, we the find M.L. equations

$$\frac{\bar{x}}{\hat{\beta}} - \hat{\alpha} = 0 \qquad …….. (1)$$

log$\hat{\beta}$ + $\frac{\partial}{\partial\hat{\alpha}}$log $\Gamma\hat{\alpha}$ - $\frac{1}{n}\sum logx = 0$

Since$\frac{\partial}{\partial\hat{\alpha}}$log $\Gamma\hat{\alpha}$ is the digamma function,$\psi$ $(\hat{\alpha})$, We may write in the simplified form

$$\log\hat{\beta} + \psi(\hat{\alpha}) - \frac{1}{n}\sum logx = 0 \qquad …….. ………(2)$$

Taking logarithms of (1) and substituting for log $\hat{\beta}$ in (2) gives

log$\hat{\alpha}$ - $\psi$ $(\hat{\alpha})$ = log $\bar{x}$ - $\frac{1}{n}\sum logx$

This equation is implicit in $\hat{\alpha}$ but may be solved with some difficulty using the Davis tables of the $\psi$ – functions. Masuyama and Kuroiwa prepared tables of logarithms and tables of the digamma functions.

**Theory of OEM &EEM**: Raman (1974) has defined the terms 'OEM' and 'EEM' to work out some meteorological parameters in the case of West Bengal state. But the terai zone of West Bengal being pre -dominantly high rainfall (on the average more than 60mm/week) area, the second criterion of Raman's definition has been modified accordingly to suit the situation of two north Bengal districts under consideration. The modified definitions of OEM and EEM as used in used in the present article are as follows: Suppose during the monsoon months of a year, a particular region having average evaporation of 'e' mm, gets 'x 'mm rainfall at the first day during the commencement of seven days' spell with total rainfall of 'x' mm. Then, this seven days' spell satisfying the following three criteria may be defined as the OEM week :

(i) x ≥ e,
(ii) X ≥ (7e+10) and
(iii) At least four of the seven days have daily rainfall ≥ 2.5 mm.

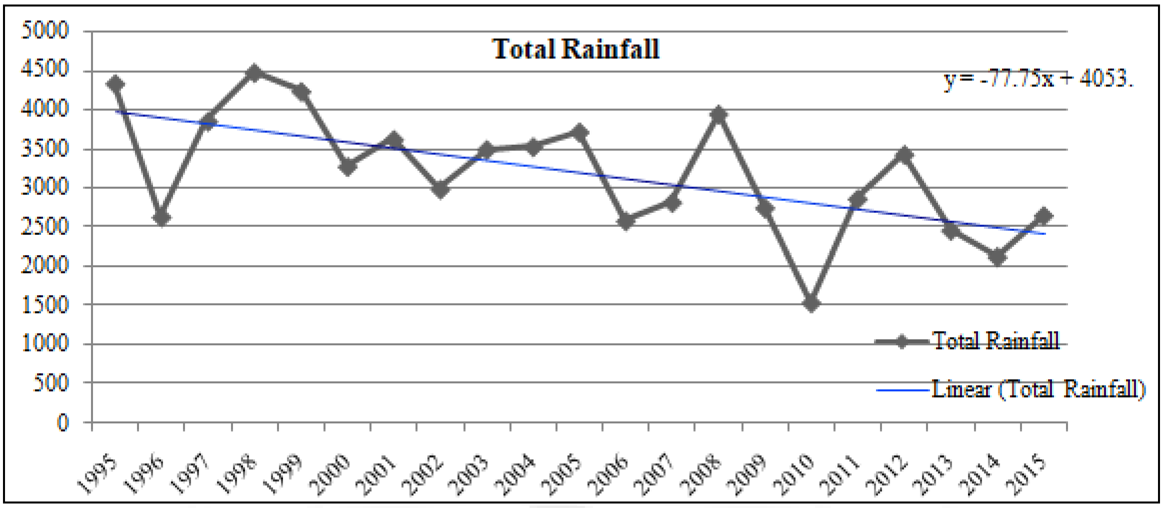
Similarly, if the region receives x mm rainfall on the last during an end of seven days' spell may be defined as the EEM week, provided the following criteria are satisfied:

(i) x'≥e ,
(ii) X'≥(7e+10) and
(iii) At least four of the seven days have daily rainfall ≥2.5 mm.

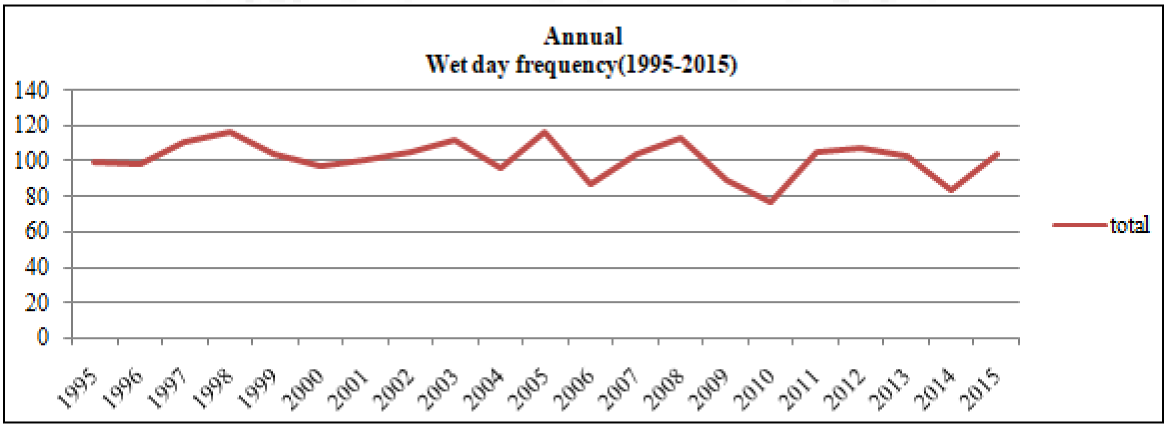
According to WMO, the WMO has divided calendar year into12 duration of 30 days each- called periods and 52 weeks –called standard meteorological weeks of 7 days each. The first week starts on 1st January and ends on 7th January and so on. The 9th (26th Feb to 4th march) week in a leap year and the 52nd week consist of 8 days.

