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Impact of Dam on River Discharge: A Study on the Damodar River, Jharkhand

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Abstract: *River impoundment by construction of dams leads to a new, controlled hydrologic regime the world over. This work examines the changes of the discharges of the Damodar river due to the construction of the Maithon and Panchet dams in the late 1950s. Daily discharge data, rainfall data, and data on inflow and outflow from the dams were analysed for pre-dam (1950–1955) and post-dam periods (1993–2007). Results indicate that duration of low flows increased after dam construction. Seasonally, down-dam monsoon streamflow was reduced, but non-monsoon flow increased following the impoundment. Mean annual flow decreased in the post-dam period. Inflow-outflow data of the dams indicate that the dams stored a significant proportion of inflow water, especially in the monsoon season, controlling floods, and released more water during the non-monsoon seasons aiding dry season farming.*

Introduction

In a natural fluvial system, an important characteristic of discharge is its variability, that varies over a wide range of spatial and temporal scales (Walker and Thoms, 1993). The flow regime of a river is considered as the primary driving force of the river ecosystem (Zuo and Liang, 2015). Construction of dams and reservoirs substantially modify natural flow regimes and a new controlled regime emerges (Williams and Wolman, 1984). Alteration of flow regime, i.e., change in daily flow, seasonal flow, and annual average flow are the major hydrologic impact of dams on the river (Poff *et al.,* 1997; Graf, 1999; Yang *et al*., 2004; Lu and Siew, 2006). Primarily, the timing, magnitude and frequency of high and low flows change subsequent to impoundment (Brandt, 2000; Graf, 2006). Seasonal pattern of streamflow is also altered by construction of dams. Dams fill its reservoir during wet seasons and release water during dry seasons to augment discharge and providing services (Batalla *et al*., 2004; Magilligan and Nislow, 2005). Apart from this general pattern, impacts of dam on river hydrologic regime may vary considerably and these variations are generally induced by the many types of dams, regional climates, initial conditions, and minimal availability of pre-dam data (Magilligan and Nislow, 2005), which make generalisation elusive.

The Damodar river of the eastern India is a classic example of river impoundment. It comprised the first large-scale river valley project of the nation: the Damodar Valley Corporation (DVC). Four major dams, namely Maithon, Panchet, Tilaiya, and Konar, were constructed during the late 1950s. With the implementation of this project, the Damodar was transformed into a controlled river system (Bhattacharya, 2011). The primary purpose of this work is to find out the nature of downstream discharge alterations of the Maithon (commissioned in 1957) and Panchet (commissioned in 1959) dams. It also attempts to shed light on the factors responsible for hydrologic alteration in relation to rainfall characteristics and dam operation.

Study area

The hydrological characteristics of the lower reach of the Damodar depends on the water received from the main river and its tributary, the Barakar. The two dams were constructed just above their confluence. The Durgapur barrage is located ~60 km below this. The river reach extending from downstream of the Maithon and Panchet dams up to the Durgapur barrage is selected for the present study (Fig. 1).

