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Determination of Maximum Storage and Drainage Coefficient from Consecutive Days Maximum Rainfall at Different Locations in India

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ABSTRACT

Knowledge about the maximum possible storage of rainwater in the field and its safe disposal is very important to save crops from the adverse impact of excess rainfall. Keeping this in view, daily rainfall data of 30 to 35 years as per availability was analyzed at four centres of All India Coordinated Research Project on Water Management i.e. (i) Samastipur (ii) Ludhiana, (iii) Hisar, and (iv) Almora. In the design of agricultural structures, generally, 10 years return period is considered, so the point, where tangent drawn on the curves of 10 years return period crosses the Y-axis, gives maximum possible storage (recommended bund height) in rice fields. Maximum possible storage (bund height) corresponding to 10 years return period was found as 25 cm, 15 cm, 13 cm, and 27.5 cm and corresponding drainage coefficient as 26.3 mm/day, 6.8 mm/day, 8.4 mm/day and 24.8 mm/day for Samastipur, Ludhiana, Hisar and Almora, respectively.

KEYWORDS

Consecutive days rainfall, Return Period, Drainage Coefficient, Storage, Bund height

INTRODUCTION

Rainfall plays a major role in recharging the soil with moisture and supplying the required quantity of water to plant through the root and ultimately influencing crop production. Rainfall characteristics such as amount, intensity, duration, and distribution vary with time and space. Basically, it is a probabilistic phenomenon and a lot of uncertainty is involved with it, so prior planning and development of better rainwater management strategies including storage and drainage is the need of the hour. Generally, low intensity rainfall occurs for longer duration and high intensity rainfall occurs for a shorter duration. In case of low intensity rainfall recharge into the soil is more and runoff is less. On the other hand, in case of high intensity rainfall, the recharge is less and runoff is more due to less infiltration opportunity time. In order to improve rainwater utilization efficiency, it is important to store and utilize it in crop production. It is equally important to safely dispose of excess water from the rice field, once water stagnation has crossed the crop tolerance period, otherwise, it will have an adverse impact on crop production.

Keeping in view, Bhattacharya *et al.* (1982) also reported that the total amount of rainfall over duration of crop tolerance period is essential for determining drainage rate for agricultural crops. Panda *et al.*(1996) proposed an approach to determine design discharge and modification in cross-section of open drains in the delta area of Odisha. His approach was based on rainfall depth-duration-frequency curves analysis. Upadhyaya and Singh (1997) analyzed 42 years 1 day and 2 to 6 consecutive days rainfall data of 5 to 20 years return period at Bhubaneswar and determined design discharge and storage by employing graphical and numerical methods. A bund of 22.5 cm height around rice fields was recommended at Bhubaneswar. Similarly, Panda and Rajput (2003) also developed water budgeting process by using field gradient and bund height and reported the value of drainage coefficient 100mmm/day for 5 years return period corresponding to 22 cm bund height in costal paddy areas of Orissa. Patle *et al.* (2005) determined the surface drainage coefficient for agricultural watershed at Akola by using 25 years daily rainfall data and developed depth – duration – frequency curve of one to four consecutive days rainfall values for 2, 5, 10 and 20 years recurrence interval (R.I.). Dabral *et al.* (2016) revealed that the maximum value of drainage coefficient for 2 to 7 days consecutive rainfall at 25 years recurrence interval using probability distribution functions varied from 41.37 mm /day to 304.23 mm/ day for Doimukh (Arunachal Pradesh).

Roy and Upadhyaya (2017) applied the Graphical method on 1 to 7 consecutive days maximum rainfall at Patna and determined drainage coefficient corresponding to the different levels of storage in fields and return periods. Upadhyaya and Roy (2018) determined the drainage coefficient and bund height around rice fields at Gaya and Bhagalpur districts of Bihar employing graphical method. For both Gaya and Bhagalpur, bund heights were found as 24 cm and corresponding drainage coefficients as 12.5 and 25 mm/day, respectively. The above review indicates that the Graphical method of determining drainage coefficient and bund height is quite reliable and can be employed to determine drainage coefficient and bund height at other locations too.

Keeping this in view, a study was undertaken at 4 centres (i.e. Samastipur, Ludhiana, Hisar, and Almora) of All India Coordinated Research Project on Water

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Management and the objective was to determine i) bund height for maximum possible storage of rainfall and drainage coefficient of safe disposal of excess water and ii) drainage coefficient for draining excess rainfall water from paddy fields at bund height of 100, 150, and 200 mm at those study locations employing graphical method.