## 3. Results and Discussion

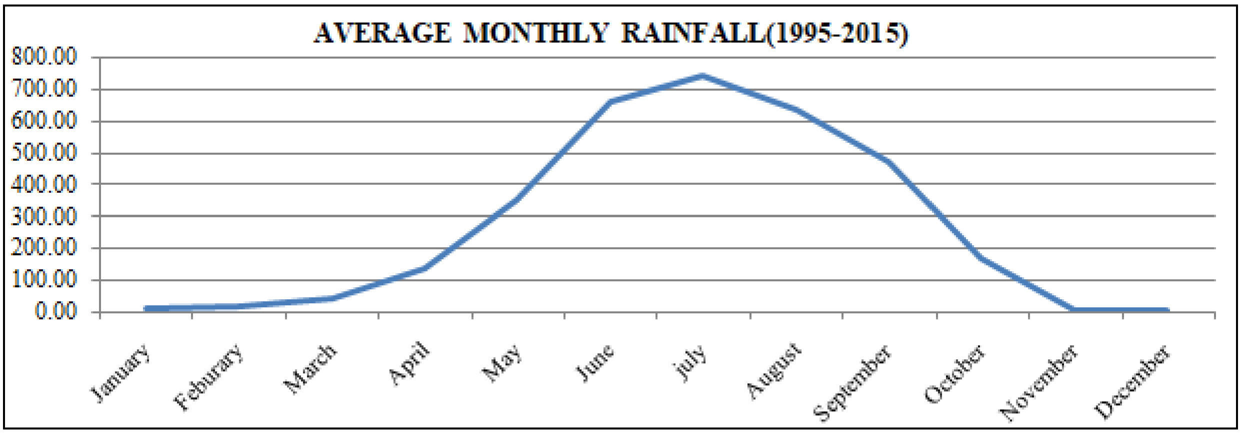
**Descriptive statistics:** The graph below demonstrates the total annual rainfall at Cooch Behar district over the study period. Trends observed indicate total rainfall between 4472.6 mm. to 1529.5 mm. per year, a yearly rainfall variation of 23.92 % over the years. Based on 21 years average the annual rainfall is 3200 mm. The year 1998 was the wettest year with 4472.6 mm of rain and the year 2010 was the driest year with 1529.5 mm of rain. A decrease in annual rainfall of 84.54 mm per year is observed. Based on fitted trend line a decrease in yearly total rainfall of 1.79% per year is also seen.




The graph below demonstrates the yearly total wet day's frequency at Cooch-Behar district. An average annual wet day is 107 days which is 29.31% of total number of days in a year. Yearly wet days counts were observed between 117 days to 77 days, a variance of 29 %. The year 1998 records the highest no. of wet days (117 days) and the Year 2010 records the lowest no. of wet days (77 days), a difference of 34% two years apart. The wet day pattern follows a very similar distribution to total rainfall pattern except in the year 2011 & 2012. A sharp increase in total annual rainfall is observed from 2011 to 2012 whereas total number of wet days remains almost same during the same period.

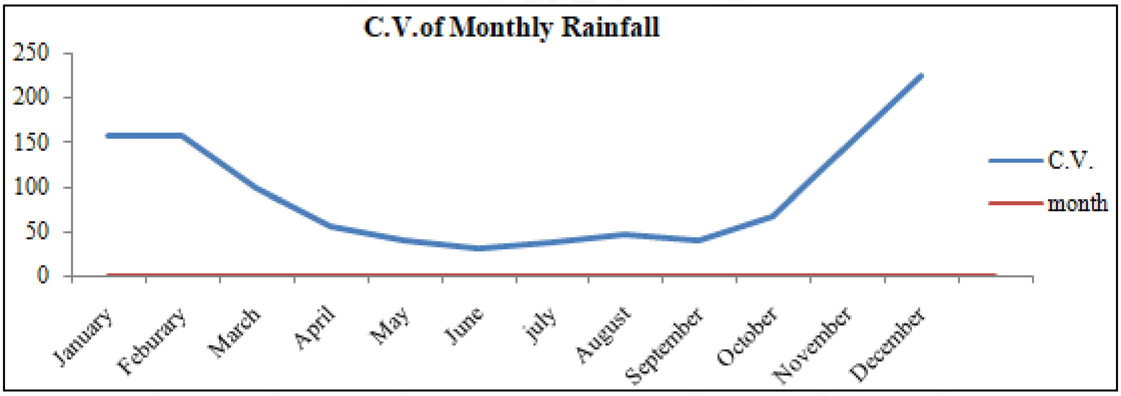



The graph below presents the average monthly rainfall between 1995 to 2015. The observed trend, gradual and consistent increase from January to April followed by a sudden & sharp increase in May & June. It peaks in July and thereafter a slight drop in August. Thereafter there is a sudden and sharp drop in rainfall in the months of September & October followed by nearly no rain in the months of November & December.



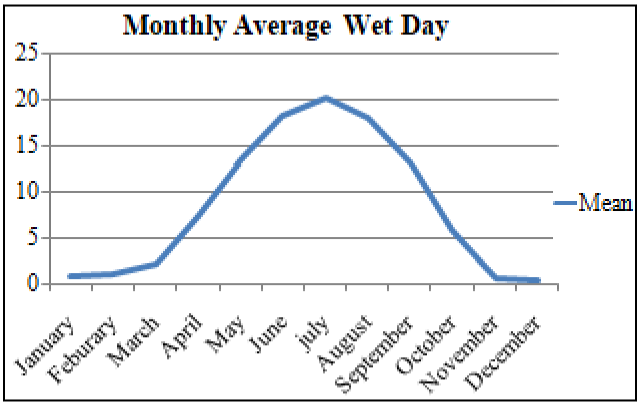

The month of July records the highest monthly average rainfall 743.48 mm or 22%of total annual rainfall. Whereas the month of November records the lowest monthly average rainfall 6.45 mm or 0.1% of total annual rain closely followed by December at 4.25 mm or 0.1% of annual total.

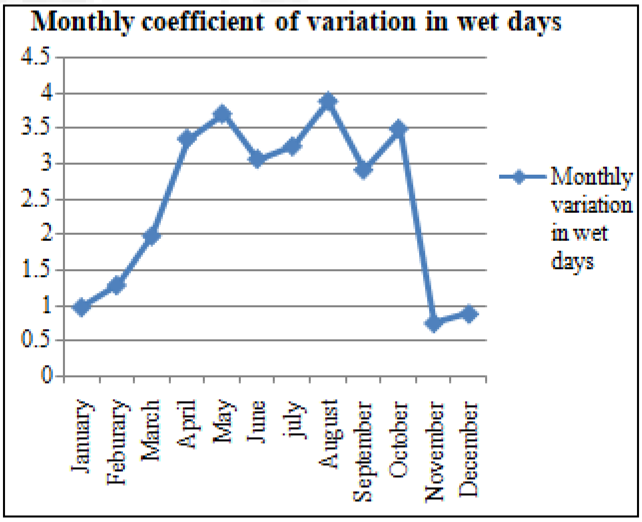
The graph below present the variation in the monthly rainfall over the study period. The variation is 50% or less in the rainfall months of May to September. However in the months of scanty rain i.e. October to April the variation is more indicating a erratic rainfall months.



