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WATER BALANCE STUDIES IN MICRO-WATERSHEDS OF UPPER DAMODAR VALLEY

K.S. Reddy[1], A.K. Bhattacharya[2] and K.V.R. Rao[3]

Abstract: A 20 year seasonal rainfall data was used to estimate the runoff, spill volumes and storage volumes of water in the small reservoirs of micro-watersheds by using Surface Water Yield Model (SWYMOD). The weekly gross water deficits/ surplus were estimated by using water balance equation for three different crop activities viz. paddy, maize and pigeon pea. The paddy crop has deficits during entire period of its growing at 75% probability. The maximum gross water deficit of 65.1 mm was noticed in 39th week during critical stage of flowering to maturity. For maize crop, the maximum deficit of 16.5 mm was seen in 34th week during grain filling stage. But, the pigeon pea has got no deficits during its critical stages of growth. By matching total water available in the reservoirs and gross water deficits at 75% probability indicated that, with the intensive irrigation strategy, the maximum area of 2.83 ha for paddy, 18.69 ha for maize and 19.02 ha for pigeon pea could be brought under irrigation when these are considered mutually exclusive activities. However, after paddy and maize, an area of 16.29 ha and 0.33 ha could be brought under little millet as rainfed crop in the selected micro-watersheds.

INTRODUCTION

The primary source to any form of water is rainfall and it is stochastic in nature. The annual rainfall of the country varies greatly being higher than 2000 nm in parts of eastern states and 25 mm or less in the deserts of Rajasthan (Singh, 1990). The above pattern of rainfall indicates that this important source of water is not uniformly distributed over the country. Moreover, the areas with high annual rainfall (>1125 mm) and seasonal dry spells experience floods and erosion hazards in agricultural lands, which is of prime concern to soil and water conservation scientists and its programmeme planners. It has been estimated that 50-60% of rainfall goes as flood, washing away 16t/ha of top soil annually. This results in acute water deficits on one hand and siltation of reservoirs on the other hand. Government of India has initiated several river valley projects with basic objective of meeting the challenge posed by recurring flood and erosion hazards by promoting soil and water conservation programmes.

In Upper Damodar Valley of South Bihar, there are several detention structures (small reservoirs) constructed across the streams in the micro-watersheds. The water stored in these structures are utilized for supplemental irrigation of the crops grown in the area. Water balance models have been extensively used for estimating different components of surface hydrology in micro watersheds (Selvarajan, 1990 and Verma, 1987). Similarly, the present study deals with water balance approach for estimating gross water deficits for different crops, grown in the study area. The water balance is also used for evolving different irrigation strategies by matching the gross water deficits with the available water in the small reservoirs of micro-watersheds.

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MATERIALS AND METHODS

Study Area

The study area is situated nearby the village Urgi in watershed no. 8/5 which is 42 km away from Hazaribagh and 2 Km from Bishnugarh. The latitude and longitude of the Urgi 24°2'N and 85o43'E respectively with an elevation of 485 m above mean sea level. The maximum and minimum annual rainfall of the region are 2092.2 mm and 692.9 mm respectively. There are five microwatersheds selected near Urgi village in the watershed no. 8/5 in Upper Damodar Valley catchment. Each micro-watershed drains runoff into an outlet called small reservoir. The description of micro watersheds (MW5, MW14, MW18, MW19, MW21) and small reservoirs (ED5, ED14, ED18, ED19 & ED21) is given in Fig.1.