MATERIALS AND METHODS

The study areas are Samstipur, Hisar, Ludhiana and Almora districts in India, which is characterized by seasonal SW monsoonal rainfall (Fig.1).

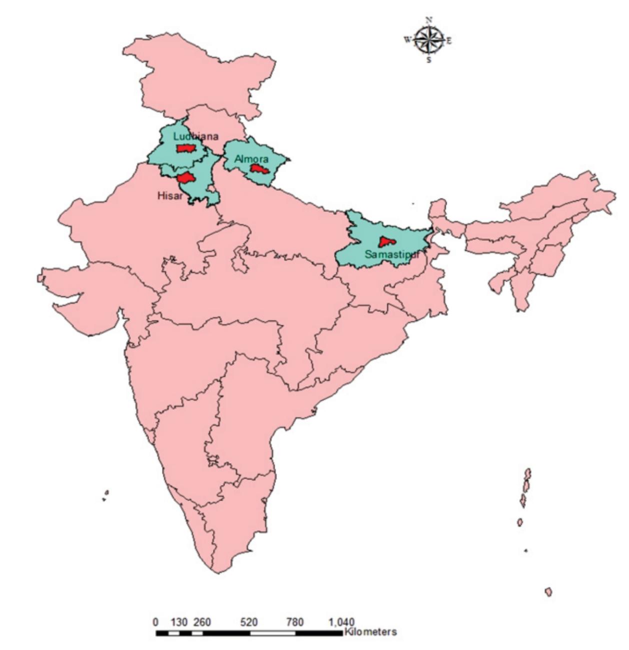

Fig. 1: Location of study areas

The location and rainfall details of study areas are as described below:

Samastipur

Samastipur is located in Bihar having latitude 25°51'21.70" N and longitude 85°47'12.56" E, which is situated at an elevation of about 51 m above MSL (Mean Sea Level). The average rainfall of the study area is about 1097 mm.The minimum temperature varies from 10.1^0 C to 26.4^0 C and maximum temperature from 23.6^{0}C to 37.5^{0}C (Fig. 2).

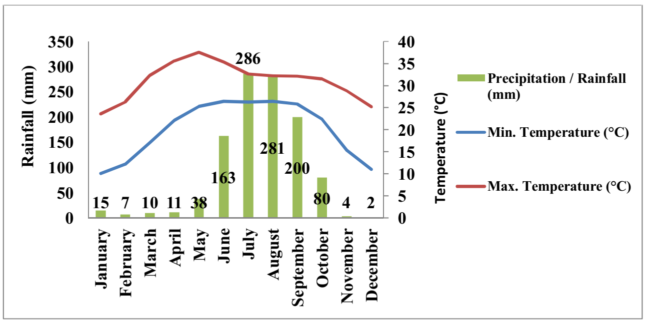

Fig. 2: Weather parameters of Samastipur
(Source:https://en.climate-data.org/asia/india/bihar/samastipur-24636/)

Ludhiana

Ludhiana is located in Punjab having latitude 30°54'3.47" N and longitude 75°51'26.19" E, which is situated at an elevation of about 253 m above MSL. The average rainfall of the study area is approximately 726 mm and rainfall reaches a peak in the month of August. The minimum temperature varies from 5.7^{0}C to 26.9^{0}C and maximum temperature from 20.1^{0}C to 41^0 C with average monthly temperature 24.3^{0}C (Fig. 3).

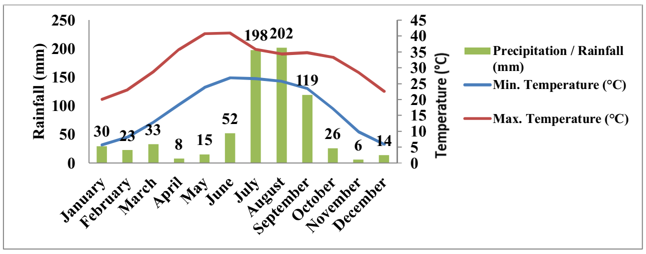

Fig. 3: Weather parameters of Ludhiana
(Source:https://en.climatedata.org/asia/india/punjab/ludhiana-889/)

Hisar

Hisar is located in the west-central part of Haryana having latitude 29° 8'57.08" N and longitude 75°43'17.95" E, which is situated an elevation of about 213 m above MSL. The average rainfall of the study area is approximately 459 mm out of which around 75 to 80 % received during SW monsoon. Minimum and maximum temperature varies from 5.8^0 C to 27.5^{0}C and 21.8^{0}C to 41.5^{0}C,respectively (Fig. 4).

