Analysis of Rainfall Trends in Damodar Valley Area

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ABSTRACT

This paper analyses annual and seasonal trends of rainfall in Damodar Valley Area (DVA) over the period of 46yrs from 1970 to 2015. Non-parametric Mann-Kendall and Sen's Test Estimate are applied for detecting and estimating rainfall trends. An analysis of data indicates that rainfall in DVA has increasing trend with statistical significance in the post monsoon season. In the month of October, rainfall in all the three catchments increased. Major findings of this study include (i) Summer monsoon rainfall accounting for around 80% of total annual precipitation in the valley, (ii) Rainfall trends in all the three catchments, (iii) Increasing rainfall trend in post monsoon season, (iv) Decreasing rainfall trend in winter season and (iv) Different trends in sub-catchments.

Keywords: *Rainfall, Trend analysis, Non-parametric Mann-Kendall test and Sen's Test Estimate.*

1. Introduction

It is well known that the Damodar Valley project started in 1949 to control flood in the lower valley area of the river Damodar. It is a multipurpose project connected with irrigation, soil conservation, forestry, hydro-electric project etc. Rainfall is a significant factor in this area specially in the monsoon season and rainfall is also a crucial factor for the farming process from showing seeds to harvesting crops. Flood situation in DVA is caused due to (a) heavy to very heavy and extreme rainfall in this area, (b) inflow of runoff water in four major dams at Tilaiya, Maithon, Panchet and Konar and also inflow and outflow volume in Durgapur Barrage. Dam operation as well as flood forecasting in DVA is controlled by FFU Division DVC in consultation with the Central Water Commission (CWC), Irrigation & Waterways Department Government of West Bengal.

Moreover, erratic rainfall can trigger various disasters e.g. flood and landslides, erosion, water logging etc. Singha (2014) studied the rainfall tends in Gomoti river and the effects of rainfall variation for agriculture products. Gajbhiye et al. (2016) in their paper analyzed seasonal and annual trends and revealed the significantly increasing trend in both seasonal and annual rainfall in Sindh river basin. Chakraborty et al. (2013) analyzed trend and variability of rainfall series at Seonath river basin, Chhattisgarh. Nkiaka et al. (2017) studied rainfall variability in the Logone catchment in Lake Chad basin. Kliment et al. (2008) analyzed long term trends of rainfall and runoff regime in upper Otava river basin. This paper discusses the long term trends of rainfall and runoff and also trend deviation related to climate change. Singh et al. (2012) discusses 50 years of rainfall data and future trend in Saharanpur region. Singh et al. (2017) statistically analyzed seasonal and annual rainfall trends over Dhanbad, Jharkhand.

This paper analyzes the seasonal and annual rainfall trends in the three catchments of DVA namely Barakar and Damodar situated in the Jharkhand state and the Lower Valley Area (LVA) of Damodar river in the West Bengal (Figures 1&2). Damodar river turns southwards from Bardhaman town in the Burdwan district.

2. Climate of Damodar Valley Area

Climate of Damodar and Barakar catchments vary from Humid Subtropical in the northern part to tropical wet and dry in the south eastern part. The main seasons are Summer, Rainy, Autumn (Post monsoon) and Winter. The summer lasts from middle of April to middle of June. May is the hottest month with hot winds called 'Loo' causing causalities in the season. Average daily temperature is around 39^0C and the minimum temperature becomes around 25^0C. The Southwest monsoon from mid of June to Mid of October brings nearly all the annual rainfall of DVA. Nearly half of annual precipitation falls in the months of July and August. Average monsoon rainfall in Damodar catchment is 1298mm and in Barakar catchment it is 1267mm. Average rainfall in the Winter season are about 38mm and 42mm in Damodar Catchment and Barakar Catchment respectively. In the pre-monsoon season, Damodar Catchment and Barakar Catchment have rainfall of 143mm and 149 mm respectively. In the post monsoon season, the respective rainfall are 176mm and 186m. In winter, the minimum temperature sometimes fall to around 5^0C and causes severe cold wave conditions. Average minimum temperature in winter season is around 10 to 18^0C.

LVA has a tropical climate. The plains are hot except during short winter season. Four clearly marked seasons are observed, namely Summer (hot season), Rainy season, Post monsoon season and Winter season. Hot season lasts from mid of March to mid of June with the day temperature from 37 to 45^0C at different parts of LVA. The high temperature often causes troughs of low pressure on the plains which is compensated by sudden brief storms known as ‘Kal-baisakhi’ or ’nor-westers’ accompanied by thunder showers. These summer storms can be quite destructive.

The summer monsoon arrives by the middle of June and continues up to middle of October. The monsoon rains in LVA in West Bengal are caused solely by the current wind from the Bay of Bengal. Rainfall may be attributed to the frequency of low pressure areas, depressions, deep depressions, cyclonic storms and systems during the month from June to September. Average rainfall in monsoon season is 1339mm. Winter which lasts for about three months is mild over the plains, the average minimum temperature not even falling to 15^0C. It is accompanied by a cold and dry northern wind, substantially lowering the humidity level. Average rainfall in winter season is 42mm. In summer the average rainfall is 188mm and in the post monsoon season, the average rainfall is 214mm.