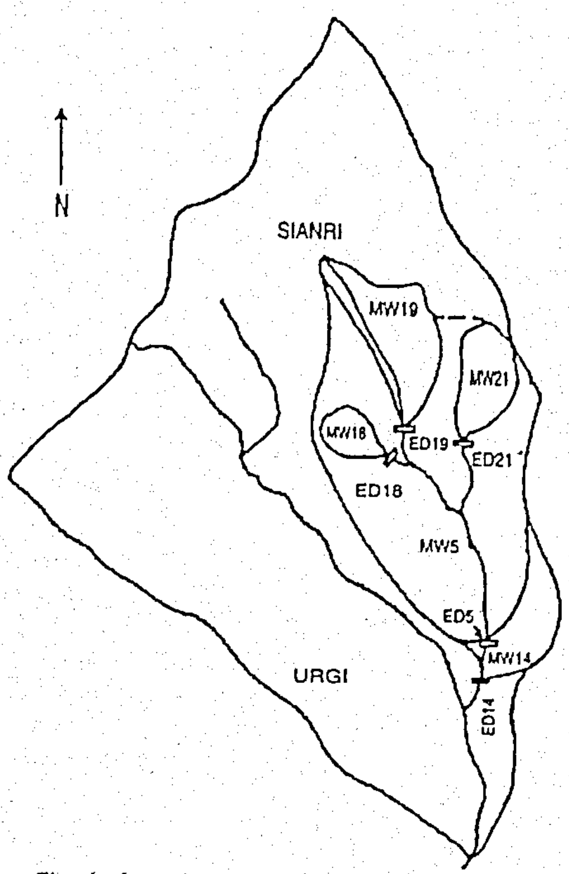

Fig. 1: Location map of microwatersheds in study area

Water balance equation

$$R + S_p = WR_o + ET_c + PERCO \pm \Delta S \quad ...(1)$$

Where

R	Rainfall, mm
S_p	Absorbed spill depth, mm
WR_o	Weighted Runoff, mm
ET_c	Crop Evapotranspiration, mm $=K_c X K_p X E_p$
PERCO	Deep Percolation, mm
ΔS	Surplus (+ve) or Deficit (-ve), mm
K_c	Crop coefficient
K_p	Pan coefficient
E_p	Pan evaporation

Estimation of Water Balance Components in Micro watersheds

Surface water yield model, SWYMOD (Reddy *et al.*, 1994) was used to estimate the curve numbers for different land uses and their hydrologic condition as given in Table 1. In order to estimate the water balance components over the micro-watersheds, the SWYMOD was used with 20 years seasonal (June to September) rainfall data. Thus, generated data included daily weighted runoff, absorbed spill depth in the micro-watersheds and storage volumes in all the small reservoirs. The average water losses in the reservoirs and their maximum capacity are given in Table 2.

The basic objective of using water balance equation was to estimate gross water deficits and to match them with available water in the small reservoirs for irrigation. The total area available in micro-watershed (MW5) for agricultural activity was 19.02 ha (Table 1). The crops grown in the study area were paddy, maize and pigeon pea. The deep percolation was taken at 7 mm / day in the rice fields (Vamadevan, 1978) in light textured soils. The pan evaporation data used were 7 mm/day for June, 5 mm /day for July, 4 mm/day for August and September and 3 mm/ day for October and November months. The

Table 1: Land use distribution and curve numbers in selected micro-watersheds

Micro watershed identification	Land use	Land use cover condition	Area (ha)	Weighted curve number
MW5	Forest	Thin canopy	2.23	81.2
	Agriculture	Ploughed	19.02	
	Bareland	No canopy	1.02	
MW 14	Forest	Thin canopy	2.02	91.2
MW 18	Forest	Thin canopy	1.11	91.5
	Bareland	No canopy	0.10	
MW 19	Forest	Thin canopy	4.76	90.6
	Bareland	No canopy	0.10	
MW 21	Forest	Thin canopy	2.02	91.2

Table 2: Water losses and maximum capacity of small reservoirs in micro-watersheds

Reservoir identification	Average observed water loss (seepage + evaporation), mm/day	Maximum capacity of small reservoirs (ha-m)
ED 5	58.30	0.65
ED 14	58.30	0.55
ED 18	84.40	0.16
ED 19	66.70	0.16
ED 21	87.50	0.09

weekly crop evapotranspiration (ET_c) for the above three crop activities were estimated by taking $K_p = 0.7$ and K_c values for the three crop activities from FAO manual (Crichley and Siegert, 1991).

The weekly rainfall, runoff and spill depths were estimated from the output of the SWYMOD. The percolation component was included for paddy only as paddy requires standing water. All the above data were then used with water balance equation and weekly water deficits/ surplus were estimated. The weekly gross water deficits were then estimated by taking application efficiency of 65% (Hukkery and Pandey, 1977) for light textured soils.