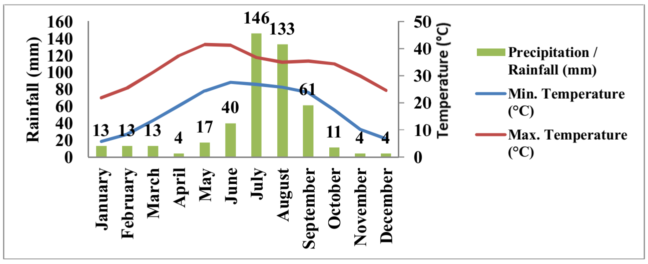

Fig. 4: Weather parameters of Hisar
(Source: https://en.climate-data.org/asia/india/haryana/hisar-51124/)

Almora

Almora is located in Uttarakhand having latitude 29°35'21.16" N and longitude 79°38'47.98" E, which is situated at an elevation of about 1633 m above MSL. The average rainfall of the study area is approximately 1575 mm and averge annual temperature 14.4 C^0. Minimum and maximum temperature varies from 1.8^{0}C to 14.8^{0}C and 11.5^{0}C to 25.9^{0}C, respectively (Fig. 5).

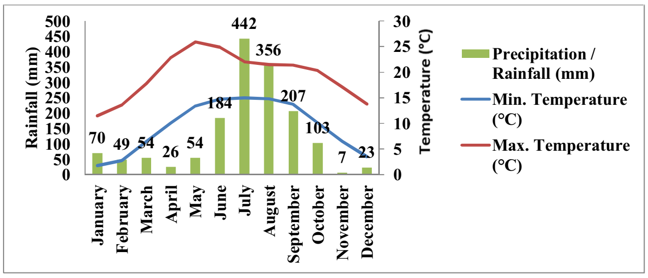

Fig. 5: Weather parameters of Almora
(Source:https://en.climate-data.org/asia/india/uttarakhand/almora-24758/)

1 to 10 consecutive days maximum rainfall was calculated from available daily rainfall data for the period varying from 30 to 35 years at four locations i. e. Samastipur, Hisar, Ludhiana and Almora districts using a computer programme written in FORTRAN-90. One to ten consecutive days maximum rainfall was arranged in descending order and Gringorten's plotting position method was employed to determine rainfall corresponding to different probability of exceedance levels (i.e. inverse of Return Period). Gringorten's formula used to compute rainfall corresponding to different probability levels is given below:

$$P(X \geq X_m) \frac{m-b}{n+1-2b}$$

Where $P(X \geq X_m)$) is probability of exceedance; m is rank number; n is total number of years, and b is a coefficient (0.44). Rainfall depth and duration curves corresponding to various return periods of 5, 10, 15, 20 years were developed for all the four locations and then, maximum bund height around paddy fields and design discharge to dispose off excess water from paddy fields at each location were calculated using the graphical method described by Upadhyaya and Singh (1997).

RESULTS AND DISCUSSION

Table 1 shows the relationship between rainfall depth and return period for 1 to 10 consecutive days of maximum rainfall. It has been observed that best fit second order polynomials describe well the relationship between rainfall depth and return period for 1 to 10 days maximum rainfall.

Table 1: Relation between rainfall depth and return period for 1 to 10 days consecutive days maximum rainfall

