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Determination of drainage coefficient and bund height of rice fields at Gaya and Bhagalpur districts in Bihar

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ABSTRACT

Rainfall plays an important role in agricultural production, particularly in rainfed areas. Less occurrence of rainfall causes drought like situation and crops suffer due to deficit of water, whereas heavy rainfall occurring for longer duration lead to flood like situation resulting in more runoff, soil erosion and crop damage. Rice can sustain water for little longer period compared to other crops, but this crop also needs drainage. 30 years daily rainfall data was collected at Gaya and Bhagalpur districts and analyzed. Two parameter Gamma distribution model was found fitting well in 1 to 7 consecutive days maximum rainfall corresponding to return periods varying from 2 to 20 years. In order to determine drainage coefficient at Gaya and Bhagalpur districts, depth-duration-return period curves were developed. Tangents were drawn on the curves from 100 mm, 150 mm and 200 mm points and slope of these tangents gave the drainage coefficients corresponding to these rain water storage levels. Since 10 years return period is generally considered in design of agricultural structures, so the poin ton Y axis, where tangent drawn on the curves of 10 years return period crosses, gives the bund height. For both Gaya and Bhagalpur bund heights were found as 24 cm and corresponding drainage coefficients as 12.5 and 25 mm/day.

Keywords: Rainfall, Drainage coefficient, Return period, Gamma distribution, Bund height

INTRODUCTION

Rainfall is one of the most important factors, which decides the fate of rainfed agriculture, predominant in India. The amount, intensity, duration and distribution of rainfall vary with time and space and it is a stochastic phenomenon. It can be predicted at different probability levels depending on the most befitting probability distribution model. Various probability distribution models like Normal, Log Normal, Pearson, Log Pearson, Extreme, Log Extreme, and Two parameter Gamma distribution on one day to 7 consecutive days maximum rainfall, weekly, monthly and annual rainfall at Bhubaneswar were tried. They observed that Two parameter Gamma distribution model was the only probability distribution, which was fitting well under all the situations. Keeping this in view, Two parameter Gamma distribution model was tried on weekly, monthly and annual rainfall as well as 1 to 7 consecutive days maximum rainfall at Patna and it was found fitting well as reported by Upadhyaya *et al.* (2009) and Roy and Upadhyaya (2017).

To meet out crop water requirement, if there is less rainfall, irrigation is required to save the crop and if there is heavy rainfall, drainage is required to save the crop root from damage. So, timely application of irrigation and drainage decides the fate of crop growth and production. Excess water deposition in the field either due to heavy rainfall or due to flow from other regions damages the crop, if water stagnation period is more than the crop tolerance period. The tolerance period of Rice for water is more than other crops, but rice also needs adequate drainage at appropriate time, otherwise its production will be adversely affected. So there is a need to develop surface drainage criteria for Rice crop. Roy and Upadhyaya (2017) developed drainage criteria for Patna and determined drainage coefficient corresponding to different level of storage in field and return periods. In this paper, 30 years one to seven consecutive days maximum rainfall has been analyzed at Gaya and Bhagalpur districts employing Two parameter Gamma distribution model and drainage coefficients as well as bund heights have been determined using Depth-duration-return period curves.

MATERIALS AND METHODS

The study area comes under Eastern part of the country, which has seasons SW Monsoon (June-September),NE Monsoon (October- December), winter (January- Feb) with single rainfall peak. This case study area experiences mono-model type rainfall characterized by single rainfall peak during a year. The location and rainfall details are as described below.

GAYA

Gaya has Latitude of $24^0 16'20''$ N, Longitude of $84^0 17'$ E to $84^0 23'30''$ E. It is situated at 111 m above sea level. Rice is the major field crop with productivity of 3352 (kg/ha). Normal rainfall in SW monsoon (June-sep) is 950 mm in NE monsoon (Oct-Dec) is 68.7 mm, in winter (Jan-Feb) is 35.1 mm and in summer (Mar-May) is 33.4 mm as shown below in Fig. 1.