Water Availability in Small Reservoirs for Irrigation

For matching the above weekly gross water deficits for three crops, the available water in different standard weeks of season, were estimated from the output generated from SWYMOD. This was done by taking minimum assured storage volume of water available in the reservoir. These storage volumes were added over five reservoirs to get the total water available for irrigation from the reservoirs.

Probability Analysis

The weekly gross water deficits for paddy, maize and pigeon pea were subjected to probability analysis by using Weibull's plotting position. Similarly, the total water available from the reservoirs was subjected to probability analysis. The gross water deficits/surplus were matched with total water available at 75% probability of exceedance to estimate the actual irrigable area under each selected crop activity.

RESULTS AND DISCUSSION

The weighted curve numbers generated by using SWYMOD indicated that the micro-watersheds have high potential of producing run off for its possible utilization for irrigation in the study area. The weighted curve numbers ranged from 81.2 to 91.5 for different land uses (Table 1). Also, the estimated water losses were observed to be more in the reservoirs varying from 58.3 to 87.5 mm / day (Table 2).

The gross water deficits/surplus estimated at 75% probability for paddy, maize and pigeon pea are presented in Fig. 2. it indicates that paddy crop has deficits in all weeks of growing period, varying from 13.2 to 65.1 mm with minimum in 29[th] week and maximum in 39[th] week. This is due to the reason that paddy crop needs more water to meet the demand of percolation and crop evapo-transpiration in light textured soils under the local climate. Similarly, the gross deficits varied from 5.6 to 16.5 mm with minimum in 35[th] week and maximum in 34[th] week for maize and 4.8 to 6.3 mm with minimum in 40[th] week and 41[st] week of growing season for pigeon pea respectively. In remaining weeks of growing season, there was sufficient rainfall to meet the ET demand for both maize and pigeon pea.

There are two alternatives of irrigation planning, one being the extensive irrigation without fulfilling the entire water requirement of crop and another is intensive irrigation with fulfilling the entire water requirement of crop with the available water. In extensive irrigation, the application of water to the upland paddy, maize and pigeon pea at their critical stages increased their yields. (Singh, 1983 and Verma,