Consecutive day	Relationship between Rainfall and Return Period (2nd order equation)			
	Samastipur	Ludhiana	Hisar	Almora
1-day	R1 = -0.325RP² + 15.65RP + 71.77	R1 = -0.181 RP² + 12.00 RP + 29.67	R1 = -0.163 RP² + 10.88 RP + 33.52	R1 = -0.276 RP² + 14.46 RP + 84.7
2-day	R2 = -0.376RP² + 18.82RP + 100.5	R2 = -0.044 RP² + 8.392 RP + 69.9	R2 = -0.168 RP² + 11.94 RP + 45.4	R2 = -0.55 RP² + 23.33 RP + 83.45
3-day	R3 = -0.538 RP² + 24.81 RP + 109.9	R3 = -0.138 RP² + 11.67RP + 57.4	R3 = -0.163 RP² + 12.31 RP + 51.27	R3 = -0.741 RP² + 29.65 RP + 95.07
4-day	R4 = -0.594 RP² + 28.04 RP + 130.9	R4 = -0.377 RP² + 17.15 RP + 46.24	R4 = -0.155 RP² + 11.74 RP + 61.67	R4 = -0.646 RP² + 29.55 RP + 128.3
5-day	R5 = -0.69 RP² + 31.87 RP + 142.7	R5 = -0.367 RP² + 17.36 RP + 55.07	R5 = -0.178 RP² + 12.75 RP + 66.45	R5= -0.72 RP² + 32.56 RP + 149.3
6-day	R6 = -0.829 RP² + 37.19 RP + 147.0	R6 = -0.261 RP² + 14.70 RP + 74.08	R6= -0.189 RP² + 13.17 RP + 69.77	R6 = -0.713 RP² + 34.72 RP + 162.6
7-day	R7= -0.817 RP² + 36.56 RP + 164.2	R7 = -0.139 RP² + 11.26 RP + 102.2	R7= -0.195 RP² + 13.28 RP + 78.97	R7 = -0.828 RP² + 36.84 RP + 176.7
8-day	R8 = -0.839 RP² + 38.30 RP + 168.6	R8 = -0.086 RP² + 10.38 RP + 111.4	R8 = -0.201 RP² + 13.47 RP + 82.72	R8 = -1.295 RP² + 49.44 RP + 128.8
9-day	R9 = -0.861 RP² + 40.11x RP + 174.0	R9 = -0.193 RP² + 13.60 RP + 96.53	R9 = -0.218 RP² + 14.26 RP + 83.65	R9= -1.094 RP² + 44.65 RP + 166.8
10-day	R10= -0.879 RP² + 40.52 RP + 183.4	R10 = -0.104 RP² + 10.82 RP + 124.4	R10 = -0.216 RP² + 14.05 RP + 88.95	R10 = -0.46 RP² + 29.92 RP + 255

Maximum rainfall of one to ten consecutive days corresponding to different return periods (5 to 20 years) at Samastipur, Ludhiana, Hisar and Almora districts are graphically shown in Figs. 6, 7, 8 and 9, respectively.