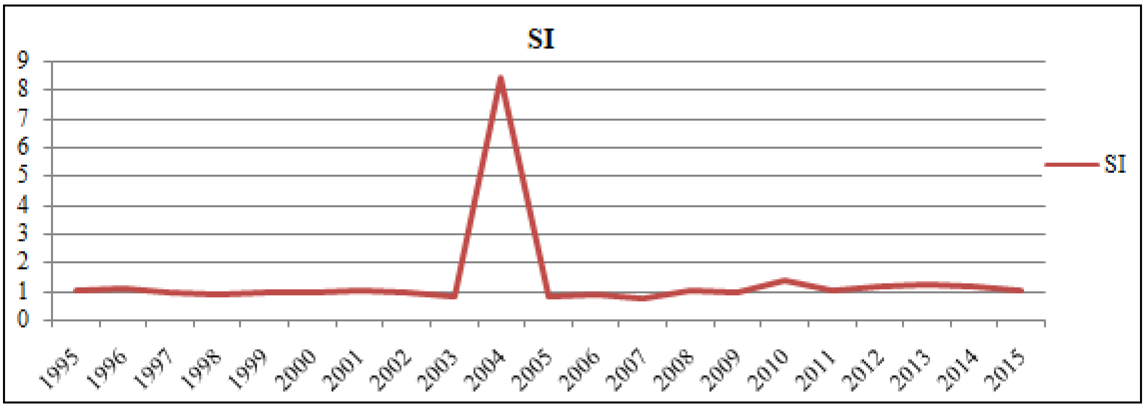

The following graph present the monthly average wet days over the study period. The observed trend is same as in case of monthly average rainfall. June, July & August together record the highest no. of wet days (20 each approx.) i.e. 52.33% of annual total.

Wet days of more than 14 days per month occurs 25 times, 8 times each in July & August, 7 times in June & 4 times in May.




Occurrence of rainy days is more uniform from May to September when variation is less than 28%. Occurrence of wet day is more erratic in other months & this is highest in the month of December followed by November & January. The variation is beyond 96%.




The above mentioned Seasonality Index has been computed over the study period.

Calculating the Seasonal index is giving the formula by Walsh and Lawer (1981):

$$S.I._k = \frac{1}{R_k}\sum_{n=1}^{12}\left|X_{nk} - \frac{R_k}{12}\right|$$

Where, $X_{nk}$ =Rainfall of month n of the year k.
$R_k$= total annual rainfall for the year k.

Low value of seasonality index indicates a shorter dry season & a better distribution of monthly rainfall among the months of a year. A high value of S.I. indicates that most of the rain occurs within few months (2-3 months) & a longer (frequent) dry season. Trend analysis has shown 2.5% increase in S.I. per year. An increasing trend is an indicator of alarming situation in Agriculture.

**Table 1:** Weekly maximum & minimum rainfall year wise

| Year | Week No | Maximum rainfall (mm) | Week No | Minimum rainfall(mm) |
|---|---|---|---|---|
| 1995 | 33 | 559.7 | 10 | 0.4 |
| 1996 | 28 | 372.4 | 13 | 0.4 |
| 1997 | 24 | 468.3 | 6 | 0.6 |
| 1998 | 36 | 632.7 | 9 | 0.2 |
| 1999 | 28 | 694.6 | 50 | 0.5 |
| 2000 | 27 | 543.8 | 44 | 0.8 |
| 2001 | 34 | 370.6 | 16 | 0.3 |
| 2002 | 29 | 374.7 | 4 | 0.2 |
| 2003 | 26 | 296.1 | 1 | 0.2 |
| 2004 | 29 | 399.5 | 42 | 1.8 |
| 2005 | 25 | 476.4 | 47 | 0.4 |
| 2006 | 27 | 394.2 | 43 | 0.2 |
| 2007 | 36 | 402.4 | 11 | 0.1 |
| 2008 | 35 | 641.4 | 6 | 1 |
| 2009 | 26 | 283.1 | 12 | 0.1 |
| 2010 | 30 | 134.5 | 7 | 0.6 |
| 2011 | 38 | 344.7 | 3 | 0.5 |
| 2012 | 28 | 371.1 | 4 | 0.2 |
| 2013 | 28 | 381.1 | 12 | 1.9 |
| 2014 | 23 | 376.7 | 50 | 0.4 |
| 2015 | 35 | 302.7 | 5 | 0.1 |

**Table 2:** Date wise & week wise maximum rainfall for different years along with monthly maximum rainfall.

| Year | Week No | Date of Rainfall | Maximum rainfall (mm) | Name of Month | Monthly Maximum rainfall(mm) |
|---|---|---|---|---|---|
| 1995 | 33 | 15.08.1995 | 183.9 | August | 1061.9 |
| 1996 | 28 | 13.07.1996 | 101.8 | July | 1193.2 |
| 1997 | 24 | 09.7.1997 | 136 | August | 1059.2 |
| 1998 | 36 | 3.9.1998 | 284.9 | August | 948.9 |
| 1999 | 28 | 10.7.1999 | 474 | July | 1274.4 |
| 2000 | 27 | 06.07.2000 | 196.3 | June | 981.1 |
| 2001 | 34 | 22.08.2001 | 132.3 | September | 760.5 |
| 2002 | 29 | 20.07.2002 | 200 | July | 1107.2 |
| 2003 | 26 | 26.07.2003 | 96.2 | June | 935.9 |
| 2004 | 29 | 11.07. 2004 | 86.6 | July | 1190.9 |
| 2005 | 25 | 18.07. 2005 | 53 | August | 778.5 |
| 2006 | 27 | 28.07. 2006 | 160 | September | 506.5 |
| 2007 | 36 | 30.08. 2007 | 47.8 | July | 618.3 |
| 2008 | 35 | 30.08.2008 | 239.6 | August | 1172.7 |
| 2009 | 26 | 23.06. 2009 | 116.8 | June | 540.3 |
| 2010 | 30 | 23.07. 2010 | 39.6 | August | 360.2 |
| 2011 | 38 | 18.9. 2011 | 214.60 | July | 800.4 |
| 2012 | 28 | 11.7. 2012 | 65.60 | July | 739.8 |
| 2013 | 28 | 10.7. 2013 | 203.20 | July | 682.7 |
| 2014 | 23 | 8.6. 2014 | 128.90 | June | 604.3 |
| 2015 | 35 | 02.09.2015 | 88.90 | August | 797.3 |