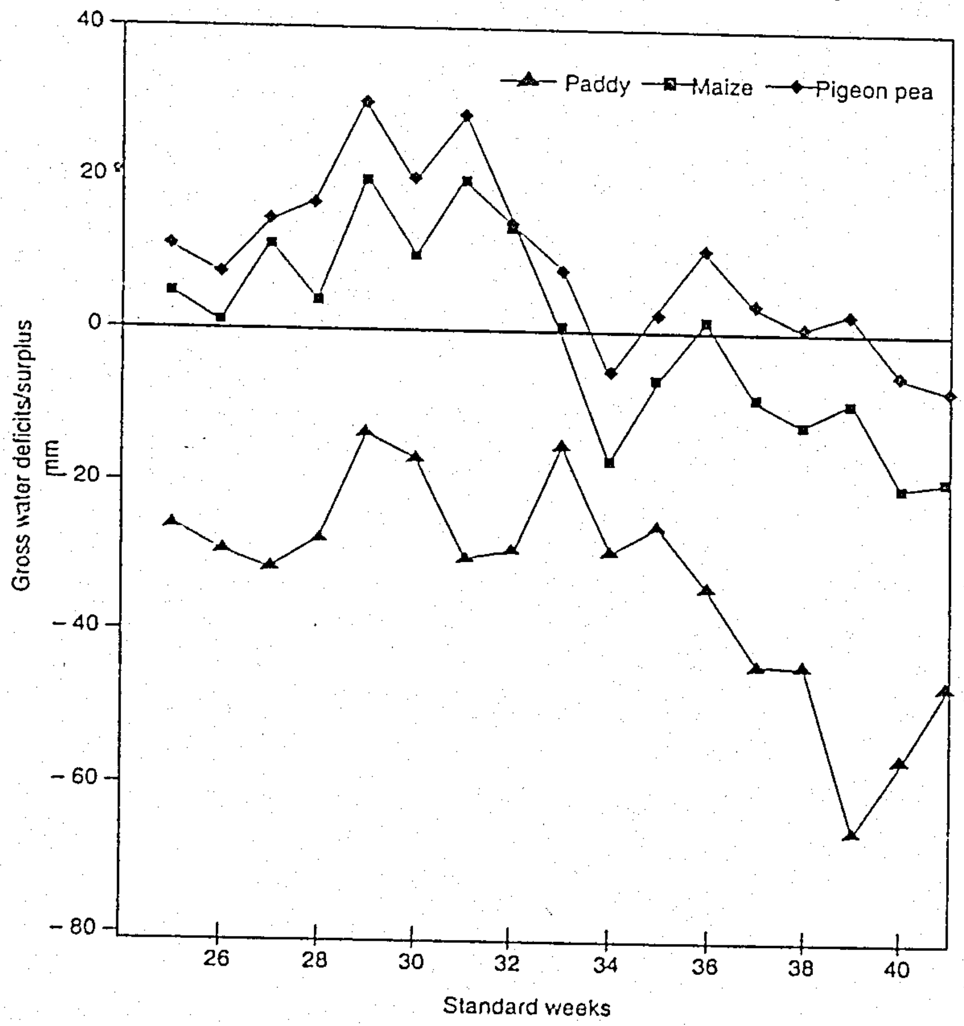

Fig. 2: Gross water deficits/surplus for paddy, maize and pigeon pea in different standard weeks at 75% probability

1987). The critical stages of paddy include panicle initiation to heading (50 - 83 DAS), heading to flowering stage (83-90 DAS) and flowering to maturity stage (90-115 DAS). The critical growth stages for maize are tasseling to silking (45-60 DAS) and grain filling (70-85 DAS) and pigeon pea has critical stage of branching (30-40 DAS) and pod filling stage (85-95 DAS) as reported by Rao (1991). From Fig. 2, it is seen that the critical stages of paddy fall in the weeks from 32 to 39 with maximum deficit of 65.1 mm in 39th week during flowering to maturity stage. However, for the maize crop during the critical stage of tasseling to silking stage from 31st to 33rd week, there is no deficit indicating adequate rainfall in the weeks. But, in grain filling stage from 34th to 36th week, maize crop has maximum deficit of 16.5 mm in 34th week. For pigeon pea, at the branching stage falling during 29th to 31st week, there is no deficit observed. The same is the case in pod filling stage from 36th to 38th week also.

While looking at the available water depths calculated over an area of 19.02 ha at 75% probability in Fig. 3, it is seen that the water available in different weeks of critical stages of paddy as discussed above (Fig. 2), could be utilized only over small areas. The other crops, maize and pigeon pea could be grown with full irrigation, if planned individually over an entire area.

The other approach of intensive irrigation considers the meeting of full demand of water requirement by crops. The maximum deficits obtained in the weeks from 28 to 39 (*i.e.* effective duration for paddy, 25 to 40 for maize and 25 to 41 for pigeon pea are 65.1 mm on 39th week with 9.7 mm water available depth, 16.5 mm on 38th week with 21.6 mm of water available depth and 6.3 mm on 4 last week with 8.2 mm of water available depth respectively. However, for maize in 38th week, available water of 11.4 mm does not fulfill the actual requirement of 11.6 mm deficit. Based on these figures, the maximum irrigable area which could be brought under intensive irrigation with total water available in the reservoirs are 2.83 ha (15%) under paddy, 18.69 ha (98.3%) under maize and 19.02 ha (100%) under pigeon pea out of the total area of 19.02 ha available for cultivation (Fig. 4) in micro-watershed MW5. All the above three crop activities are mutually

