

CHAPTER 4

From watershed to sub-basins: Analyzing the scale effects of watershed development in Narmada river basin, central India

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4.1 Introduction

Narmada basin is one of the water-rich basins of India with an estimated renewable surface water resource of 27 Million Acre Feet (MAF) as per a 1993 estimate (GOI, 1999), though the latest assessment carried out by Central Water Commission (2017) showed a total renewable water availability of 45.24 BCM (CWC, 2017). The Narmada River originates from East of Madhya Pradesh, enters into Gujarat, and ends up in the Gulf of Cambay. Approximately, 90% of the basin is falling in Madhya Pradesh (MP) (Fig. 4.1). Since the mid-1990s, MP government has made concerted efforts in watershed development and water harvesting through decentralized administration and governance under Rajeev Gandhi Watershed Mission and Rajeev Gandhi Rural Drinking Water Supply (RWSS) mission. Subsequently, intensive watershed development work was taken up in 1694 watersheds of the basin between 1995–95 and 2001–02. Besides this, many donor agencies have supported local NGOs to independently implement watershed development projects.

The intensive rainwater harvesting activities, and groundwater development, which occur as an aftermath of intensive watershed development program, have the potential to cause major socioeconomic and hydrological changes at various levels in the basin from village to watershed to sub-basin to the entire basin. Limited field observations from intervention areas have made many NGOs argue that local groundwater recharge improved

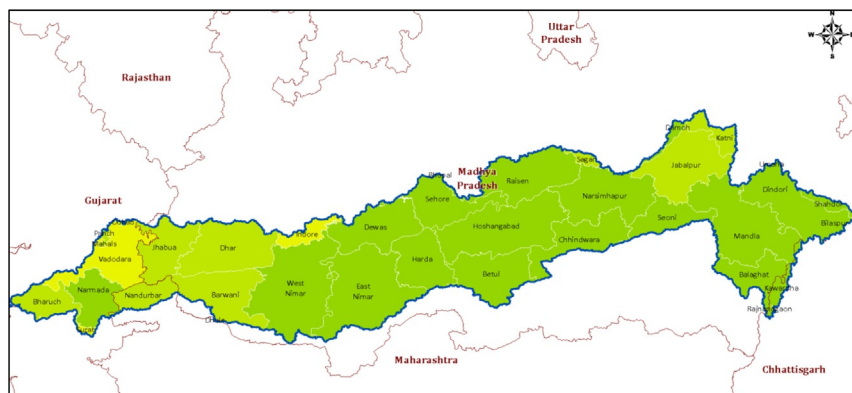


Fig. 4.1 District falling in Narmada basin.

as a result of watershed/water harvesting interventions, and the improved hydrological regime conditions not only help people improve their socio-economic conditions through enhanced water uses, but also increases the lean season flows in downstream areas and increases the local groundwater buffer for drought years. Notwithstanding the limitation induced by the neglect of the change in local water demands due to induced supplies, the unit of such analysis is never extended beyond the village or the watershed selected for the project.

The effects of watershed-based catchment treatments and groundwater use on the basin hydrology were not considered when water from the river was allocated by the Narmada Water Disputes Tribunal allocated among the four party states and when Narmada valley development projects were originally planned (Kumar, 2010, 2014; Kumar et al., 2005). Watershed development was rather viewed as a complementary work for sustainable basin management, often limited to a few hilly watersheds.

But, as some researchers observe, since the days of conceptualization of the Narmada Master Plan, the water management concerns and priorities in the basin have changed with changing socioeconomic conditions and political climate. During the period from 1993 to 2003, the focus of the Congress-led government in the state has been entirely on watershed development, decentralized water harvesting, and groundwater use. This according to the researchers had effects on the hydroecology in the form of reduced runoff generation, reduced stream flows, and faster groundwater

drawdown. They use the recent hydrological records that show much lower basin yields to support their argument (see [Kumar, 2010](#); [Kumar et al., 2005](#)).

4.2 Objective, methodology, and scope

The study had two major objectives: analyze the socioeconomic and hydrological impact of watershed development and water harvesting activities at the local level; and assess the effect of watershed development and water harvesting activities on the availability of flows at sub-basin level. As mentioned earlier, approximately, 90% basin area is falling in MP. Geographically, 22 districts of Madhya Pradesh (MP) are situated in Narmada basin either fully or partly. The basin covers 100% area of three districts, 60%–90% area of five districts, 30%–60% area of seven districts, and 3%–30% area of another seven districts.