**Table 3:** Yearly mean dates of OEM & EEM and duration of CDS at Cooch Behar

| Year | Date of onset | Week NO. | Date of end | Week No. | Duration of CDS | Week No. |
|---|---|---|---|---|---|---|
| 1995 | 28 May | 22 | 23 September | 38 | 1-10 May | 17,18 |
| 1996 | 28 May | 22 | 7 September | 36 | 18-27 September ; 8-17 October;18-27 October; | 38,39,41,42,43 |
| 1997 | 8 June | 23 | 20 September | 38 | 18-27 October | 42,43 |
| 1998 | 31 May | 22 | 5 September | 36 | 8-17 September ;8-17 October | 36,37,38,41,42 |
| 1999 | - | | - | | 21-30 October | 42,43,44 |
| 2000 | 28 May | 22 | 23 September | 38 | 18-27 October | 42,43 |
| 2001 | 3 June | 22 | 8 September | 36 | 18-27 October | 42,43 |
| 2002 | 2 June | 22 | 28 September | 39 | 18-27 October | 42,43 |
| 2003 | 8 June | 23 | 13 September | 37 | - | |
| 2004 | 13 June | 24 | 25 September | 39 | 18-27 October | 42,43 |
| 2005 | 12 June | 24 | - | | 8-17 October | 41,42 |
| 2006 | 11 June | 24 | 23 September | 38 | - | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2007 | 3 June | 22 | 8 September | 36 | 18-27 October | 42,43 |
| 2008 | 2 June | 22 | 28 September | 39 | 8-17 October | 41,42 |
| 2009 | 1 June | 22 | - | | 18-27 October | 42,43 |
| 2010 | 14 June | 24 | 6 September | 36 | 18-27 October | 42,43 |
| 2011 | 4 June | 23 | 23 September | 38 | 8-17 October;18-27October | 41,42,43 |
| 2012 | 3 June | 22 | 22 September | 38 | 19-28 October | 42,43 |
| 2013 | 4 June | 23 | 9 September | 36 | 17-26 September ;17-26 October | 38,39,42,43 |
| 2014 | 4 June | 23 | - | | 29 Sep -8 October ; 19-28 October | 39,40,41,42,43 |
| 2015 | 28 May | 22 | 2 September | 35 | 8-17 October;18-27October | 41,42,43 |

**Table 4:** Estimated parameters of rainfall Characteristics of Cooch Behar

| Particulars | Cooch -Behar |
|---|---|
| Mean date of OEM | 4 June |
| Median date of OEM | 2 June |
| Mean deviation from mean (OEM dates) | 4 days |
| Quatrile deviation (OEM dates) | 4 days |
| Earliest probable date of OEM (p=0.50) | 31 May |
| Latest probable date of OEM (p=0.50) | 8 June |
| Mean date of EEM | 17September |
| Median date of EEM | 14 September |
| Mean deviation from mean (EEM dates) | 9 days |
| Quatrile deviation (EEM dates) | 9 days |
| Earliest probable date of EEM (p=0.50) | 8 September |
| Latest probable date of EEM (p=0.50) | 26 September |
| Average number of dry spell/year (4 days or more) | 8 days |
| Average deviation of dry days /year | 8 days |
| Average number of CDS /year | 1.78 |
| Average amount of rainfall in OEM week | 119.09 mm per week |
| Range (rainfall during OEM weeks) | 9.6 – 376.7 mm per week |
| Average amount of rainfall in EEM week | 60.50 mm per week |
| Range (rainfall during EEM weeks) | 0.4 – 632.7 mm per week |

Analysis of 21 years' rainfall data, shows OEM between 28th May to 14th June with an average rainfall of 119 mm/week. The mean and median dates of OEM are 4th and 2nd June respectively. The mean deviation from mean and quartile deviation of mean dates of different years are same i.e. 4 days.Hence the earliest and the latest probable dates of OEM are 31st May and 8th June respectively. The monsoon effectively ceased between 2nd September to 28th September with an average rainfall of 60.50 mm/week. The range of amount of rainfall during OEM week in different years is between 9.6 – 376.7 mm per week and that of EEM week between 0.4 – 632.7 mm per week. The total number of CDS is 26 during the years 1995-2015, of which 15 occur during end of October, 6 in mid October, 2 in end of September and 1 each in first part of May, mid of September and 1st part of October.

**Table 5:** Monsoon onset (week), withdrawal (week) and length (week) of Cooch Behar

| Year | Monsoon onset Week | Monsoon withdrawal Week | Annual rainfall (mm) | Length |
|---|---|---|---|---|
| 1995 | 22 | 38 | 4331 | 16 |
| 1996 | 22 | 36 | 2621.1 | 14 |
| 1997 | 23 | 38 | 3848.7 | 15 |
| 1998 | 22 | 36 | 4472.6 | 14 |
| 1999 | - | - | 4230.6 | - |
| 2000 | 22 | 38 | 3269.3 | 16 |
| 2001 | 22 | 36 | 3615.4 | 14 |
| 2002 | 22 | 39 | 2978.5 | 17 |
| 2003 | 23 | 37 | 3486.8 | 14 |
| 2004 | 24 | 39 | 3521.7 | 15 |
| 2005 | 24 | - | 3710 | - |
| 2006 | 24 | 38 | 2571.6 | 14 |
| 2007 | 22 | 36 | 2808.7 | 14 |
| 2008 | 22 | 39 | 3941.8 | 17 |
| 2009 | 22 | - | 2739.2 | - |
| 2010 | 24 | 36 | 1529.5 | 12 |
| 2011 | 23 | 38 | 2853.5 | 15 |
| 2012 | 22 | 38 | 3422.3 | 16 |
| 2013 | 23 | 36 | 2451.5 | 13 |
| 2014 | 23 | - | 2115.5 | - |
| 2015 | 22 | 35 | 2640.12 | 13 |
| Mean | 22.65 | 37.23 | 3198.068 | 14.65 |
| Mode | 22 | 38 | - | 14 |
| S.E.± | 0.813 | 1.3 | 765.16 | 1.41 |

The average onset of monsoon is 23rd SMW (4 -10th June). Its range varies from 22nd - 24th SMW over the study period. Monsoon commenced as early as 22nd SMW in1995, 1996, 2000 (28th May), 1998 (31st May), 2009 (1st June), 2002,2008 (2nd June), 2001, 2007 (3rd June). Late onset of monsoon is found on 24th SMW in 2006 (11th June), 2005 (12th June), 2004 (13th June) & 2010 (14th June). The average withdrawal of monsoon is in the 37th SMW (10 -16th September). The range of withdrawal of monsoon is 35th SMW to 39th SMW. The earliest withdrawal of monsoon is observed on 2nd September in 2015 and it is as late as 28th September in 2002, 2008& 25th September in 2004.