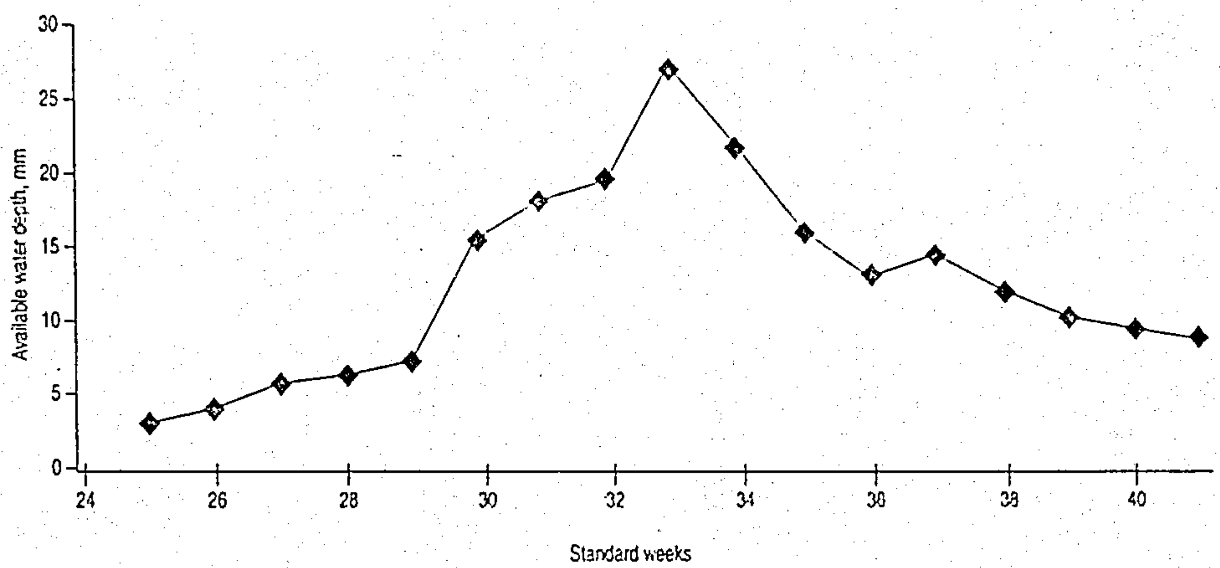

Fig. 3: Total water available in reservoirs of micro watersheds for irrigation in differentstandard weeks at 75% probability

exclusive. In the first two cases, the remaining area after paddy and maize, respectively. 16.19 ha and 0.33 ha can however be put under the little millet as rainfed crop.

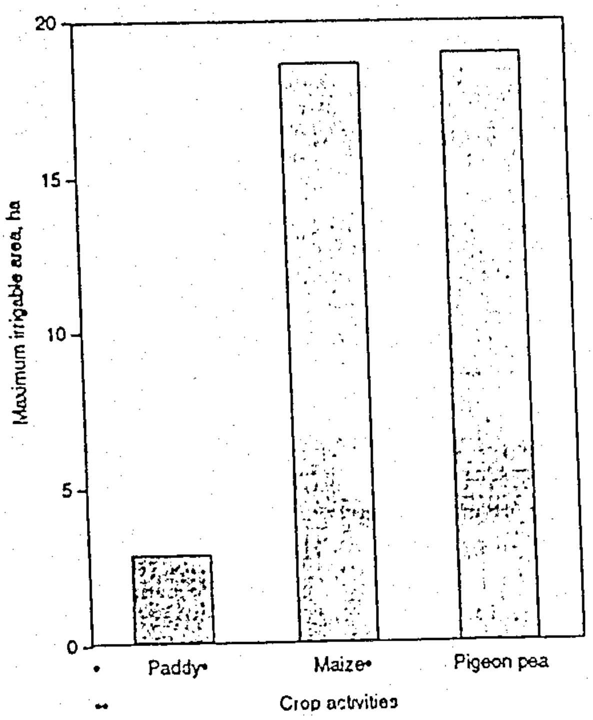

Fig. 4: Estimated maximum irrigable area from total available water in reservoirs for different crop activities

CONCLUSIONS

From the present study, the following conclusions are drawn:

1) Modelling approach used with long term rainfall data helps in estimating the components of water balance equation accurately.
2) Water balance approach results in more accurate estimates of gross water deficits for the crop activities (paddy, maize and pigeon pea) considered in the project site.
3) The water balance above study also helps to evolve different irrigation strategies with available water in the reservoirs and result in better crop planning.