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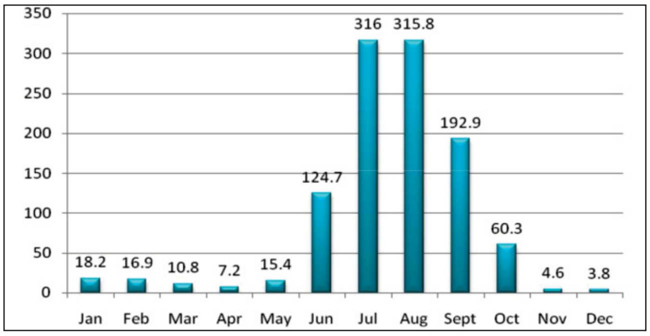

Fig. 1: Mean Annual Rainfall for Gaya District
(Source: krishi.bih.nic)

BHAGALPUR

It is situated between 25^0 77N to 25^0 3N latitude and longitude of 80^0 37 to 87^0. Altitude of the place is 42.9 m. Rice is major field crop with productivity of 2342 (kg/ha). Normal rainfall in SW monsoon (June-Sep) is 992 mm, in NE monsoon (Oct-Dec) is 97 mm, in winter (Jan-Feb) is 26 mm and in summer (Mar-May) is 93mm as shown below in Fig. 2.

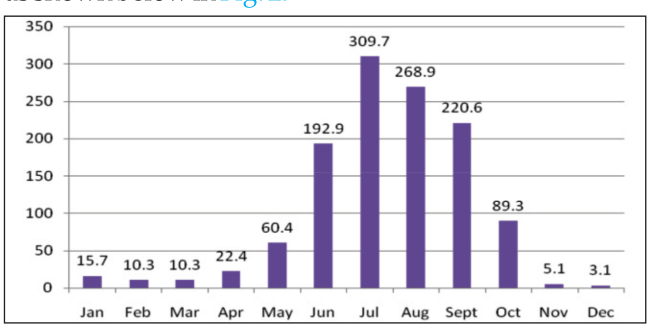

Fig. 2: Mean Annual Rainfall in Bhagalpur District
(Source: krishi.bih.nic)

In order to study the variability of rainfall at Gaya and Bhagalpur area, daily rainfall data were collected for 30 year from 1986 to 2015 and 1 day to 7 consecutive days maximum rainfall for 30 years were generated. These hydrologic data series were analyzed by two parameter Gamma distribution model. The details of this model are given below.

Two parameter Gamma distribution model

Two parameter Gamma probability function as defined by Hogg and Craig (1969) and Mooley (1974) is

$$f(Y) = \frac{Y^{\alpha-1} e^{\frac{-Y}{\beta}}}{B^{\alpha}\Gamma(\alpha)}$$

and two parameter gamma distribution function is defined as

$$P(\alpha,\beta,Y,) = \left(\frac{Y}{\beta}\right)^{\alpha} \frac{e^{\frac{-Y}{\beta}}}{\Gamma(\alpha+1)} M\left(1, 1+\alpha, \frac{Y}{\beta}\right)$$

Where M $(1, 1+\alpha, \frac{Y}{\beta})$ is Kummer function and is defined as

$$M\left(1,1+\alpha,\frac{Y}{\beta}\right) = 1 + \frac{1.(\frac{Y}{\beta})}{(1+\alpha)} + \frac{1.2.(\frac{Y}{\beta})^2}{(1+\alpha).(2+\alpha).2!} + \cdots + \frac{1.2.3 \ldots n.(\frac{Y}{\beta})^n}{(1+\alpha).(2+\alpha)\ldots(n+\alpha).n!}$$

Here α and β are shape and scale parameters, respectively. These parameters are defined as:

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{\left(1 + 4\frac{A}{3}\right)}\right)$$

In which $$A = \ln Y_m - \frac{\sum_{i=1}^{n} \ln Y}{n}$$

Here n is the number of values in data series greater than zero, Y_m is the arithmetic mean of consecutive days maximum rainfall values. α can be corrected for biasness and thus estimated value of α becomes

$$E(\alpha) = (n-3)\frac{\alpha}{n} \quad \text{for } n \geq 4$$

And estimated value of β becomes

$$\beta = \frac{Y_m}{\alpha}$$

Chi-square test statistics is computed employing the equation given below.