**Finding of different distributions:** The probability distributions viz. normal, lognormal, gamma, weibull, Exponential was identified to evaluate the best fit probability distribution for rainfall. In addition the different forms of these distributions were also tried and thus the probability distributions viz. normal, lognormal , gamma, weibull, Exponential were applied to find out the best fit probability distribution.

**Identifying the best fit distribution:** The three goodness of fit test mentioned above were fitted to the maximum rainfall data treating different data set. The test statistic of each test were computed and tested at (α=0.01) level of significance. Accordingly the ranking of different probability distributions were marked from 1 to 16 based on minimum test statistic value. The distribution holding the first rank was selected for all the three tests independently. The assessments of all the probability distribution were made on the bases of total test score obtained by combining the entire three tests. The total score of the entire three tests were summarized to identify the best fit distribution on the bases of lowest score obtained.

Finally the best fit probability distributions for maximum rainfall on different sets of data were obtained and the best fit distribution for each set of data was identified. The above methodology can also be used for studying the probability distribution pattern for other weather variables.

**Table 6:** Best Fitted Distribution and Parameter Year-Wise

| YEAR | Best fit Distribution | Parameter |
|---|---|---|
| 1995 | Gamma | α=0.48772 β=239.85 |
| 1996 | Gamma | α=0.59529 β=190.09 |
| 1997 | Weibull | α=0.53681 β=58.779 |
| 1998 | Gamma | α=0.74914 β=161.35 |
| 1999 | Gamma | α=0.8157 β=172.88 |
| 2000 | Lognormal | σ=1.3791 μ=3.8863 |
| 2001 | Weibull | α=0.58727 β=83.639 |
| 2002 | Gamma | α=0.66309 β=121.4 |
| 2003 | Weibull | α=0.56535 β=72.473 |
| 2004 | Weibull | α=0.76297 β=85.969 |
| 2005 | Gamma | α=0.78037 β=120.8 |
| 2006 | Gamma | α=0.52804 β=131.62 |
| 2007 | Gamma | α=0.67581 β=118.75 |
| 2008 | Gamma | α=0.71235 β=153.71 |
| 2009 | Gamma | α=0.96824 β=94.467 |
| 2010 | Weibull | α=0.66646 β=46.101 |
| 2011 | Weibull | α=0.64819 β=71.71 |
| 2012 | Weibull | α=0.62111 β=83.589 |
| 2013 | Weibull | α=0.74898 β=58.599 |
| 2014 | Gamma | α=0.69251 β=98.959 |
| 2015 | Gamma | α=0.90729 β=91.806 |

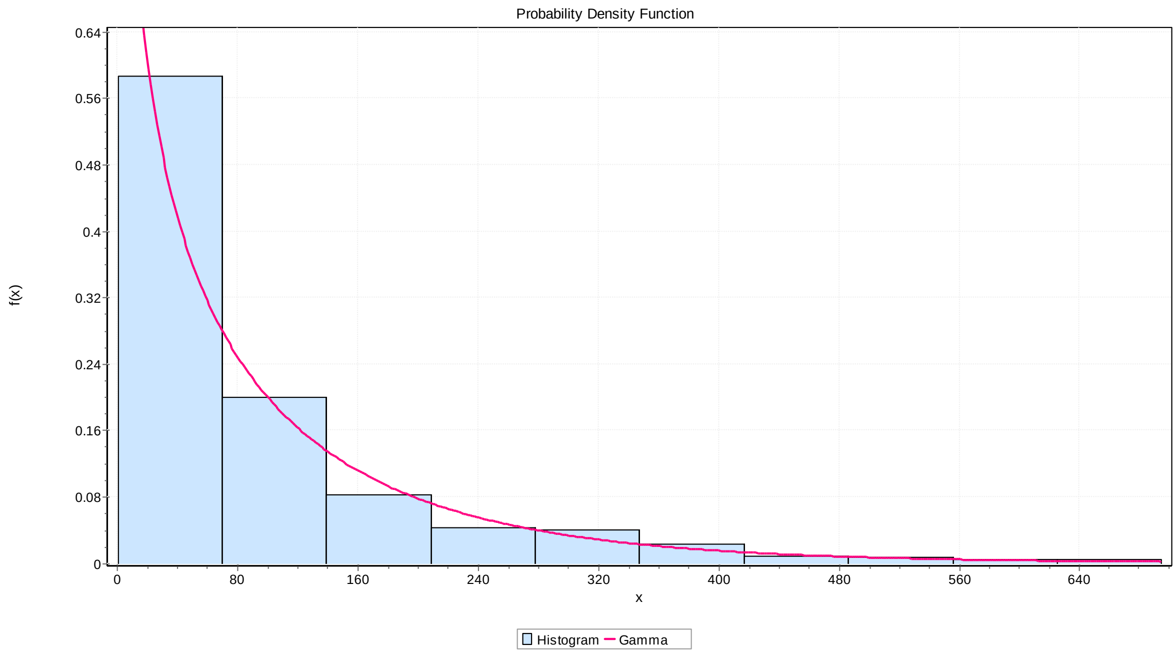



**Figure 1:** Density graph of Gamma distribution

**Table 7:** Goodness of Fit (study period 1995-2015)-Summary

| # | Distribution | Kolmogorov Smirnov | | Anderson Darling | | Chi-Squared | |
|---|---|---|---|---|---|---|---|
| | | Statistic | Rank | Statistic | Rank | Statistic | Rank |
| 1 | Exponential | 0.12124 | 3 | 30.843 | 4 | 126.06 | 4 |
| 2 | Gamma | 0.03843 | 1 | 2.1812 | 1 | 34.624 | 2 |
| 3 | Lognormal | 0.13382 | 4 | 18.71 | 3 | 110.9 | 3 |
| 4 | Normal | 0.20793 | 5 | 52.63 | 5 | 154.5 | 5 |
| 5 | Weibull | 0.06559 | 2 | 3.0505 | 2 | 28.505 | 1 |