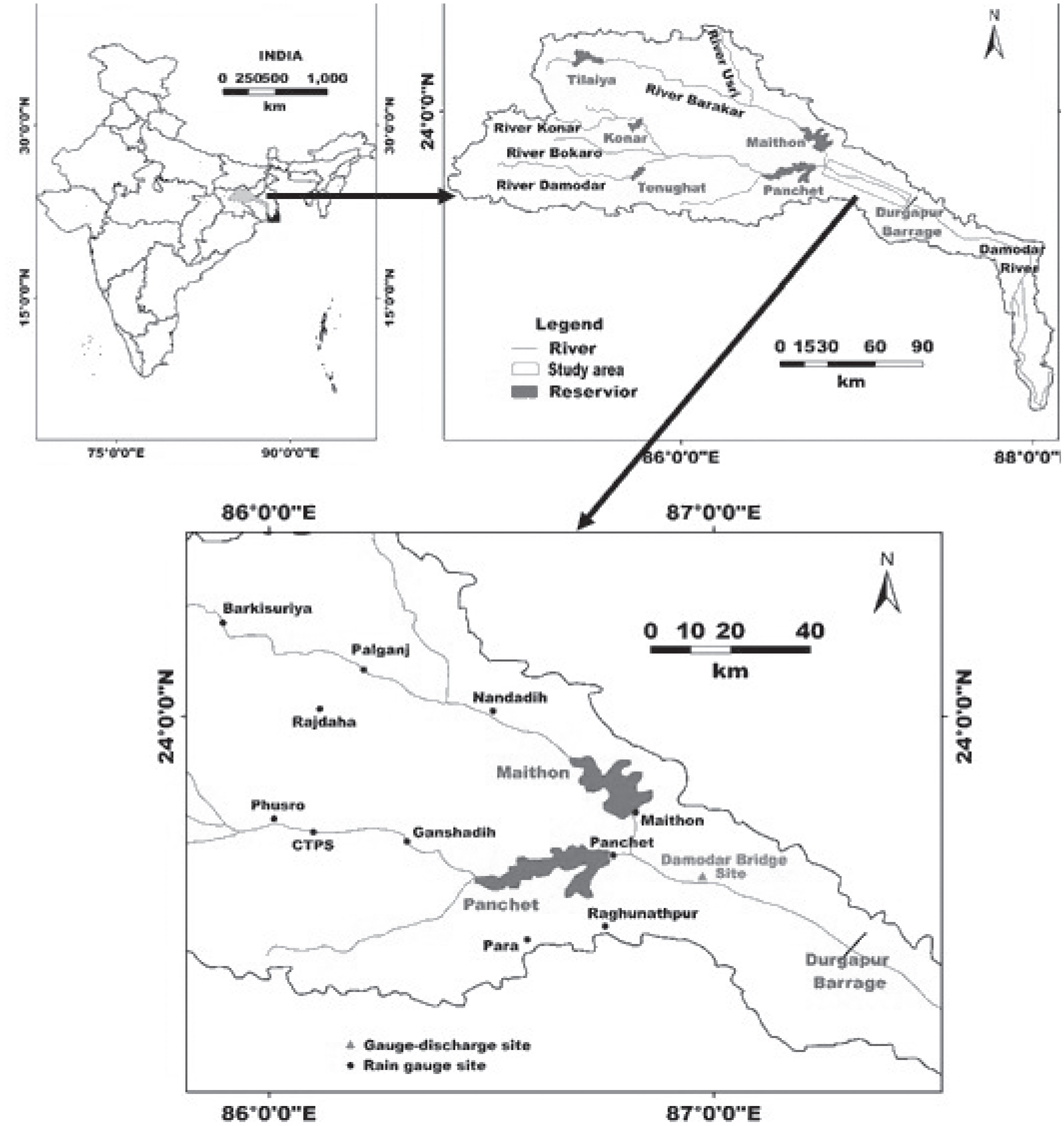

Figure 1. Location of the study area with selected positions of rain gauges and the river gauge at the bridge site near Madhukunda

Materials and methods

To analyse the flow characteristics of the Damodar during pre-dam and post-dam periods, daily discharge data were collected from the *Water Year Books* published by the Damodar Valley Corporation. The data from 1950 to 1955 (pre-dam period) and from 1993 to 2007 (post-dam period) were collected for Damodar Bridge Site, 3 km northeast of Madhukunda railway station. Data for the year 1995 of the post-dam period has been collected from Bhattacharyya (2011). Both monthly and yearly rainfall data were collected from the office of the Manager of Reservoir Operation (MRO), DVC, Maithon. Rainfall data for the pre-dam period (1942–1957) were available for five rain gauge stations viz., Palganj, Para, Panchet, Rajdaha, and Raghunathpur. For post-dam period of 1993–2007, rainfall data were collected for seven stations viz., Palganj, Panchet, Maithon, Nandadih, Barki Suriya, Ganshadih and Chandrapura Thermal Power Station (CTPS), distributed over the Damodar and Barakar catchments. Besides these, the data on daily inflow and outflow of water for both dams were collected from the above mentioned office for the post-dam period (1993–2007). These collected data were analysed to bring out the following parameters.