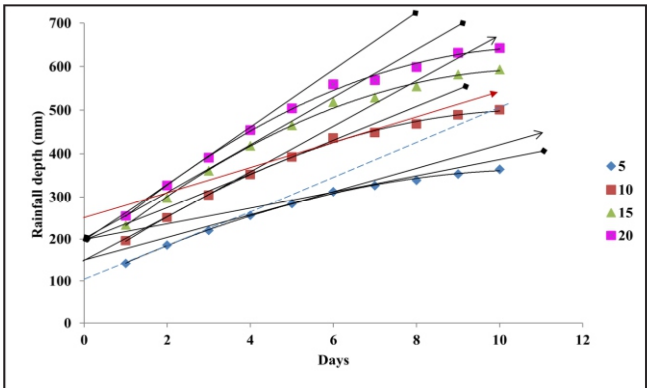

Fig. 6: Rainfall depth-duration-return period curves at Samastipur

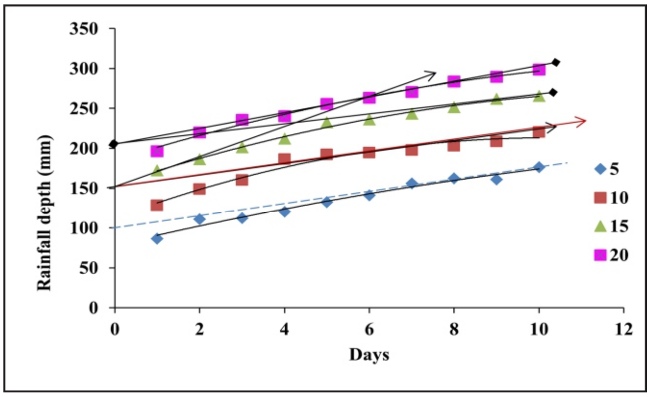

Fig. 7: Rainfall depth-duration-return period curves at Ludhiana

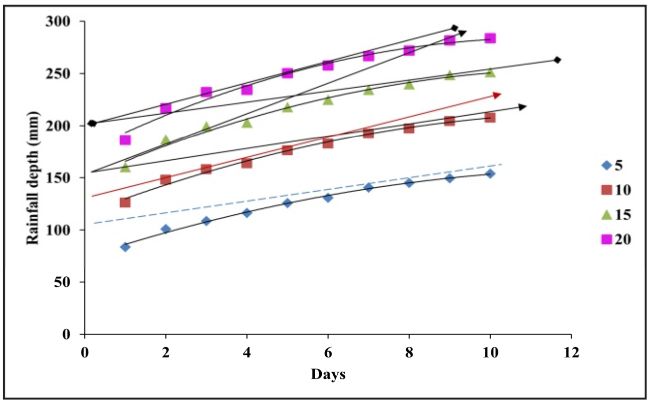

Fig. 8: Rainfall depth-duration-return period curves at Hisar

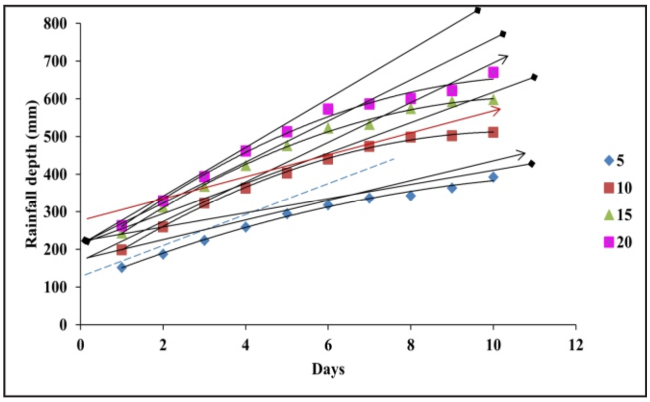

Fig. 9: Rainfall depth-duration-return period curves at Almora

From these figures, slopes of tangents drawn on curves of various return periods from 100 mm, 150 mm and 200 mm rainfall depth points were calculated, which represent drainage coefficients corresponding to different level of storage and return periods. It may be observed that the slope of tangent lines increase with increase in return period and decrease with increase in storage. Drainage coefficients computed at Samastipur, Ludhiana, Hisar and Almora, are given in Table 2. The tangents drawn on maximum point of 10 years return period curves have given the recommended bund height at Samastipur, Ludhiana, Hisar and Almora districts (Table 2).

Table 2: Drainage coefficient (mm/day) corresponding to different return periods at different locations in India

Different locations	Bund height and Drainage coefficient corresponding to 10 years return period		Return period (years)	Drainage coefficients (mm/day)		
	Bund height (cm)	Drainage coefficient (mm/day)		100 mm Storage	150 mm Storage	200 mm Storage
Samastipur	25	26.3	5	30.7	23.5	16.4
			10	-	40.6	33.5
			15	-	-	45.0
			20	-	-	51.1
Ludhiana	15	6.8	5	7.1	-	-
			10	-	6.8	-
			15	-	13.1	5.9
			20	-	-	10.2
Hisar	13	8.4	5	5.2	-	-
			10	-	5.5	-
			15	-	11.5	4.4
			20	-	-	9.0
Almora	27.5	24.8	5	32.2	25.0	17.9
			10	-	42.7	35.6
			15	-	-	46.3
			20	-	-	52.3

Conclusions

Maximum rainfall of 1 to 10 consecutive days at four locations i.e. Samastipur, Ludhiana, Hisar and Almora were computed and depth-duration-return period curves were developed. Gringorten's plotting position method was employed to determine 1 day as well as 2 to 10 consecutive days maximum rainfall corresponding to return periods varying from 5 to 20 years. It was observed that the drainage coefficient increases with increase in return periods and decreases with increase in storage. In design of agricultural structures, generally 10 years return period is considered, so recommended bund height which represents the maximum possible storage corresponding to 10 years return period for Samastipur, Ludhiana, Hisar and Almora was found as 250 mm, 150 mm, 130 mm and 275 mm and corresponding drainage coefficient as 26.3 mm/day, 6.8 mm/day, 8.4 mm/day and 24.8 mm/day, respectively.

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