**Table 8:** Fitting Results (study period 1995-2015)

| # | *Distribution* | *Parameters* |
|---|---|---|
| 1 | Exponential | λ =0.01074 |
| 2 | Gamma | α34366.0= β92.041= |
| 3 | Lognormal | σ1958.1 = μ4425.3= |
| 4 | Normal | σ72.411 = μ270.39= |
| 5 | Weibull | α64476.0= β 101.97= |

**Table 9:** Number of years of monsoon onset and withdrawal at Cooch Behar

| Onset of monsoon | Withdrawal of Monsoon | | |
|---|---|---|---|
| | Early (2-10 Sept.) | Normal (11-19 Sept.) | Late (20-28 Sept.) |
| Early ( 28-2 June) | 3(4249.60) | 0 | 4 (3750.43) |
| Normal( 3-8 June) | 3(2958.53) | 1(3486.8) | 3 (3635.5) |
| Late( 9-14 June) | 1(1529.5) | 0 | 2(3046.65) |
| Amount of rainfall (mm) | 2912.54 | 3486.8 | 3477.52 |

*Figure within the parenthesis is the average annual rainfall in mm.

The total annual rainfall is more than average (3198 mm) during the year in which monsoon onset is observed in 22nd and 23rd SMW. It is less than average (1529 -3046 mm) when onset is around 24th SMW. Heavy deficit in rainfall (1529.5 mm) is found when commencement of monsoon is late (around 24th SMW)but withdrawal of monsoon is early (36th SMW). Total annual rainfall is highest (4249.6 mm)when there is early commencement (22nd SMW) as well as early withdrawal (36th SMW) of monsoon. The second highest annual rainfall (3750 mm) is observed when onset of monsoon is early but its withdrawal is late. With early to normal onset of monsoon and early withdrawal the average number of dry spell is more. The earliest commencement of dry spell is observed in 1995 when there is late withdrawal of monsoon. However most CDS occur late and its occurrence varies from 36th to 44th SMW.

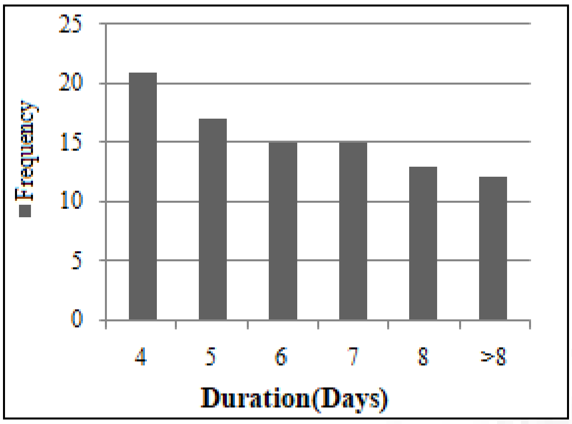



**Figure 2:** Occurrence of dry spells (≥4 days)

**Table 10:** Weekly best fit distribution & its parameter estimates

| *Week no* | *Best fit dist* | *Parameter estimate* |
|---|---|---|
| 10 | Log- logistic | α=0.82435 β=0.70477 |
| 11 | Log normal | σ=1.8401 μ=1.3782 |
| 12 | Log normal | σ=1.9756 μ=1.5481 |
| 13 | weibull | α=0.64761 β=31.478 |
| 14 | Log- logistic | α=1.9269 β=26.758 |
| 15 | Gamma | α=1.3114 β=17.587 |
| 16 | Gamma | α=1.9469 β=21.41 |
| 17 | Normal | σ=35.96 μ=47.853 |
| 18 | weibull | α=0.87393 β=61.01 |
| 19 | Gamma | α=1.7363 β=30.057 |
| 20 | Normal | σ=47.487 μ=57.9 |
| 21 | Log normal | σ=0.77245 μ=4.3988 |
| 22 | Normal | σ=77.307 μ=127.54 |
| 23 | weibull | α=1.2027 β=142.82 |
| 24 | Exponential | λ=0.00681 |
| 25 | weibull | α=1.3152 β=225.7 |
| 26 | Log normal | σ=0.76464 μ=4.7152 |
| 27 | Gamma | α=1.7926 β=109.41 |
| 28 | Exponential | λ=0.00465 |
| 29 | Gamma | α=0.86931 β=168.96 |
| 30 | Exponential | λ=0.0081 |
| 31 | Gamma | α=1.3447 β=69.256 |
| 32 | weibull | α=1.0134 β=110.85 |
| 33 | Exponential | λ=0.00502 |
| 34 | Log normal | σ=1.0367 μ=4.5407 |
| 35 | Log- logistic | α=1.8568 β=83.408 |
| 36 | weibull | α=0.82011 β=116.61 |
| 37 | Gamma | α=0.98831 β=88.867 |
| 38 | Gamma | α=0.79016 β=142.86 |
| 39 | Gamma | α=1.9844 β=51.608 |
| 40 | Exponential | λ=0.01568 |
| 41 | Exponential | λ=0.01422 |
| 42 | Log- logistic | α=0.86575 β=11.066 |