Daily discharge

Daily data collected from the office were divided into 9 magnitude categories and percentage of the total number of days to each category were calculated for both the pre-dam and the post-dam period (Bhattacharyya, 2011).

Seasonal discharge

Monthly data were calculated by adding average discharge during each day for every month and grouped into monsoon and non-monsoon periods to realise the seasonal flow characteristics (Bhattacharyya, 2011).

Annual discharge

Mean annual flow – also called average daily flow – indicates the mean volume of water flowing throughout a year along a given section of the river channel. It is calculated as:

$$\text{Mean Annual flow} = \frac{(Q1+Q2+Q3\ldots\ldots Q365)}{365}$$

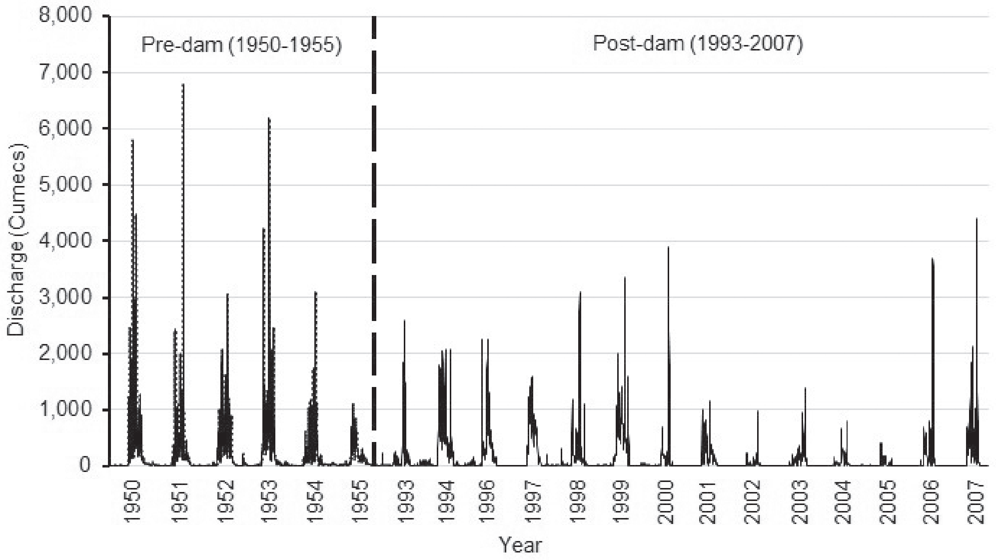

Figure 2. Damodar: Daily discharges during pre-dam and post-dam periods near Madhukunda. Source: MRO, DVC, Maithon (2017)

When daily discharge data for the whole year is not available, number of available days were used. To get a representative average daily discharge, the annual figures for a number of years were averaged (Williams and Wolman, 1984).

Pre-dam and post-dam variability of monthly and annual flows were calculated as coefficient of variation (CV) from mean and standard deviation (SD):

$$CV = \frac{SD}{Mean} \times 100$$

Results and discussion

Daily discharge

Daily discharge data of both pre-dam and post-dam periods show the trends of water flow through river channel at a glance. In general, there are some high peaks in the pre-dam period while post-dam period are showing the dominance of moderate to low peaks (Fig. 2). During the pre-dam period (1950–1955) 82.0% of days have experienced a flow of less than 283.2 cumecs (10,000 cusecs) while this was 85.9% of days in the post-dam period (1993–2007). Thus, the frequency of low flows increased in the post-dam period by 4.7%. Flows within 283.2–566.4 cumecs (10,000–20,000 cusecs), decreased by 19.4% in the post-dam period. On the other hand, flow above 2265.6 cumecs (80,000 cusecs) was 0.9% of days in the pre-dam period and 0.4% of days in the post-dam period. Flows of 1982.4–2265.6 cumecs (70,000–80,000 cusecs), regarded as high flow, reduced by 13.0% in the post-dam period. So, the high flows (more than 1982.4 cumecs) recorded more than two-fold (56.4%) decrease after the construction of the dams. Flows of moderate intensity (566.4-1982.4 cumecs) showed both decreasing and increasing patterns (Table 1).