3. Data and Study Area

The Damodar river (Figure 1) originates in the hills of Chota Nagpur in south Bihar (now in Jharkhand). This 590 km long river has frequently been exposed to large scale flood damages in the past 200 years or so. The valley is also critically poised in relation to the path of the monsoon rains that account for around 80% of the total annual precipitation in the valley.

DVA covers the area from longitude 84.7 to 88.5^0E and latitude from 22.1 to 24.5^0N. The Damodar river is a tributary of the Hooghly river. It flows more or less in the west to east direction through Jharkhand and West Bengal.

3.1 Damodar catchment

The river has a catchment of about 12724 sq. km. It has a number of tributaries and sub-tributaries, such as Barakar, Konar, Bokaro, Haharo, Jamunia, Ghari, Guaia, Khadia and Bhera. Average annual rainfall in Damodar catchment is 1272.1mm.

3.2 Barakar catchment

The Barakar is the most important tributary of the Damodar. It originates near Padma in Hazaribagh district and flows through Jharkhand before meeting the Damodar near Dishergarh in West Bengal. The Damodar and the Barakar trifurcates the Chota Nagpur plateau. The rivers pass through hilly areas with great force, sweeping away whatever lies in their path. Barakar catchment covers an area of about 6914 sq.km. Average annual rainfall in the Barakar Catchment is 1260.2mm.

3.3 Lower valley area

LVA lies in the Gangetic plains and it covers four districts, namely Bardhaman, Hooghly, Howrah and East Mednipur (Figure 2). Other rivers in LVA are Rupnarayan, Kana Damodar, Hooghly, Banka etc. LVA covers an area of about 4597 km. Average annual rainfall in LVA is 1329.2 mm and average annual rainfall is more in the southern part of lower valley (1650.1 mm). Its total length from its source Chota Nagpur plateau in Jharkhand to its confluence with Hooghly in West Bengal is about

590 km, half of which is in Jharkhand and the remaining half is in West Bengal. It takes a southerly turn from Bardhman town and joins river Hooghly about 50 km upstream from Kolkata. The Damodar valley covers an area of 24,235 (12724+6914+4597) sq km in Jharkhand and West Bengal.

Ten rain gauge stations in Damodar Catchment, six rain gauge stations in Barakar Catchment and four rain gauge stations in LVA at different

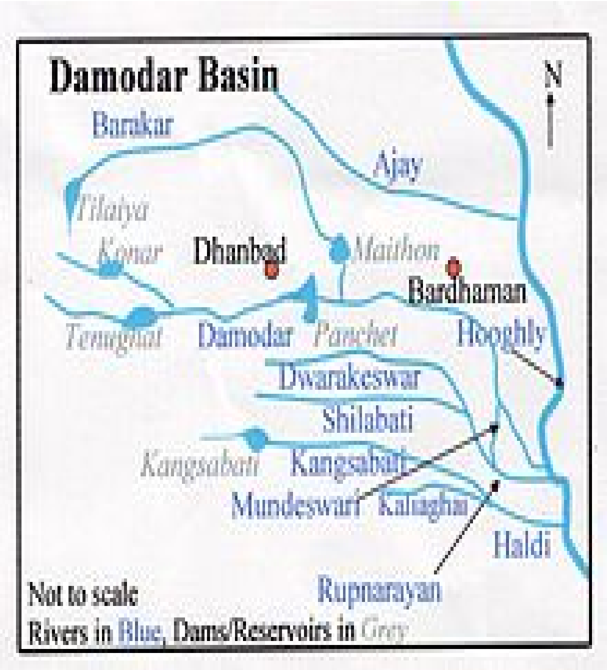

Figure 1: Map of Damodar basin with dams and tributaries.

positions are selected for covering the whole study area. Data from these rain gauge stations are obtained from DVC Meteorological unit of IMD. This data set has been used to calculate monthly, seasonal and annual rainfall totals for each catchment and perform the trend analysis. Table 1 show the locations of the stations. A data set is considered homogeneous if the variables are one type i.e. binary or categorical. When the variables are mixed i.e. binary and categorical, then the data set is heterogeneous. Visually the data will have the same scatter on a scatter plot. Homogeneity of the data set is performed in monthly total rainfall data for the stations. A graphical analysis is done to check the homogeneity of the data set.

4. Methodology and Data Analysis

4.1 Stepwise methodology of the study

Station Based Daily Precipitation Data

↓

Monthly Total rain fall

↓

Seasonal and Annual rain fall

↓

Trend analysis

↙ ↘

Station Basis | Catchment Analysis

↙ ↙ ↘

Description Analysis | Mann Kendal Test | Sen's Test

The Mann-Kendall Test is used to determine whether a time series has a monotonic upward or downward trend. It does not require that the data be normally distributed or linear. It does require that there is no autocorrelation. The null hypothesis for this test means that there is no trend, and the alternative hypothesis is that there is a trend in the two-sided test or that there is an upward trend (or downward trend) in the one-sided test. For the time series x_1, .., x_n, the MK Test uses the following statistic:

$$S = \sum_{i=1}^{n-1} \sum_{j=k+1}^{n} sign\left(x_j - x_i\right)$$

Note that if $S > 0$ then later observations in the time series tend to be larger than those that appear earlier in the time series, while the reverse is true if $S < 0$.
The variance of S is given by

$$var = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_t f_t(f_t - 1)(2f_t + 5)\right]$$

where t varies over the set of tied ranks and f_t is the number of times (i.e. frequency) that the rank t appears.