$$x_v^2 = \frac{\sum_{i=1}^{n}(y_i - y_m)^2}{\beta^2 \alpha}$$

Computed Chi-square values are compared with tabulated Chi-square values for (n-1) degree of freedom at 95% confidence level. If computed Chi-square value at 95% confidence level is less than Chi-square value given in the table then the Gamma distribution fits the series of one day as well as consecutive days maximum rainfall series.

In order to determine the rainfall values at desired probability levels, probabilities were calculated for the rainfall values starting from 2 mm with an increment of 2 mm and ending to the values at which probability becomes 99%. A table having rainfall values and probability was generated from above analysis. In order to compute rainfall values at different probability levels the technique of linear interpolation as defined below was employed.

If at level of probability, P, value of rainfall, R, has to be determined and corresponding to Pi and Pi+1are known, then interpolated value of rainfall, R, was computed as below.

$$R = \frac{(R_{i+1} - R_i)}{(T_{i+1} - T_i)}(T - T_i) + R_i$$

A computer programme was written in FORTRAN 90 to create tables containing 1 to 7 consecutive days' maximum rainfall as well as probabilities and technique of linear interpolation to compute rainfall at desired probability levels or corresponding return periods.

Two Graphs for Gaya and Bhagalpur were developed for different return periods by considering rainfall (mm) on Y axis and days on X axis. Best fit curves were plotted and tangents were drawn on these curves from 100 mm and 150 mm rainfall points on Y axis. The slope of the tangent gave drainage coefficient corresponding to desired return period. In design of agricultural structures, generally 10 years return period is considered. So, the point on Y axis, where the tangent drawn on the highest point of 10 years return period curve cuts, gives bund height.

RESULTS AND DISCUSSION

One day maximum rainfall to seven consecutive days maximum rainfall were calculated from daily rainfall data for 30 years at Gaya and Bhagalpur employing Computer programme written in FORTRAN 90 and are given in Table 1 and Table 2. These maximum rainfalls were analyzed by two parameter Gamma distribution model. One to seven consecutive days' maximum rainfall corresponding to different return periods (*i.e.* reverse of probability levels) at Gaya and Bhagalpur are shown graphically in Fig. 4 and Fig. 5, respectively.

Table1: Maximum Consecutive Day Rainfall at Gaya for 30 Years (1986-2015)

Year	1 Day Max	2 Days Max	3 Days Max	4 Days Max	5 Days Max	6 Days Max	7 Days Max
1986	74.4	78.1	80.6	104.2	126.9	128.8	137.3
1987	68.6	94.5	109.7	144.5	163.9	165.2	190.0
1988	119.0	132.1	160.8	170.4	175.6	175.6	182.6
1989	79.7	84.6	105.7	122.0	129.1	143.1	166.5
1990	119.6	223.5	274.3	307.9	397.9	409.1	457.6
1991	95.7	136.0	148.0	148.0	148.0	148.0	198.0
1992	167.6	225.6	299.7	335.1	390.3	408.9	412.7
1993	149.1	222.1	278.5	285.3	293.3	327.3	327.3
1994	123.5	135.3	145.5	171.5	181.7	212.8	224.6
1995	55.3	72.6	82.8	93.4	126.6	129.4	129.4
1996	118.5	189.7	248.4	272.3	289.4	290.9	292.0
1997	65.6	94.6	107.3	155.3	184.2	194.0	196.3
1998	94.2	130.2	145.2	148.4	156.9	158.9	159.9
1999	79.3	103.0	113.4	149.0	178.0	188.4	189.1
2000	90.3	116.2	121.2	122.6	152.8	154.2	170.4
2001	115.7	116.5	119.6	126.6	126.6	132.0	135.0
2002	87.0	102.5	107.0	107.0	107.0	132.4	152.2
2003	63.2	123.75	181.65	206.05	247.35	298.15	338.55
2004	63.0	99.7	111.6	126.6	126.8	126.8	126.8
2005	84.8	85.0	108.9	133.4	152.3	172.9	173.5
2006	66.8	88.2	99.2	104.0	104.6	104.6	106.0
2007	77.6	80.8	84.8	109.2	112.4	112.8	127.2
2008	75.8	119.9	152.6	198.4	239.4	243.8	245.8
2009	118.6	133.6	146.5	159.6	160.1	203.8	242.3
2010	210.0	212.1	248.7	252.1	264.3	272.5	272.5
2011	85.0	85.8	109.6	116.0	128.2	129.2	129.2
2012	144.2	256.4	290.8	292.6	292.6	300.3	306.3
2013	117.4	200.4	201.2	235.4	266.4	273.0	273.4
2014	88.0	105.6	122.3	131.2	141.6	167.3	174.7
2015	169.2	196.2	210.6	226.8	252.8	266.6	266.6