Seasonal discharge

Data and graph show some contrasting picture of seasonal flows during pre-dam and post-dam periods (Table 3, Fig. 3). Mean percentage of flow in summer season (March–May) was 1.9% and 2.7% of total annual flow during pre-dam and post-dam periods respectively, which indicate 0.9% of increase after dam construction. Variability also decreased slightly in the post-dam period from 89.57 to 77.97, showing much regularity in flow compared to the pre-dam period.

Table 1. Damodar: Changes in daily discharge near Madhukunda during pre-dam and post-dam periods

Discharge (cumec)	Pre-dam (1950–1955)		Post-dam (1993–2007)		Difference (%)
	Days	Percent	Days	Percent	
below 283.2	1797	82.05	3859	85.91	+4.7
283.2–566.4	176	8.04	291	6.48	–19.4
566.4–849.6	96	4.38	156	3.47	–20.8
849.6–1132.8	54	2.47	66	1.47	–40.5
1132.8–1416	25	1.14	58	1.29	+13.2
1416–1699.2	11	0.50	19	0.42	–16.0
1699.2–1982.4	7	0.32	15	0.34	+6.3
1982.4–2265.6	5	0.23	9	0.20	–13.0
above 2265.6	19	0.87	19	0.42	–51.7
Total	2190	100.00	4492	100.00	—

Source: MRO, DVC, Maithon (2017)

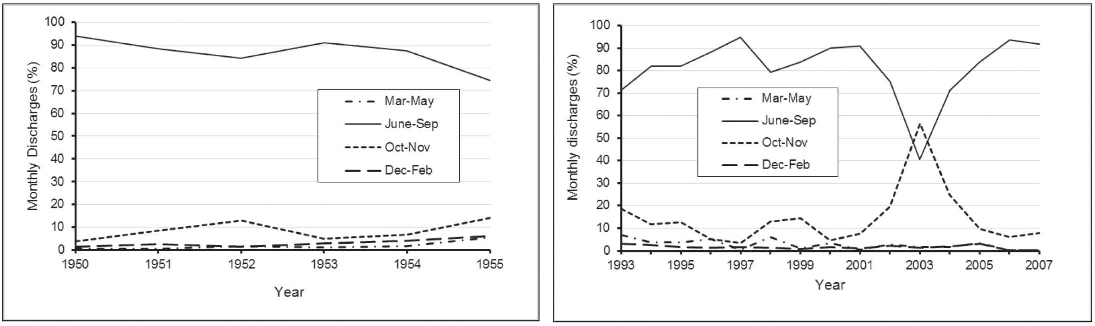

Figure 3. Damodar: Seasonal discharge in (a) pre-dam and (b) post-dam periods near Madhukunda. Source: MRO, DVC, Maithon (2017)

During the monsoon season (June–September) mean percentage of discharge was 86.5% in the pre-dam period while in the post-dam period, it was 81.2% and the variability of flow increased from 7.2% to 16.2% in the post-dam phase. Thus, the flow in the monsoon season was comparatively regular and flow volume was also large before the construction of the dams. Discharge during autumn season (October–November) was increased from 8.7% to 14.4% in the post-dam period, showing 5.9% increase in water flow for these months.

Variability in flow increased from 44.4% to 88.2% in the post-dam period, but this is more due to the abnormal release of water by the dams in 2003, due to high intensity of rainfall in the catchment areas. Thus, the river carried more water in these post-monsoon months after construction of the

Table 2. Damodar: Changes in seasonal discharge during pre-dam and post-dam periods near Madhukunda (in per cent).