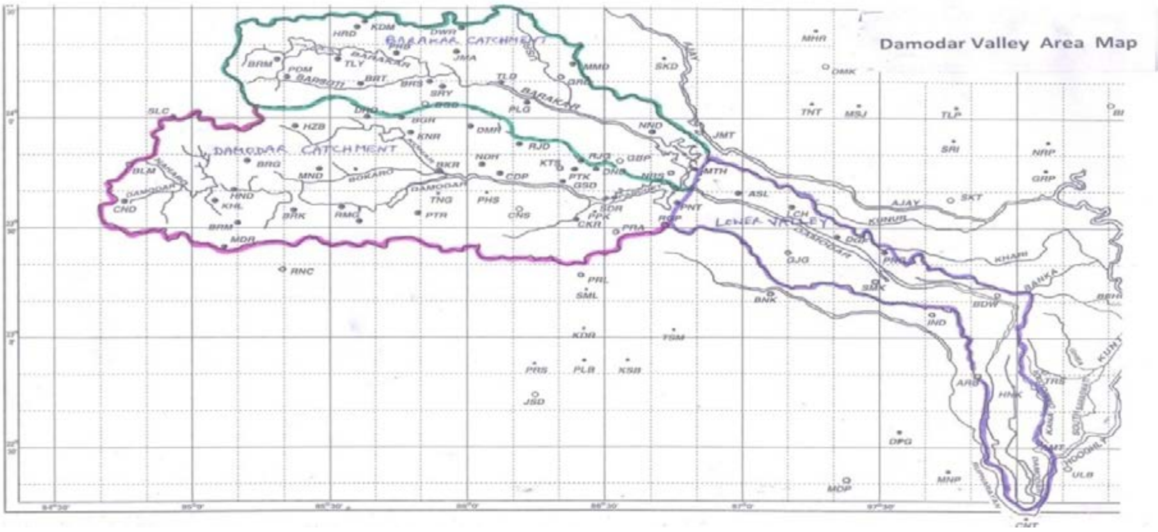

Figure 2: Damodar Valley Area (Green demarked area is Barakar Catchment, orange demarked area is Damodar Catchment and blue demarked area is Damodar Lower Valley Area.

Table 1. Location of rain gauge stations.

Name of Station	Name of District	Name of Catchment	Latitude (Deg.Dec.)	Longitude (Deg.Dec.)
Barkisuriya	Giridih	Barakar	24.18	85.88
Tuladih	Giridih	Barakar	24.17	86.12
Tilaiya	Koderma	Barakar	24.32	85.42
Barhi	Hazaribagh	Barakar	24.28	85.30
Nandadih	Dhanbad	Barakar	23.92	86.67
Maithon	Dhanbad	Barakar	23.78	86.82
Panchet Hill	Dhanbad	Damodar	23.62	86.78
Bishungarh	Hazaribagh	Damodar	24.03	85.77
Hazaribagh	Hazaribagh	Damodar	23.98	85.37
Putki	Dhanbad	Damodar	23.78	86.23
Rajdaha	Dhanbad	Damodar	24.00	86.33
Bokaro	Bokaro	Damodar	23.78	85.88
Sindri	Dhanbad	Damodar	23.65	86.50
Mandu	Hazaribagh	Damodar	23.80	85.47
Ramgarh	Ramgarh	Damodar	23.63	85.50
Sillichak	Chatra	Damodar	24.03	84.93
Durgapur	West Burdwan	Lower valley	23.48	87.32
Asansol	West Burdwan	Lower valley	23.39	86.91
Burdwan	East Burdwan	Lower valley	23.14	87.56
Uluberia	Howrah	Lower valley	22.16	88.12

The Mann-Kendall Test uses the following test statistic:

$$z = \begin{cases} (S-1)/se, & S > 0 \\ 0, & S = 0 \\ (S+1)/se, & S < 0 \end{cases}$$

where *se* = the square root of *var*. If there is no monotonic trend (the null hypothesis), then for time series with more than 10 elements, $z \sim N(0, 1)$, i.e. z has a standard normal distribution. Normally Z>1 it is significant positive change and Z<-1 then it is significant negative Change.

Mann-Kendall Test is accepted because (i) it does not require that the data be normally distributed or linear, (ii) there is no autocorrelation and it is a (iii) non-parametric test. Annual rainfall change percentage has been calculated by the formula of Yue and Hashino (2003) ie.

Percentage Change (%) = B x length of year x 10/ Mean.

Table 2. Seasonal Rainfall in the Barakar Catchment (Period 1970-2015).

Catchment	Season	Mean rainfall (mm)	SD rain fall (mm)	Range	
				Min Rainfall (mm)	Max Rainfall (mm)
Barakar	Winter (Jan-Feb)	42	14	00	82
	Pre monsoon (Mar-May)	149	61	114	276
	Monsoon (June-Sep)	1267	193	1132	2612
	Post monsoon (Oct-Dec)	186	86	108	453

Table 3. Seasonal rainfall in the Damodar Catchment (Period 1970-2015).