Narmada River has 41 tributaries, of which 39 tributaries are draining from MP. Data on tributary-wise area of treated microwatersheds are not available. Data collected from Rajiv Gandhi Watershed Mission show that intensive watershed development work was carried out in Khandwa, Khargone, and Jhabua. Among these four districts, which are leading in watershed development, stream flow-gauging stations are available in Kundi sub-basin of Khargone district and Hathni sub-basin of Jhabua district. Therefore, these two districts were purposively selected for the study. Since Khargone district is falling in Kundi sub-basin, we have used district-level data as representing the sub-basin. In case of Jhabua district, which occupies only 66% of Hathni sub-basin area, we have culled out sub-basin level data from the district-level data. From each district, one microwatershed, which is intensively treated, was chosen for rigorous study involving primary data collection. These microwatersheds are those which have more than 90% their geographical area treated under employment assurance scheme (EAS) during 1995–96 to 1999–2000. From both the districts, a nontreated microwatershed, which is contiguous to the treated microwatershed, was selected for comparison.

4.2.1 Lines of analysis

⇒ Use of satellite imagery: to assess the changes in land use pattern and cropped area at sub-basin, watershed, and microwatershed levels due to the watershed interventions.

- ⇒ Geographic Information system (GIS) to capture the temporal and spatial variations in the land use at sub-basin and watershed levels using primary survey data as well as satellite imagery.
- ⇒ Longitudinal and cross-sectional analysis: comparison of pre- and post-watershed intervention periods for the same watershed as well as treated and nontreated watersheds.
- ⇒ Mapping: changes in land use, particularly cropping pattern and cropping system, were mapped on village revenue maps.
- ⇒ Estimation of water balance: by considering the groundwater recharge and extraction figures for the year 2004 for one of the treated microwatersheds using water-level fluctuation approach.
- ⇒ Regression between runoff and rise in well water level (dependent variables) and rainfall (independent variable) carried out for analyzing hydrological changes at the macrolevel.

4.2.2 Tools and techniques

The study involved: (1) analysis of data collected from complete household census of the selected microwatersheds by administering structured questionnaire to collect socioeconomic data; (2) analysis of data on water-level fluctuations in wells in the treated and control watersheds during pre- and postmonsoon periods for the year 2004; (3) analysis of stream flow data at 10-day intervals for one of the selected sub-basins collected from Narmada Control Authority, Indore, MP; (4) analysis of rainfall and land use data collected from the corresponding district land record offices of the selected sub-basins, and water level fluctuation data and specific yield values for the aquifer formations of the sub-basins from the state geohydrology survey unit of the sub-basins; (5) analysis of agricultural statistics obtained from district agriculture office for the districts representing the two sub-basins; (6) analysis of data on watershed development programs collected from district level CEO, Panchayat Office for the two sub-basins.

4.3 Results and discussion

4.3.1 Socioeconomic changes

Analysis of socioeconomic data showed that there was a remarkable growth in population at the sub-basin level during the study period in both Kundi and Hathni sub-basins, with annual compounded growth rate of 2.4% and 3.2%, respectively. But, the treated watersheds show much lower growth

in population as compared to the control (untreated) watersheds in both the basins—3.45% against 4.5% in Kundi watersheds and 0.39% and 4.49% in Hathni watersheds, though their growth rates are higher than the aggregate sub-basin level growth rates. A marked increase in livestock population during the study period was also observed at Kundi sub-basin, with much lower growth in the microwatershed. But, the growth in the treated watershed (0.56%) was slightly higher than that in the untreated watershed (0.17%).

Cross-sectional analysis brings out sharper differences. The livestock population per household is 4.1 and 6.29 animals in treated watersheds, in Kundi and Hathni sub-basins, respectively, compared to 2.56 and 5.56 animals per household in nontreated watersheds of the respective basins. This indicates more intensive livestock-rearing activities in the treated watersheds. The rapid rise in livestock holding at micro- and macrolevels would lead to increased demand for water for domestic uses, cattle drinking, and animal feeding.