Table 2: Maximum Consecutive Days Rainfall at Bhagalpur for 30Years (1986-2015)

Year	1 Day Max	2 Days Max	3 Days Max	4 Days Max	5 Days Max	6 Days Max	7 Days Max
1986	60.5	81.9	98.2	118.2	119.4	135.4	163.6
1987	83.2	91.6	106.3	144.2	155.1	167.6	175.9
1988	183.5	206.9	213.3	217.5	236.9	241.1	294.3
1989	92.1	100.9	137.6	157.7	169.8	169.8	198.3
1990	85.3	92.4	102.3	115.9	132.3	132.3	152.7
1991	77.8	105.5	105.5	121.6	133.6	162.1	186.5
1992	102.5	138.4	152.7	164.3	175.9	179.5	180.3
1993	227.2	350.1	486.8	502.8	516.6	524..0	528.2
1994	100.0	134.45	184.05	230.7	274.4	290.9	292.0
1995	92.0	112.2	119.2	125.9	146.2	168.1	168.1
1996	67.7	83.0	84.5	133.2	135.4	136.9	142.6
1997	66.1	90.0	137.4	141.8	142.9	142.9	150.9
1998	81.2	91.3	112.5	117.4	135.3	139.7	145.6
1999	96.6	116.4	136.5	163.7	177.8	187.8	188.4
2000	183.5	200.9	213.3	217.5	236.9	241.1	294.3
2001	55.0	72.5	82.5	82.5	82.5	82.5	99.0
2002	134.4	136.0	146.0	158.3	188.3	215.5	232.8
2003	110.0	179.1	192.1	217.7	248.7	276.9	276.9
2004	102.7	138.7	173.5	210.2	246.2	281.7	315.8
2005	141.3	170.5	180.5	189.1	258.7	335.9	341.1
2006	132.5	220.2	263.1	317.2	403.2	446.1	471.3
2007	110.2	162.4	176.3	187.7	194.3	219.8	221.6
2008	71.1	95.7	130	143.4	156.2	168.4	172.4
2009	134.2	203.8	268.2	314.0	320.5	325.5	392.0
2010	62.8	105.5	114.1	141.9	160.6	166.7	171.8
2011	152.1	195.1	208.2	212.8	224.3	241.5	246.0
2012	136.4	247.1	277.2	323.6	329.0	329.0	341.8
2013	123.7	173.0	203.0	203.5	210.3	237.9	262.1
2014	69.3	86.5	99.1	104.7	115.7	132.1	133.5
2015	153.0	175.7	175.7	178.0	193.4	193.4	194.1