Catchment	Season	Mean rainfall (mm)	SD rain fall (mm)	Range	
				Min Rainfall (mm)	Max rain fall (mm)
Damodar	Winter	38	16	00	93
	Pre monsoon	143	64	117	261
	Monsoon	1298	187	1026	2704
	Post monsoon	176	78	102	422

Table 4. Seasonal rainfall in the Lower Valley Area (Period 1970-2015).

Catchment	season	Mean rainfall (mm)	SD rain fall (mm)	Range	
				Min Rainfall (mm)	Max rain fall (mm)
Lower Valley	Winter	42	20	00	133
	Pre monsoon	188	102	119	282
	Monsoon	1339	238	1073	2723
	Post monsoon	213	117	67	515

5. Discussion

The results of this study based on statistical analyses are depicted in Tables 2-7 and Figures 3-8 for easy reference. Barakar catchment rainfall range is found maximum in the monsoon season and the study in Barakar catchment conducted taking rainfall data of 6 (six) stations at different corners of the catchment. In all the six stations, winter rainfall has decreasing trend. Pre-monsoon and monsoon rainfall have shown increasing trends. Five stations out of six except Tuladih in the post moon show increasing trend due to increase in rainfall in the month of October in the last 20 years. Season wise mean rainfall, SD, and range of rainfall in Barakar catchment are shown in Table 2. Season wise bar diagram on the basis of mean rainfall in Figures 3(b) to 3(e). Table 5 shows Z value, mean, SD (Standard Deviation), CV(%) and Sen's Estimation of changes in Barakar catchment. Bar diagram of mean monthly and seasonal rainfall in Barakar Catchment are shown in Figure 3(a).In Damodar Catchment range, the pre-monsoon rainfall is higher than other catchments. Rainfall from 10 stations have been taken at different corners of the catchment in this study. In sum, decrease trend has been noticed in winter rainfall. However, there is slight increasing trend in post monsoon season. Season wise mean rainfall, SD and range of rainfall in Damodar catchment are shown in Table 3 and season wise bar diagram on the basis of mean rainfall is shown in Figure 5(b) to 5(e) Table 6 shows Z value, mean, SD (Standard Deviation), CV(%) and Sen's Estimation of changes in Damodar catchment. Bar diagram of mean monthly rainfall in Damodar Catchment is shown in Figure 5(a).

Figure 3 (a to e): Bar diagram of mean monthly and seasonal rainfall in Barakar catchment.

Table 5. Z values, tends and Sen's Estimate change in Barakar Catchment.

Station	Season	Mean	SD	CV (%)	MK Test(Test Z)	Trend	Sen's slope Estimate Change in Rainfall (B)(mm/Yr)
Maithon	Winter	44	15	34	-0.73	↓	-1.35
	Pre monsoon	152	60	39	1.12	↑	1.55
	Monsoon	1272	204	16	1.36	↑	1.64
	Post monsoon	183	88	48	0.32	↑	0.38
	Annual	1651	225	14	0.72	↑	0.57
Tilaiya	Winter	42	13	31	-0.54	↓	-2.25
	Pre monsoon	150	61	41	1.09	↑	2.50
	Monsoon	1273	198	16	0.98	↑	1.56
	Post monsoon	182	85	47	0.65	↑	0.46
	Annual	1647	219	13	0.78	↑	0.61
Barki Suriya	Winter	45	14	31	-0.46	↓	-2.54
	Pre monsoon	149	58	39	1.38	↑	3.26
	Monsoon	1280	203	16	1.43	↑	3.78
	Post monsoon	189	86	46	0.68	↑	0.58
	Annual	1663	228	14	0.92	↑	0.72
Tuladih	Winter	40	12	30	-0.26	↓	-1.85
	Pre monsoon	147	58	39	1.87	↑	3.78
	Monsoon	1274	201	16	1.96	↑	4.20
	Post monsoon	188	82	44	- 0.24	↓	-1.20
	Annual	1649	221	13	1.38	↑	0.67
Nandadih	Winter	43	16	37	-0.62	↓	-1.75
	Pre monsoon	152	62	41	0.97	↑	2.35
	Monsoon	1260	197	15	1.25	↑	3.32
	Post monsoon	188	84	45	1.02	↑	4.72
	Annual	1643	223	13	0.98	↑	0.49
Barhi	Winter	38	15	39	-0.34	↓	-1.95
	Pre monsoon	144	57	39	0.73	↑	1.54
	Monsoon	1243	190	15	1.49	↑	2.65
	Post monsoon	186	87	47	0.78	↑	1.74
	Annual	1611	210	13	0.87	↑	0.42

Percentage of change in annual rainfall at Maithon (15.5%), Tilaiya (16.6%), Barhi (11.7%), Barki Suriya (19.1%), Tuladih (18.4%), and Nandadih (13.4%).