Period	Parameters	Summer (Mar–May)	Monsoon (Jun–Sep)	Autumn (Oct–Nov)	Winter (Dec–Feb)
Pre-dam (1950–1955: 6 years)	Seasonal average	1.87	86.54	8.56	3.03
	Standard deviation	1.68	6.24	3.80	1.60
	Co-efficient of variation	89.57	7.21	44.38	52.95
Post-dam (1993–2007: 15 years)	Seasonal average	2.72	81.24	14.42	1.62
	Standard deviation	2.12	13.12	12.72	0.91
	Co-efficient of variation	77.79	16.15	88.22	56.41

Source: MRO, DVC, Maithon (2017)

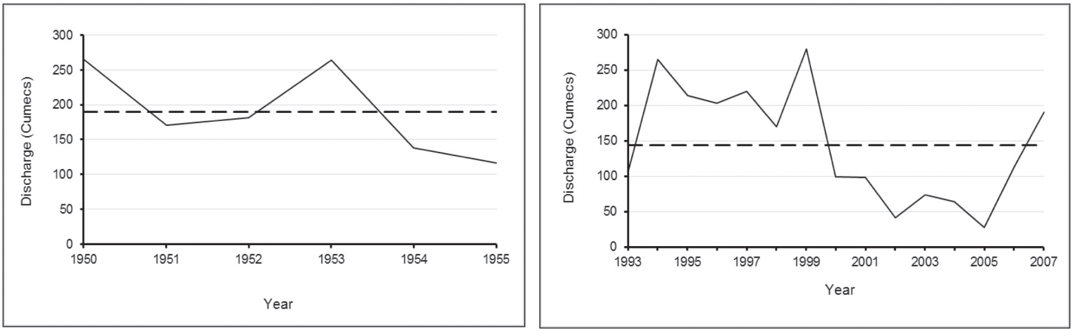

Figure 4. Damodar: Mean annual discharges in pre-dam and post-dam periods near Madhukunda. Source: MRO, DVC, Maithon (2017)

Table 3. Changes in annual discharges of the Damodar: Pre-dam and post-dam scenario at Madhukunda

Period	Parameters	Discharge (cumec)
Pre-dam (1950–1955: 6 years)	Average	189.42
	Standard deviation	57.41
	Co-efficient of variation	30.31
Post-dam (1993–2007: 15 years)	Average	144.39
	Standard deviation	78.30
	Co-efficient of variation	54.23

Source: MRO, DVC, Maithon (2017)

dam and the variability has increased in the post-dam period. In the winter season (December–February), the Damodar recorded a considerable decrease in flow, from 3.0% to 1.6% after construction of the dam (Table 2, Fig. 3,).

Annual discharge

The mean annual discharge of the Damodar was 189.42 cumecs in the pre-dam period and 144.39 cumecs in the post-dam period. This shows that, on an average, mean annual flow decreased by 24% after impoundment of the river. Standard deviation and variability of mean annual flow were 57.41 and 30.31 in the pre-dam period, whereas in the post-dam period, these values were 78.30 and 54.23, respectively. Thus, in the post-dam period, mean annual flow not only decreased in the downstream section but also have become more irregular in nature (Table 3, Fig. 4).

Rainfall variability

Analysis of daily, monthly and mean annual discharges of the Damodar indicate that water flow at Damodar Bridge Site near Madhukunda markedly altered after the construction of dams. To understand the factors behind these alterations, rainfall of Damodar and Barakar river catchments upstream of the dam were compared for pre-dam and post-dam periods. Annual storage of water inflow into the dam and release pattern of water from the dam were assessed to find out the possible causes of discharge alteration.

Table 4. Rainfall parameters of pre-dam and post-dam periods in the Damodar and Barakar catchments (in cm)

Period	Rainfall Parameters	Panchet	Para	Raghunathpur	Rajdaha	Palganj	
Pre-dam (1950–1955: 6 years)	Annual mean	125.59	125.00	135.36	119.62	124.12	
	Standard deviation	23.22	21.21	25.91	8.63	23.98	
	Co-efficient of variation	18.49	16.96	19.14	7.22	19.32	
		Panchet	Maithon	Barki Suriya	Ganshadih	Palganj	CTPS
Post-dam (1993–2007: 15 years)	Annual mean	123.12	146.70	129.74	130.66	131.01	117.5
	Standard deviation	21.35	42.59	27.74	28.46	27.25	25.56
	Co-efficient of variation	17.34	29.03	21.38	21.78	20.80	21.76