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RAINFALL ANALYSIS IN MICROWATERSHEDS OF UPPER DAMODAR VALLEY

K.S. Reddy[1], K.V.R. Rao[2], R.M. Singh[2] and A.K. Bhattacharya[3]

Abstract: Daily rainfall data of 20 years (1972-91) was collected from the local observatories of Bishnugadh in Upper Damodar Valley. The data are analysed by fitting different distributions like Normal, Lognormal (LN), Log Pearson-III (LP-III) Gumbel and Gamma. One day maximum, weekly, monthly and seasonal rainfall data are fitted in the above distributions and their corresponding rainfall events are estimated at 20, 40, 60 and 80% probabilities of exceedence. From the present rainfall analysis, it is observed that, Gumbel followed by Gamma are identified the best for one day maximum rainfall; Log Normal for weekly rainfall; Gumbel for monthly rainfall and Normal, Gumbel and Log Normal for seasonal rainfall. The above inferences are drawn based on the minimum D-index values obtained in the analysis.

INTRODUCTION

Rainfall is a random hydrologic event which is highly variable in both space and time. Being the primary source of water resource development in the micro-watersheds, its estimation at different probabilities is important for efficient planning of soil and water conservation programmes and the optimum utilization of water resource in various production systems. Most of the watershed planning activities include the estimation of runoff volume, design of water storage structures and design of erosion control structures and efficient utilisation of run off for irrigation to different crops. Hence, analysis of rainfall at different time interval like one day, weekly, monthly and seasonal is important for better planning and management of costly input like water. The rainfall analysis was done by fitting different theoretical distributions like Normal, Log Normal (LN), Pearson Type-III, Gamma and Gumbel. A study conducted in Kullu Valley reveals that Gumbel distribution fitted well to the observed rainfall data of annual, seasonal, monthly and weekly totals (Rana and Thakur, 1995). There are several analyses of rainfall data by fitting different theoretical distributions for drainage planning (Bhattacharya and Sarkar, 1982; Abdul Islam and Ashwini Kumar, 1997). Similarly, the present rainfall analysis is done to identify the distributions suitable for estimation of rainfall and its occurrence at different probabilities in Upper Damodar Valley region of South Bihar.

MATERIAL AND METHODS

The study area is situated nearby the village Urgi in watershed no. 8/5 of Upper Damodar Valley catchment area of south Bihar and the catchment is divided into number of micro-watersheds and treated with soil and water conservation measures. It is 42 km away from Hazaribagh and 2 km from Bishnugadh. The latitude and longitude of the area are 24°2' N and 85°43'E respectively. The daily rainfall data for the months (June-October) was collected from the local meteorological observatories of Bishnugadh for the period of 20 years from 1972-1991. Five distributions *viz.* Normal, LN, LP-III, Gamma and Gumbel are considered for the present rainfall analysis. The rainfall total of one

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day maximum, weekly, monthly and seasonal (June-September) were made and fitted with above distributions. The Weibull's plotting position was used for calculating observed rainfall at different probabilities of 20%, 40%, 60% and 80%. For comparison of relative fitness of different distributions, D-index (Verma *et al.*, 1989) was calculated as given below and distribution with minimum index value was considered as best fit distribution.

$$D\text{-}Index = \sum_{i}^{4} \frac{\left| X_i.Observed - X_i.Estimated \right|}{\bar{X}} \quad \ldots(1)$$

Where $\bar{X}$ = Mean of the observed rainfall, mm

i = Series of rainfall amounts at 20, 40, 60 and 80% probabilities of exceedence

For analysing weekly rainfall totals, the data comprised of 362 of non-zero events out of total 440 (22 standard weeks). To treat the zero's in weekly rainfall analysis, the joint probability method suggested by Haan (1994) is used to estimate the probability of exceedence of rainfall as given below:

$$Prob(X \geq x) = Prob(X \neq 0) Prob(X \geq x / X > 0) \quad \ldots(2)$$

For the analysis of weekly and monthly rainfall totals, the daily rainfall data from June to October are used. For seasonal rainfall analysis, a total of June to September months is considered. The rainfall amounts associated with 20%, 40%, 60% and 80% of exceedence, were estimated by using standard methods of selected distributions. Some of the best fitted distributions with rainfall data are given below:

Normal distribution

$$P_Z(Z) = \frac{1}{\sqrt{2p}} e^{-\frac{z^2}{2}}, -\alpha < Z < \alpha \quad \ldots(3)$$