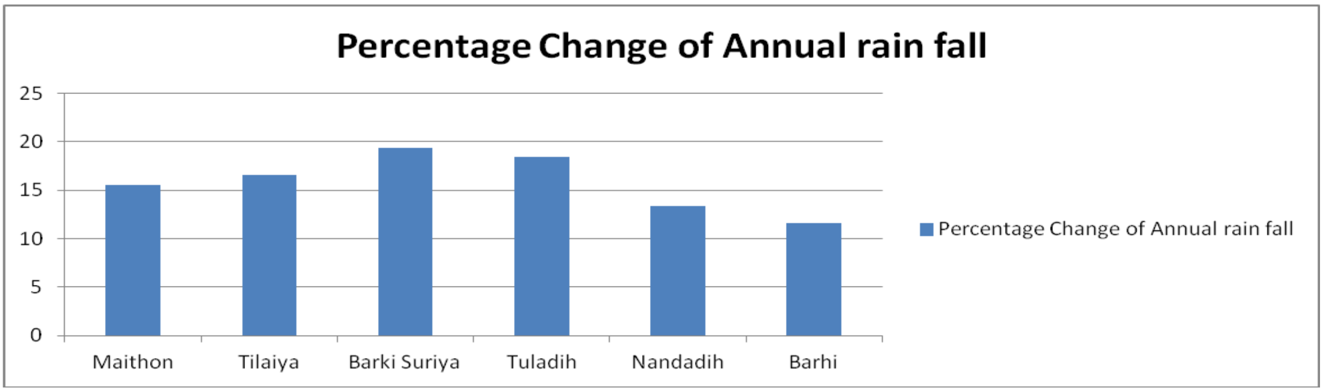

Figure 4: Percentage change of annual rainfall in Barakar Catchment at six grid points (Stations).

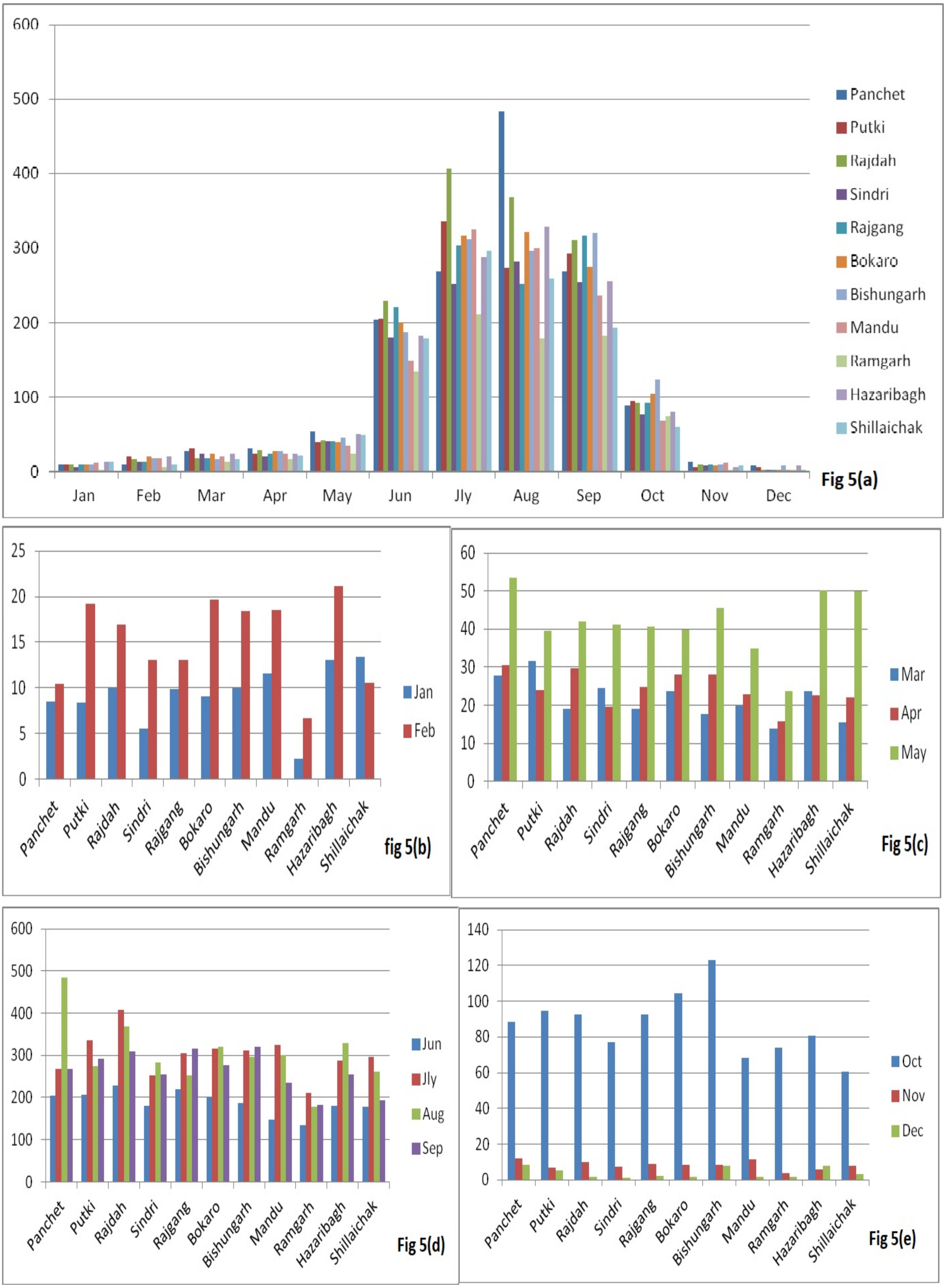

Figure 5 (a to e): Bar diagram of mean monthly and seasonal rainfall in Damodar catchment.