**Table 11:** Long term average weekly rainfall (mm) at different probability levels of Cooch Behar

| week | Average rainfall (mm) | P=0.3 | P=0.4 | P=0.5 | P=0.6 | P=0.7 |
|---|---|---|---|---|---|---|
| 10 | 0.77 | 1 | 0 | 0 | 0 | 0 |
| 11 | 5.30 | 2 | 0 | 0 | 0 | 0 |
| 12 | 11.35 | 7.6 | 4 | 1.8 | 0.3 | 0 |
| 13 | 28.65 | 25 | 13.5 | 6.35 | 2.1 | 0 |
| 14 | 26.30 | 25.7 | 19 | 12.85 | 5.1 | 0 |
| 15 | 20.86 | 26.05 | 20.1 | 15.35 | 11.3 | 7.7 |
| 16 | 35.7 | 46.1 | 37.05 | 29.4 | 22.55 | 15.9 |
| 17 | 43.3 | 56.8 | 42.9 | 29.6 | 15.8 | 0 |
| 18 | 60.3 | 71.8 | 51.8 | 36.8 | 25.1 | 15.8 |
| 19 | 49.8 | 61.7 | 50 | 40.4 | 31.95 | 24.2 |
| 20 | 57.9 | 77.8 | 62.1 | 47.4 | 32.8 | 17 |
| 21 | 108.1 | 21.5 | 6.55 | 2.15 | 0 | 0 |
| 22 | 127.6 | 144 | 109.6 | 77 | 44.8 | 10.4 |
| 23 | 138.7 | 166.4 | 132.6 | 105.2 | 61.6 | 60.6 |
| 24 | 139.9 | 169.4 | 127 | 94.4 | 67.6 | 4.5 |
| 25 | 205.1 | 259.4 | 210.8 | 170.6 | 135.4 | 102.9 |
| 26 | 145.6 | 25.2 | 7.05 | 2.13 | 0 | 0 |
| 27 | 196.1 | 239.4 | 196.4 | 161 | 130.2 | 102.2 |
| 28 | 215.2 | 258.4 | 196.8 | 148.8 | 109.6 | 76.4 |
| 29 | 146.9 | 174.3 | 129.8 | 95.6 | 68.4 | 46 |
| 30 | 117.1 | 148.4 | 113 | 85.5 | 63 | 44 |
| 31 | 93.1 | 113.4 | 90 | 71.3 | 55.4 | 41.3 |
| 32 | 110.6 | 132.8 | 101.6 | 77 | 57 | 40 |
| 33 | 199.1 | 239.4 | 182.4 | 138 | 101.6 | 70.8 |
| 34 | 153.0 | 30.2 | 8.85 | 2.8 | 0.89 | 0 |
| 35 | 137.8 | 0 | 0 | 5.8 | 0 | 0 |
| 36 | 139.3 | 146 | 104.8 | 74.4 | 51.4 | 33.1 |
| 37 | 87.8 | 105.6 | 80.2 | 60.5 | 44.5 | 31 |
| 38 | 107.5 | 126.3 | 91 | 64.4 | 43.5 | 26.8 |
| 39 | 97.5 | 121.2 | 99.6 | 81.6 | 65.8 | 51 |
| 40 | 54.7 | 67 | 48.6 | 34.4 | 22.7 | 12.9 |
| 41 | 53.6 | 45.2 | 45.3 | 29.6 | 16.8 | 5.9 |
| 42 | 29.9 | 9.6 | 0.145 | 0 | 0 | 0 |

Rainfall at different confidence levels show that rain started around10th SMW at 0.3 confidences level whereas it is in the 15th SMW when confidence level is 0.7. The highest PET is 24.78 mm/week in 17th SMW i.e. in the last week of May when monsoon is about to arrive. The higher values of PET (i.e. more than 14) are observed from 11th SMW i.e. middle of March to 41st SMW i.e. 2nd week of October when late autumn season is about to arrive. Once late autumn begins the PET values sharply decrease. The lowest is 3.745 mm/week at 2nd SMW i.e. in the 2nd week of January which is at the middle of winter season.

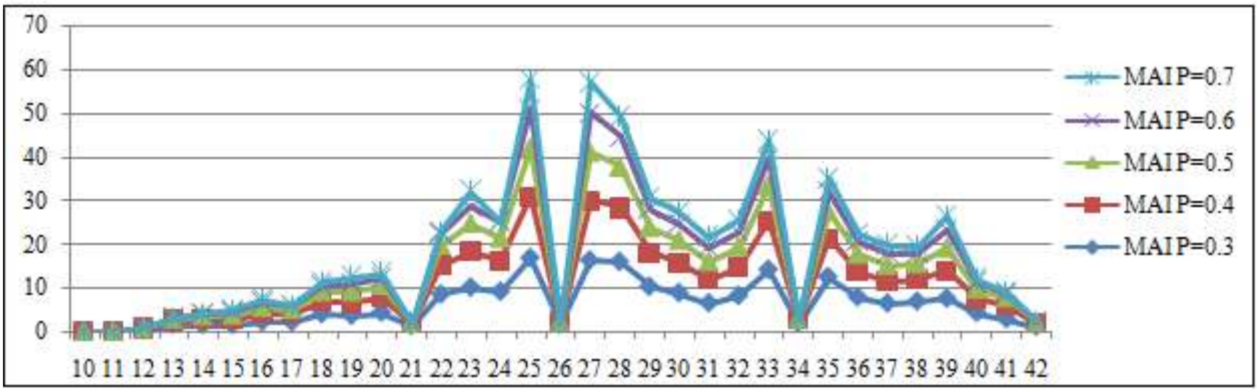



**Figure 3:** Plot of MAI values vs. week no. at different probability levels.

**Table 12:** Long term Moisture Availability Index at different probability levels of Cooch Behar

| *Week* | *Average MAI* | *MAI P=0.3* | *P=0.4* | *P=0.5* | *P=0.6* | *P=0.7* |
|---|---|---|---|---|---|---|
| 10 | 0.0635 | 0.082576 | 0 | 0 | 0 | 0 |
| 11 | 0.298 | 0.112486 | 0 | 0 | 0 | 0 |
| 12 | 0.717 | 0.480405 | 0.252845 | 0.11378 | 0.018963 | 0 |
| 13 | 1.912 | 1.668892 | 0.901202 | 0.423899 | 0.140187 | 0 |
| 14 | 1.692 | 1.653797 | 1.222651 | 0.826898 | 0.328185 | 0 |
| 15 | 1.33 | 1.661352 | 1.281888 | 0.978954 | 0.720663 | 0.491071 |
| 16 | 1.783216783 | 2.302697 | 1.850649 | 1.468531 | 1.126374 | 0.794206 |
| 17 | 1.747376917 | 2.292171 | 1.731235 | 1.194512 | 0.637611 | 0 |
| 18 | 3.445714286 | 4.102857 | 2.96 | 2.102857 | 1.434286 | 0.902857 |
| 19 | 3.014527845 | 3.734867 | 3.026634 | 2.445521 | 1.934019 | 1.464891 |
| 20 | 3.308571429 | 4.445714 | 3.548571 | 2.708571 | 1.874286 | 0.971429 |
| 21 | 7.353741497 | 1.462585 | 0.445578 | 0.146259 | 0 | 0 |
| 22 | 7.659063625 | 8.643457 | 6.578631 | 4.621849 | 2.689076 | 0.62425 |
| 23 | 8.540640394 | 10.24631 | 8.165025 | 6.477833 | 3.793103 | 3.731527 |
| 24 | 7.701624002 | 9.325626 | 6.991467 | 5.196807 | 3.721442 | 0.247729 |
| 25 | 13.50230415 | 17.07702 | 13.87755 | 11.23107 | 8.913759 | 6.774194 |
| 26 | 9.904761905 | 1.714286 | 0.479592 | 0.144898 | 0 | 0 |
| 27 | 13.53347136 | 16.52174 | 13.55418 | 11.11111 | 8.985507 | 7.05314 |
| 28 | 13.48370927 | 16.19048 | 12.33083 | 9.323308 | 6.867168 | 4.786967 |
| 29 | 8.799041629 | 10.44025 | 7.774783 | 5.726265 | 4.097035 | 2.755316 |
| 30 | 7.088377724 | 8.983051 | 6.840194 | 5.175545 | 3.813559 | 2.663438 |
| 31 | 5.46201232 | 6.652977 | 5.280141 | 4.183045 | 3.25022 | 2.422998 |
| 32 | 6.929824561 | 8.320802 | 6.365915 | 4.824561 | 3.571429 | 2.506266 |
| 33 | 11.95078031 | 14.36975 | 10.94838 | 8.283313 | 6.098439 | 4.2497 |
| 34 | 10.87420043 | 2.146411 | 0.628998 | 0.199005 | 0.063255 | 0 |
| 35 | 9.156146179 | 12.69103 | 8.770764 | 6.232558 | 4.451827 | 3.076412 |
| 36 | 7.653846154 | 8.021978 | 5.758242 | 4.087912 | 2.824176 | 1.818681 |
| 37 | 5.453416149 | 6.559006 | 4.981366 | 3.757764 | 2.763975 | 1.925466 |
| 38 | 5.952380952 | 6.993355 | 5.03876 | 3.565891 | 2.408638 | 1.483942 |
| 39 | 6.19047619 | 7.695238 | 6.32381 | 5.180952 | 4.177778 | 3.238095 |
| 40 | 3.601053325 | 4.410797 | 3.199473 | 2.264648 | 1.494404 | 0.849243 |
| 41 | 3.496412264 | 2.948467 | 2.95499 | 1.930855 | 1.09589 | 0.384866 |
| 42 | 2.440816327 | 1.216327 | 0.644898 | 0.334694 | 0.152653 | 0 |