Where Z = standard normal variate

$Z = (x-\bar{X})/\sigma$

$\bar{X}$ = mean of the rainfall data, mm

σ = standard deviation of the rainfall data, mm

Gumbel Distribution

$$P_x = e^{-ey} \quad \ldots(4)$$

Where y = reduced random variate

$X_1 = \bar{X}(1+KC_V)$

CV = coefficient of variation ($\sigma/\bar{X}$)

$K = (y-\bar{y}_n)/\sigma_n$

$\bar{Y}_n$ = expected mean of reduced extremes

σ_n = Expected standard deviation of reduced extremes (the value of $\bar{Y}_n$ and σ_n are taken from standard tables for the given 'n' number of observations)

Lognormal Distribution

$$P_X(Z_y) = \frac{1}{\sqrt{2\pi}} e^{\frac{z_y^2}{2}} \quad \ldots(5)$$

Where $Zy-(y-\bar{y})/\sigma_y$

$y = \ln X$; $\bar{y} = \ln X$

$\sigma_y = \ln \sigma$

X_1 = Antilog $(y+\sigma_y.Zy)$

For normal and lognormal, the standard variates for the selected probabilities are obtained from the standard tables and the corresponding rainfall was estimated.

RESULTS AND DISCUSSION

The estimated one day maximum rainfall at different probabilities are presented in Table 1. It is seen from this table that the per cent deviations from the observed rainfall data (Weibull distribution), are more in numerical value at both 20% and 80% probabilities. The per cent deviation values ranged from 2.44 and 13.52 at 20% probability and 7.19 to 18.53 at 80% probability. Moreover, the numerical deviations are observed to be more in Normal, LN and LP-III distributions when compared to Gumbel and Gamma. Also, D-index is observed to be minimum (0.19) for Gumbel, followed by Gamma with 0.20. Hence, Gumbel and Gamma distributions fitted well with the one day maximum rainfall and give the reliable estimates in the selected study region. The estimated weekly rainfall presented in Table 2 indicates that the per cent deviations are numerically minimum (3.71 to 25.28) in LN distribution when compared to other distributions. The D-index value for LN distribution is minimum (0.62) over the other distributions. It can be inferred from the above results that Lognormal distribution used for estimating weekly rainfall totals is the best fitted for the study region. For the weekly rainfall totals, Normal, Gumbel and Gamma distributions gave over estimate of rainfall with high per cent deviations (16.05 to 122.99) from the observed rainfall (Table 2).

Table 1: Estimated one day maximum rainfall (mm) at different probabilities from selected distributions

Probability of exceedence	Distributions					
	Normal	LN	LP-III	Gumbel	Gamma	Weibull
20%	128.5 (-7.62)	120.3 (-13.52)	125.9 (-9.49)	131.1 (-5.75)	135.7 (-2.44)	139.1
40%	108.3 (7.77)	102.3 (1.89)	103.0 (2.89)	104.3 (3.88)	107.1 (6.67)	100.4
60%	90.8 (4.37)	84.1 (-12.07)	76.5 (-12.07)	85.1 (-2.18)	89.3 (2.64)	87.0
80%	70.4 (12.46)	69.6 (11.18)	51.0 (-18.53)	67.1 (7.19)	70.0 (11.82)	62.6
Mean	99.5 (2.26)	94.1 (-3.29)	89.2 (-8.33)	96.9 (-0.39)	100.5 (3.34)	97.3
D-Index	0.31	0.32	0.39	0.19	0.20	

Values given in parentheses are per cent deviations from the observed data.

Table 2: Estimated weekly rainfall (mm) at different probabilities from selected distributions

Probability of exceedence	Distributions					
	Normal	LN	LP-III	Gumbel	Gamma	Weibull
20%	115.5 (19.57)	121.0 (25.28)	102.9 (6.52)	112.1 (16.05)	115.8 (19.88)	96.6
40%	85.9 (38.55)	58.7 (-5.37)	74.2 (19.68)	76.9 (24.03)	73.7 (18.87)	62.0
60%	52.9 (51.14)	33/7 (-3.71)	53.0 (51.43)	53.0 (51.43)	50.0 (42.86)	35.0
80%	38.8 (122.99)	18.5 (6.32)	13.0 (22.41)	33.0 (89.66)	31.6 (81.61)	17.4
Mean	73.3 (38.91)	58.0 (99.0)	60.9 (15.45)	68.8 (30.33)	67.8 (28.48)	52.8
D-Index	1.56	0.62	0.77	1.21	1.14	

Values given in parentheses are per cent deviations from the observed data.