Table 6. Z values, tends and Sen's Estimate change in Damodar Catchment.

Station	Season	Mean	SD	CV(%)	MK Test(Test Z)	Trend	Sen's slope Estimate Change in Rainfall (mm/yr)
Panchet	Winter	40	17	42	-0.86	↓	--1.52
	Pre monsoon	145	63	43	0.86	↑	1.13
	Monsoon	1302	189	15	1.05	↑	2.32
	Post monsoon	181	77	42	1.35	↑	3.35
	Annual	1668	232	14	0.71	↑	0.68
Putki	Winter	37	15	41	-0.76	↓	-1.02
	Pre monsoon	144	65	45	0.69	↑	0.82
	Monsoon	1305	187	14	0.97	↑	1.05
	Post monsoon	178	75	42	1.25	↑	2.65
	Annual	1664	249	15	0.82	↑	0.62
Rajdah	Winter	36	14	39	-0.97	↓	-3.46
	Pre monsoon	142	62	44	0.54	↑	0.88
	Monsoon	1295	190	15	0.74	↑	1.48
	Post monsoon	182	76	42	1.57	↑	2.58
	Annual	1655	246	15	0.78	↑	0.53
Sindri	Winter	41	18	44	-0.44	↓	-1.35
	Pre monsoon	148	65	43	0.37	↑	0.69
	Monsoon	1305	191	15	0.68	↑	0.85
	Post monsoon	174	79	45	1.11	↑	2.21
	Annual	1668	239	14	0.62	↑	0.44
Bokaro	Winter	36	15	42	-1.02	↓	-3.05
	Pre monsoon	136	63	46	0.87	↑	1.25
	Monsoon	1283	191	15	0.96	↑	1.87
	Post monsoon	165	78	47	1.32	↑	2.65
	Annual	1620	234	14	0.87	↑	0.65
Bishungarh	Winter	36	18	50	-0.69	↓	-2.25
	Pre monsoon	144	66	46	0.92	↑	1.39
	Monsoon	1304	189	14	-0.62	↓	-1.87
	Post monsoon	176	80	45	1.32	↑	2.86
	Annual	1666	241	15	-0.58	↓	-0.68
Mandu	Winter	40	15	38	-1.42	↓	-2.56
	Pre monsoon	142	63	44	-1.09	↓	-1.98
	Monsoon	1296	185	14	-1.24	↓	-2.09
	Post monsoon	178	76	43	1.47	↑	2.65
	Annual	1656	238	14	-1.26	↓	-0.72
Ramgarh	Winter	37	16	43	-0.49	↓	-0.65
	Pre monsoon	142	65	46	0.79	↑	0.96
	Monsoon	1294	188	15	-1.38	↓	-2.36
	Post monsoon	175	80	46	1.29	↑	2.59
	Annual	1653	226	13	-0.51	↓	-0.62
Hazaribagh	Winter	40	16	40	-0.80	↓	-0.89
	Pre monsoon	145	63	43	0.68	↑	0.43
	Monsoon	1302	190	15	0.72	↑	1.35
	Post monsoon	180	79	44	0.99	↑	2.25
	Annual	1669	231	14	0.64	↑	0.56
Shillaichak	Winter	37	17	46	-0.52	↓	-0.95
	Pre monsoon	142	64	45	1.34	↑	2.76
	Monsoon	1294	188	15	0.98	↑	2.43
	Post monsoon	171	80	47	1.12	↑	3.05
	Annual	1644	228	13	0.85	↑	0.67

Percentage of change of annual rainfall: Panchet 18.3%, Putki 16.7%, Rajdah 14.4%, Sindri 11.8 %, Bokaro 18.1%, Bishungarh 18.3%, Mandu 20.4%, Ramgarh 16.8%, Hazaribagh 15.1 % and Shillaichak 18.3%.

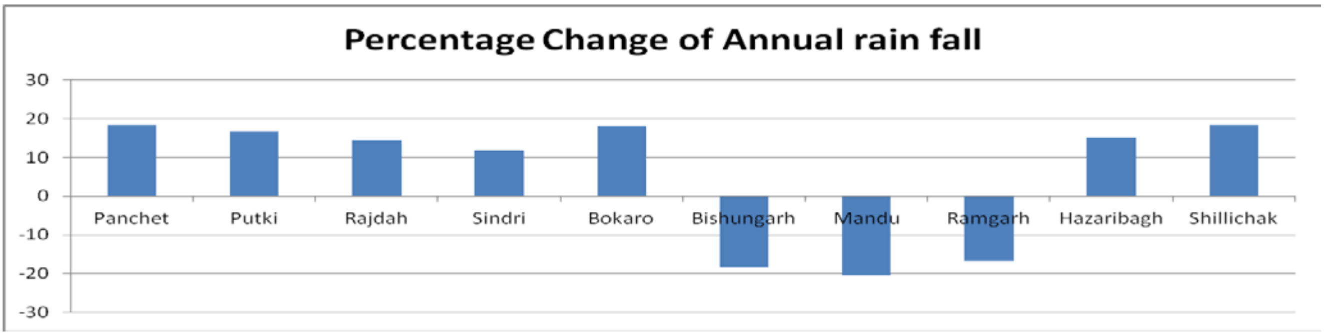

Figure 6: Percentage changes in the annual rainfall in Damodar Catchment at ten grid points (Stations).