Source: MRO, DVC, Maithon (2017)

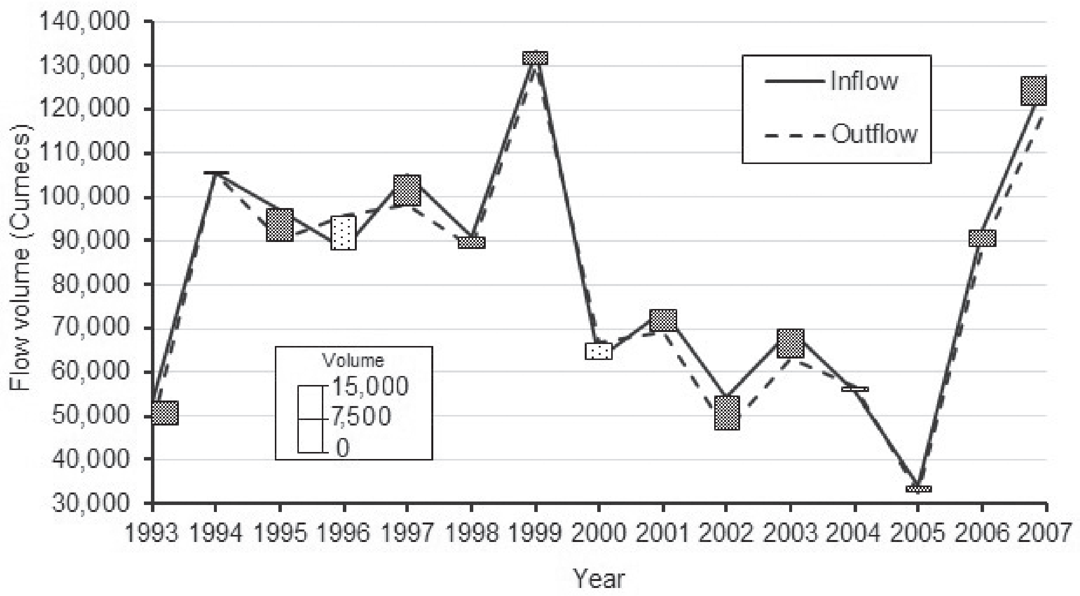

Figure 5. Cumulative storage of water by Maithon and Panchet dams. Crossed line box indicate 'Storage year' and dotted box is for 'Non-storage year'. Source: MRO, DVC, Maithon (2017)

The Damodar and all its major and minor tributaries are rain-fed. Thus, the discharge through this river system is completely depended on rainfall in the catchment area. Bulk of rainfall of the Damodar basin occur in the monsoon season, and rest of the year largely remains dry except occasional rainfall due to thunderstorms and winter disturbances. The rainfall also vary spatially over the basin. As the rainfall is the only source of water flow in the Damodar, changes of rainfall characteristics have important bearings on flow regime of the river.