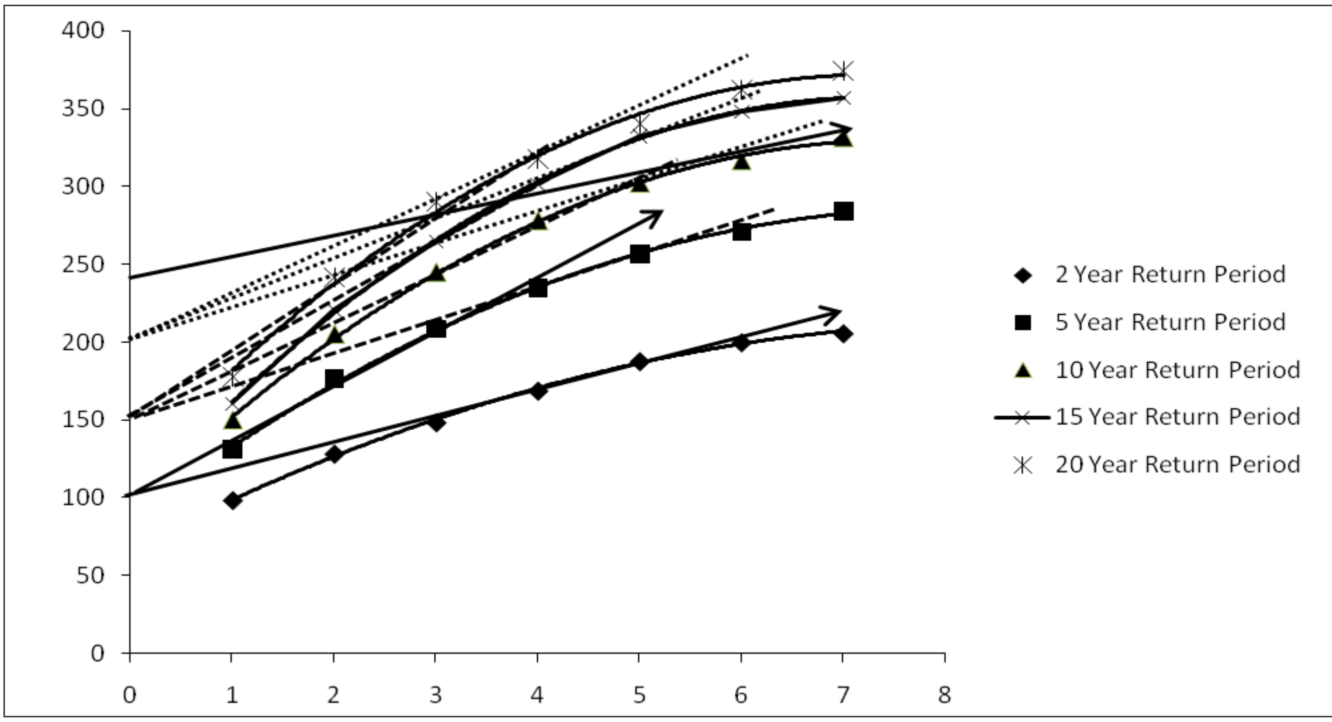

Fig 3: Rainfall depth-duration-return period curves at Gaya

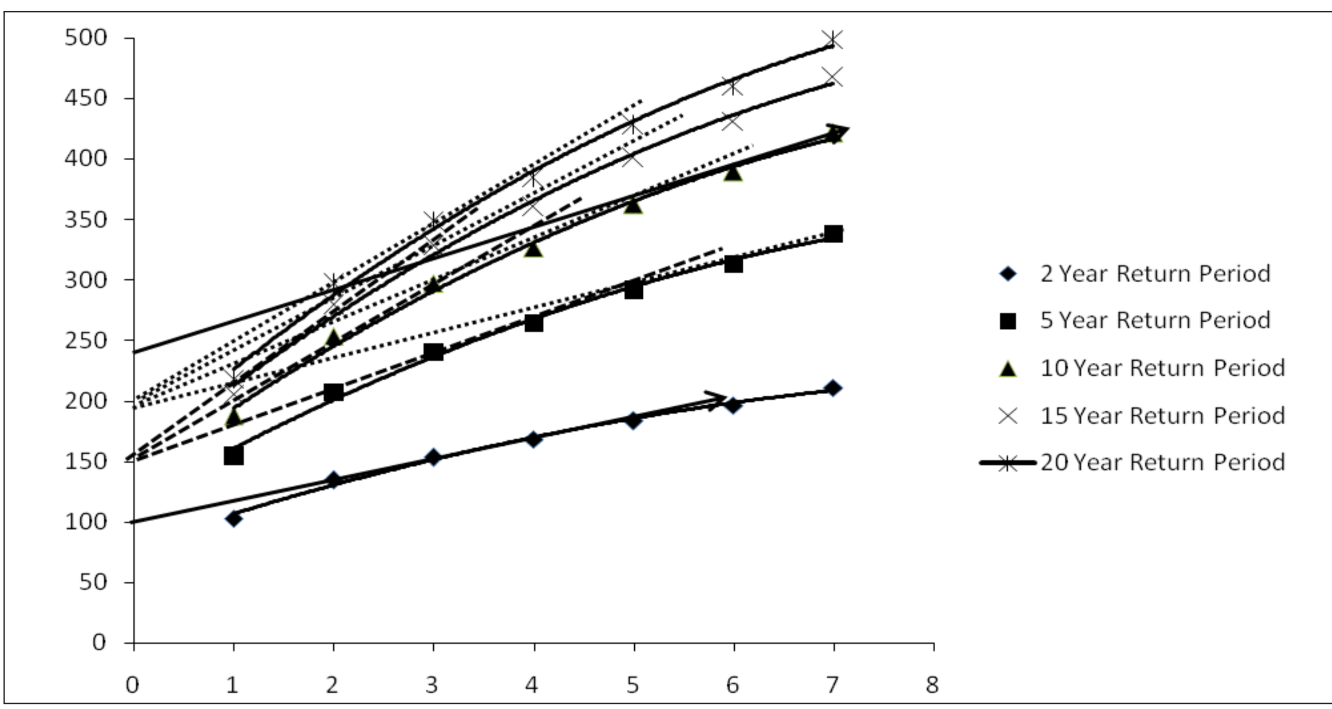

Fig. 4: Rainfall depth-duration-return period curves at Bhagalpur

From these figures, slopes of 100, 150 and 200mm tangents were computed. These slopes are basically drainage coefficients (water to be drained in a day expressed as mm/day) corresponding to different level of storage and return periods. Drainage coefficients computed at Gaya and Bhagalpur are given below in Table 3and Table 4.

It is evident from above tables that the values of drainage coefficients computed for Bhagalpur are more than those for Gaya.The tangents drawn on maximum point of 10 years return period curve at Gaya and Bhagalpur cutes Y axis at 240 mm, so bund height of 24 cm around rice fields at Gaya and Bhagalpur may be recommended. Drainage coefficients

Table 3: Drainage coefficient (mm/day) corresponding to different return periods

Return period (years)	Storage		
	100 mm	150 mm	200 mm
2	17.5	-	-
5	36.0	21.4	-
10	-	31.6	20.0
15	-	40.0	25.0
20	-	45.5	35.0

Table 4: Drainage coefficient (mm/day) corresponding to different return periods at Bhagalpur

Return period (years)	Storage		
	100 mm	150 mm	200 mm
2	17.5	-	-
5	-	27.5	20.0
10	-	46.7	32.5
15	-	55.0	41.2
20	-	-	50.0

corresponding to this bund height for Gaya and Bhagalpur are computed as 12.5 mm/day and 25 mm/day, respectively. This is because one day as well as consecutive day's maximum rainfall at Bhagalpur is more than Gaya.

CONCLUSIONS

One day as well as seven consecutive days maximum rainfall at Gaya and Bhagalpur was computed and two parameter Gamma distribution model was found fitting well the rainfall series because computed chi square values were less than tabulated chi square values.Rainfall values corresponding to different return periods were computed and depth-duration-return period curves were developed. Drainage coefficients were computed for Gaya and Bhagalpur. Bund height to store rainfall at Gaya and Bhagalpur were found as 24 cm. Since consecutive days rainfall at Bhagalpur was more than Gaya, so drainage coefficients was also more i.e 25 mm/day at Bhagalpur than 12.5 mm/day at Gaya corresponding to 24 cm bund height.

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