The estimated monthly and seasonal rainfall totals at 20, 40, 60 and 80% probabilities are presented in Table 3 and Table 4. A close perusal of Table 3 indicates that Gumbel distribution gives reliable estimate of monthly rainfall with minimum D-index value of 0.16, when compared to other distributions. Moreover, the per cent deviations ranged from 1.43 to 5.24 and are the lowest at all probabilities for the Gumbel distribution. The normal followed by Gumbel and LN distributions are well fitted for seasonal rainfall data with D-index values of 0.12, 0.13 and 0.14 respectively (Table 4). The per cent deviations are also observed to be lower than the values under Gamma and LP-III distributions at all probabilities for seasonal rainfall.

Table 3: Estimated monthly rainfall (mm) at different probabilities from selected distributions

Probability of exceedence	Distributions					
	Normal	LN	LP-III	Gumbel	Gamma	Weibull
20%	350.8 (6.87)	376.7 (14.78)	359.6 (9.57)	340.8 (3.84)	327.1 (-0.34)	328.2
40%	261.5 (16.02)	193.4 (-15.20)	266.6 (18.28)	237.2 (5.24)	210.7 (-6.52)	225.4
60%	185.4 (15.23)	103.9 (-35.43)	89.2 (-44.56)	163.2 1.43)	132.1 (-17.90	160.9
80%	96.0 (7.38)	59.7 (-33.22)	13.5 (-84.90)	93.9 (5.03)	32.1 (-64.09)	89.4
Mean	223.4 (11.17)	183.4 (-8.73)	182.2 (-9.33)	208.8 (3.88)	175.5 (-12.68)	201.0
D-Index	0.45	0.83	1.10	0.16	0.51	

Values given in parentheses are per cent deviations from the observed data

Table 4: Estimated seasonal rainfall (mm) at different probabilities from selected distributions

Probability of exceedence	Distributions					
	Normal	LN	LP-III	Gumbel	Gamma	Weibull
20%	1228.6 (-3.36)	1230.0 (-3.25)	1232.2 (-3.08)	12.51.4 (-1.57)	1152.8 (-9.32)	1271.3
40%	1100.0 (0.23)	1090.6 (-0.71)	1093.5 (-0.45)	1077.3 (-1.92)	1041.71 (-5.16)	1089.4
60%	992.2 (-2.77)	958.0 (-6.12)	920.8 (-9.77)	953.1 (-6.60)	930.6 (-8.81)	1020.5
80%	864.4 (6.62)	848.0 (4.60)	741.1 (-8.59)	836.6 (3.19)	819.1 (1.04)	810.7
Mean	1046.5 (-0.35)	1031.6 (-1.77)	996.9 (-5.08)	1029.6 (-1.96)	986.1 (-6.11)	1050.2
D-Index	0.12	0.14	0.20	0.13	0.21	

Values given in parentheses are per cent deviations from the observed data

CONCLUSIONS

A twenty years (1972-91) daily rainfall data were obtained from the local observatories of Bishnugadh area in the Upper Damodar Valley. The data are analysed for fitting one day maximum, weekly, monthly and seasonal rainfall data, through distributions like Normal, LN, LP-III, Gumbel and Gamma. From the present rainfall analysis over the study area, the following distributions are identified for the reliable estimates of rainfall of different time interval considered:

1. Gumbel and Gamma distribution can be used for the estimation of one day maximum rainfall.
2. Lognormal can be used for fitting the weekly rainfall data and provides reliable estimates at different probabilities.
3. Gumbel distribution is identified as the best fitting distribution for the estimation of monthly rainfall at different probabilities.
4. Normal Gumbel and Log Normal distributions can be used as given in their order of preference for estimation of seasonal rainfall at different probabilities.

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