Analysis of rainfall data indicates that

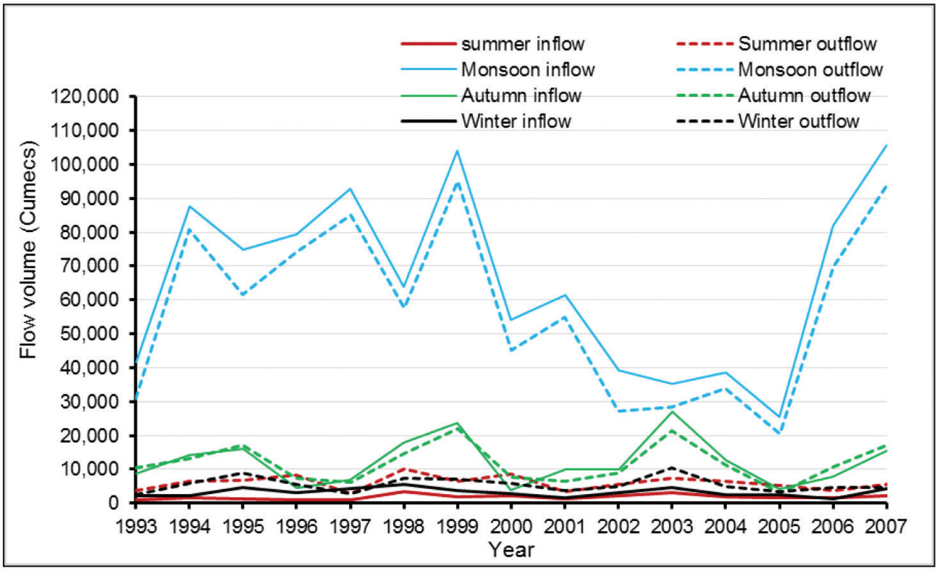

Figure 6. Seasonal patterns of water inflow and release from Maithon and Panchet reservoirs. Source: MRO, DVC, Maithon (2017)

during pre-dam period, mean annual rainfall of the Damodar and Barakar river catchments varied from 120 cm to 135 cm, and variability of rainfall between these years were also low at 7% to 19%. During the post-dam period, mean annual rainfall of different stations was 118–147 cm with a variability of 17% – 29% (Table 4). Thus, it seems that mean annual rainfall during pre-dam and post-dam periods did not undergo any significant change. Minor changes were seen at different places, such as mean annual rainfall increased slightly at Palganj, and Panchet experienced a small decrease during the post-dam period.

Water storage

Except for the years 1994, 1996, 2000 and 2004, some amount of water was stored by the Maithon and Panchet dams, ranging from 1370.29 to 7616.76 cumecs in different years (Fig. 5). In relation to the total annual inflow into the dam, 2% to 14% of water were stored by the dam annually from 1993 to 2007. Total amount of water entering into the dam would have flowed downstream if the dam was not constructed in the upstream portion. This is why, a reduction of mean annual discharge during post-dam period occurred and the variability of mean annual discharge have also increased.

Pattern of water release

Depending on DVC's water release policy, the Maithon and Panchet dams created a distinctive seasonal pattern of discharge (Fig, 6). During the Monsoon season (June–September), the dams underwent a large inflow of water from the catchment area. Depending on its storage capacity, the dams store a certain amount of this incoming water. The dams stored from 6.9% (1996) to 30.6% (2002) of incoming water in this season, contributing to flood control and accounting for the low discharge value at the Damodar Bridge Site in the post-dam period.

In the autumn season (October–November), the dam stored water in some years, and released water more than its net storage in some years. While the storage of incoming water ranged from 7.5% (1999) to 34.7% (2001), release of water was 6.4% (1995) to 94.8% (2000) more than incoming water.

The dams released a large amount of its stored water during the summer season (March–May) and a small proportion in winter (December–February). In 2003, 132.02% more water was released than normal inflow of water into the dam during the summer season which was lowest for the post-dam periods and 698.70% more water than normal flow was released in 1996. Rest of the years showed a large amount of water released during summer seasons. During the winter season, the dams also released more water than it received but the amount is as high as the summer season. Between 9.6% (2007) and 242.2% (2006) more water was released from the dam during this season.

Conclusion

From the above analysis it is found that the timing and magnitude of discharge of the Damodar river were affected by construction of the Panchet and Maithon dams. Characteristics of daily flow, seasonal flow, and mean annual flow of the river changed significantly. Duration of low flows increased, while the peak flows decreased after dam construction. Seasonally, down-dam monsoon flows reduced, but down-dam non-monsoon flows increased following impoundment. Mean annual flow also decreased in the post-dam period. It is notable that amounts of annual rainfall of the catchment areas remained almost unchanged during the pre-dam and post-dam periods. The dams stored a significant proportion of inflow, especially in the monsoon season, controlling floods, and released waters during non-monsoon seasons, aiding dry season agriculture.

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