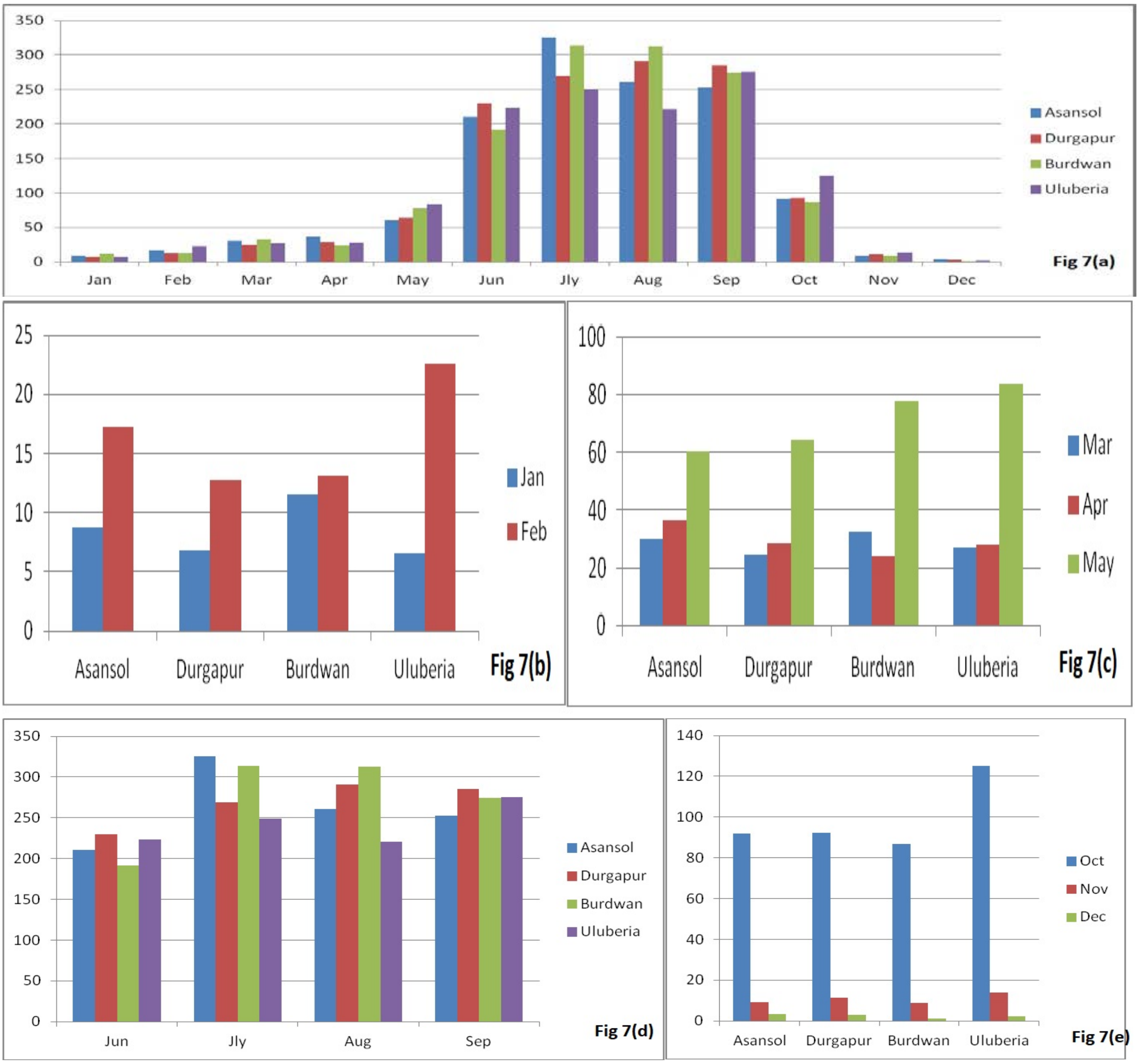

Figure 7 (a to e): Bar diagram of mean monthly and seasonal rainfall in Lower Valley area.

Table 7. Z values, tends and Sen's Estimate change in Lower valley of D.V. area.

Station	Season	Mean	SD	CV(%)	MK Test(Test Z)	Trend	Sen's slope Estimate Change in Rainfall (mm/year)
Asansol	Winter	40	18	45	0.65	↑	0.35
	Pre monsoon	192	103	54	1.51	↑	3.21
	Monsoon	1336	236	18	0.33	↑	0.46
	Post monsoon	215	118	55	1.32	↑	2.34
	Annual	1783	274	15	0.25	↑	0.48
Durgapur	Winter	43	21	49	0.35	↑	0.86
	Pre monsoon	190	102	54	1.42	↑	2.48
	Monsoon	1338	237	18	0.68	↑	1.42
	Post monsoon	210	116	55	1.22	↑	2.22
	Annual	1781	266	15	0.49	↑	0.58
Burdwan	Winter	41	22	54	0.59	↑	1.24
	Pre monsoon	186	100	54	0.78	↑	6.32
	Monsoon	1340	235	17	0.71	↑	3.75
	Post moon	213	114	53	1.15	↑	4.62
	Annual	1780	269	15	0.56		0.66
Uluberia	Winter	44	19	43	0.24	↑	0.68
	Pre monsoon	184	101	55	0.98	↑	3.78
	Monsoon	1342	235	17	0.81	↑	4.80
	Post monsoon	213	117	55	0.57	↑	2.36
	Annual	1783	261	15	0.71	↑	0.68