From the above plotted graph for MAI it is observed that land preparation for olitorius Jute and direct seeded Aus rice can be started safely on 18th SMW i.e. around 1st week of May. The MAI values at the 21st SMW (i.e. end of May) are less than 0.3 at probability levels P≥0.5. This indicates that no farming operation can be done during that week. Sowing of Aman rice can be started from 22nd SMW onwards as the MAI values are more than 2 at all probability levels except at P=0.7 when MAI is at the lower limit of the range. However its sowing can be safely started from the 23rd SMW onwards. Again there is a sudden drop in moisture level in the 26th SMW when even no farming operation is possible at all probability levels P≥0.4. It implies that transplanting of rice cannot be started before 27th SMW. Another drop in moisture level is found in the 34th SMW when even no farming operation is possible at all probability levels P≥0.4. So the flowering stage of rice (considered to be most critical) should be over before 34th SMW. Again harvesting of jute must be completed by the beginning of 33rd week so that sufficient standing water is available in the canals and other low lying areas for retting of jute. This is possible if farmers can complete sowing of jute by beginning of 16th week strictly as olitorius is a 120 days crop.

## 4. Summary and Conclusion

For entire period of study although the average onset of monsoon in this area is closer to that of Kerala (normal monsoon date according to IMD, June 2) when the southwest monsoon hits its first spell in the Indian Peninsula, the average retreat of monsoon in this part of Terai zone of West Bengal occurs 2 weeks advance than withdrawal of monsoon rains from the rest of India.During 1995 to 2015 the onset of effective monsoon is delayed by one month as compared to the study period of 1971-1990. On the other hand the withdrawal of monsoon is two weeks advance in comparison to 1971-1990 (Das et al, 1996). Thus the monsoon spell is squeezed by one and half month.It maybe assumed that the arrival of monsoon rains over this part of West Bengal has relation with the onset of monsoon at Kerala. As a result, contrary to other parts of West Bengal,this region experiences about 3.5 months' duration of monsoon rains, i.e., on the average only 2 weeks more than southern part of West Bengal (Das et al, 1996).The observed variation in the OEM date is only 4 days as compared to 9 days for the period of 1971-1990. However the variation in EEM dates for both of the periods is same.In this region, there is possibility of occurrence of dry spell of 10 days or more once in every year, on the average ; the starting date of this dry spell being any time during around 1st and 2nd week of May,i.e.10days from the day of onset of monsoon. Again, such a dry spell may appear once in every year, on the average, around 2nd and 3rd week of September. There is also possibility of another such spell of dry days in this area in every in every year, on the average, anytime during 2nd and 4th week of October.The average number of dry spell per year is found to be more in comparison to the study period of 1971-1990. The average amount of rainfall observed in OEM week are almost same for both of the periods but during 1995-2015 it is less than half of the rainfall in EEM week during 1971-1990.The ability of the gamma distribution and parameter estimates to adequately fit the empirical distribution of values in the entire study period have been tested using the KS goodness of fit test. Gamma and Weibull distributions are the best fitted distributions for the rainfall years in Terai region of Cooch Behar district of West Bengal.The ability to represent the rainfall using the gamma distribution parameters allows for interpretation of the parameter estimates as a compact summary of the full rainfall distribution, through analysis of the distribution parameters, it is possible to estimate the likelihood of an area receiving rainfall amounts that would cause flooding, wash out dams or provide sufficient water to support crops.Different agricultural operations can be scheduled using different assured rainfall probabilities. Sowing of jute must be completed by the beginning of 16th week so that sufficient water is available for retting. Sowing of direct seeded Aus paddy can be safely done from 18th SMW onwards. Sowing of Aman paddy can be started from 22nd SMW onwards but its transplanting cannot be done before 27th SMW.Observed critical dry spell duration can be used as an indicator of drought risk.This research could prove valuable to a wide range of groups from scientists studying precipitation, to policy makers assessing forecast information, to farmers in crop planning.

## 5. Acknowledgement

Mere infinite thanks must not suffice to convey the sense of gratefulness and indebt ness from the core of my heart to the respected chairman of my advisory committee, Dr. S. Basak, Lecturer, Department of Agricultural Statistics, Uttar Banga Krishi Viswavidyalaya, Pundibari, CoochBehar for his auspicious and affectionate supervision, wholesome advice and encouragement, valuable suggestions, and untiring endeavor, creative criticism, abiding interest and mountain sources of inspiration throughout the course of investigation.In thanking all those people, I must emphasis that I am fully responsible for any shortcoming that remains.

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