Percentage of Change in the Annual Rainfall: Asansol 12.1 %, Durgapur 14.6 %, Burdwan 16.6 % and Uluberia 17.2 %

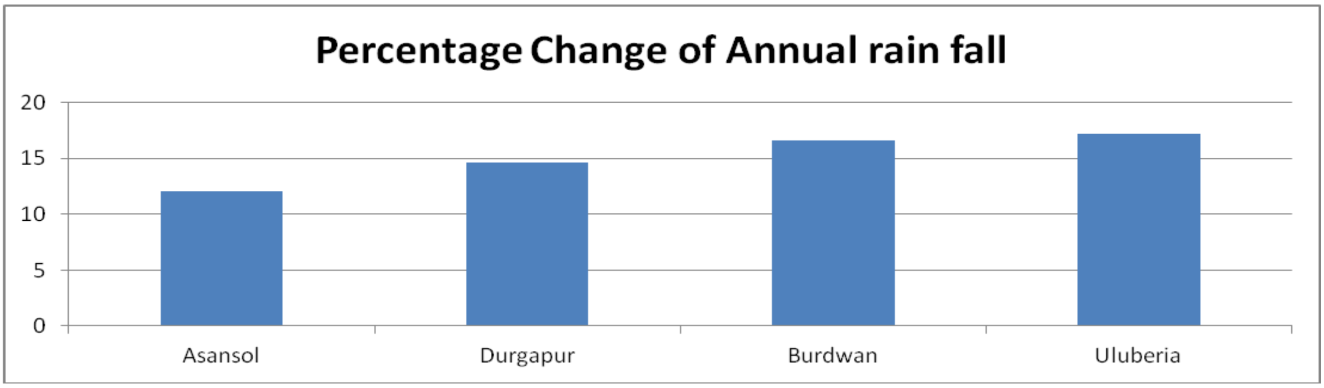

Figure 8: Bar diagram of percentage change in the annual rainfall in Damodar Lower Valley Area at four grid points(Stations).

In Lower Valley i.e. most flood prone area in this valley, 4 stations have been considered for the study and it is very important to mention that at four stations, rainfall in four seasons have been showing increasing trends. Season wise mean rainfall, SD, and range of rainfall in Lower Valley are shown in Table 4. Season wise bar diagram on the basis mean rainfall is depicted in Figures 7(b) to (e). Table 7 shows Z value, mean, SD (Standard Deviation), CV(%) and Sen's Estimation of changes in Lower Valley area. Bar diagram of mean monthly rainfall is presented in Figure 7(a).

7. Conclusions

Based on this study, the following conclusions can be made:

1. In Damodar Valley Area, maximum rainfall occurred in the summer monsoon season i.e. in the months of June, July, August and September. Total annual average rainfall occurring in the Damodar Catchment, Barakar Catchment and Lower Valley are 78%,77% and 75% respectively.

2. Rainfall in the pre-monsoon months have been increasing in nine stations except in Mandu of the Damodar catchment. In total, six stations of Barakar catchment and Asansol, Durgapur, Burdwan, Uluberia of the Lower Valley Area indicate increasing trends in rainfall.

3. Rainfall during the summer monsoon season increased in Barakar Catchment, Eastern part of Damodar Catchment (considering location of stations) and south of lower Valley Area (considering location of stations), but decreased in western part of Damodar catchment as per analysis based on data from different stations in this study.

4. Rainfall in post monsoon season increased in all catchments due to increase in average rainfall in the month of October which might be due to the occurrence Cyclonic storms in last two decades.

5.Rainfall during the winter season decreased in all catchments in Damodar Valley area resulting in drier winter.

6. (a)Percentage of change in the annual rainfall in Barakar Catchment at six stations such as Maithon, Tilaiya, Barhi, Barki Suriya, Tuladih and Nandadih are 15.5%, 16.6%, 11.7%, 19.1%, 18.4% and 13.4% respectively (Figure 4).

(b) Percentage of changes in the annual rainfall in Damodar Catchment are: Panchet 18.3%, Putki 16.7%, Rajdah 14.4%, Sindri 11.8%, Bokaro 18.1%, Bishungarh(-)18.3%, Mandu(-)20.4%, Ramgarh(-)16.8%, Hazaribagh 15.1% and Shillaichak 18.3% (Figure 6).

(c) Percentage of change in the annual rainfall in Damodar Lower Valley Area are: Asansol 12.1 %, Durgapur 14.6 %, Burdwan 16.6 % and Uluberia 17.2 % (Figure 8).

7. It is observed that the annual rainfall over Bishungarh, Mandu and Ramgarh decreased by 18.3%, 20.4% and 16.8% respectively. These grid points (stations) are located in the south western parts of Jharkhand state.

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