Our analysis showed not so significant increase in number of people engaged in different rural occupations such as agriculture, animal husbandry, and local employment, for the watershed in Kundi sub-basin. Differences are sharp when compared with the situation in nontreated watersheds. People in treated watersheds, viz., Bada Bhawata and Khedi, remained engaged in agriculture for an average of 5.4 and 8.4 months compared to 4.1 and 6.6 months in nontreated watersheds, viz., Bahedwa and Jaljyoti. In Khedi watershed, there was marginal rise in agricultural employment after the intervention from 8.3 to 8.4 months. A higher percentage of the people are engaged in animal husbandry in treated watersheds (11.75% and 24.4% in Bada Bhawata and Khedi, respectively) as compared to untreated watersheds (9.8% and 21.35% in Bahedwa and Jaljyoti). This may be explained by the larger livestock holdings in the treated watersheds. This can be attributed to better availability of fodder.

It is a truism that better management of natural and environmental resources in rural areas leads to reduced distress migration. There has been sharp reduction in the number of family members engaged in migration in both treated and untreated watershed, the reduction being higher in the untreated watersheds (1.75% against 2.3%) of Kundi sub-basin, for which data are available. One could argue that the watershed interventions have helped contain the impact of consecutive drought. Of the 244 respondents from the treated watersheds in Hathni sub-basin, 115 reported that getting temporary employment during implementation of WDP and reduction of migration period are two major impacts they realized so far.

However, informal discussion with stakeholders of WDP and interaction with watershed community during field work revealed that temporary nature of employment generation did not significantly affect the overall migration in general except a little change in the period and pattern of migration.

The study did not show any marked difference in the local employment generation potential in both the basins. Increased agricultural production, improvement in soil condition, and introduction of income generation activity through self-help group are other benefits reported by 8, 4, and 21 respondents, respectively.

4.3.2 Changes in land use

As per the data from agricultural census, 1989–90 and 1995–2000, land use shows declining trend between 1989–90 and 1999–2000 in Kundi sub-basin. Data collected from district land records office, Jhabua, also corroborated this for Hathni basin. Total reported area came down from 1,349,000 to 1,019,000 hain Kundi basin and from 271,000 to 269,000 hain Hathni basin. Forest area has drastically shrunk from 34.85% to 9.75% in Kundi, while it reduced from 3.22% to 2.75% in Hathni. Land that is not available for cultivation increased from 15.3% to 22% in Kundi sub-basin and from 21.3% to 23.6% in Hathni. Cultivable waste land increased from 2.3% to 3.6% and 2.3% to 2.6% in Kundi and Hathni, respectively. Net sown area increased from 46.7% to 63.2% (of the cultivable area) in Kundi and did not change much in Hathni basin. Gross cropped area increased from 51.6% to 73.6% in Kundi, but marginally reduced from 70.90% to 68.8% in Hathni.

Kharif and winter cropped area were found to be showing declining trend in Kundi basin. This is mainly because of the reduction in reporting area. Therefore, it is important to look at the changes in cropping intensity. The cropping intensity (expressed as a ratio of gross cropped area and net sown area) increased after the watershed interventions from 110% to 116%. The analyses of agricultural statistics for the 5-year periods 1992–96 (preintervention) and 1996–2003 (postintervention) showed that the average production and productivity of many of the crops also declined with decline in cropped area. While the reduction in crop production could be attributed to the reduction in aggregate area under each crop, reduction in yield of some crops would have contributed to this. It was interesting to note that the yield of crops such as wheat and cotton had increased after the watershed interventions, while that of many rain-fed crops had reduced.

The reduction in yield of rain-fed crops could be the overall impact of the consecutive poor monsoons in many years after the watershed interventions.

Analysis of data collected from primary survey carried out in the micro-watersheds, presented in [Table 4.1](#), indicated that cultivated area, irrigated area, Kharif cropped area, and winter cropped area increased by 8.5%, 45.8%, 14.2%, and 53.2% in treated watershed and by 21.5%, 46%, 57.6%, and 25.6% in nontreated watershed of Kundi basin postwatershed intervention period. One can argue that while increase in winter cropped area was by virtue of improved water availability in treated watersheds, in the untreated watersheds the farmers are expanding the area under rain-fed crops to meet the increased food and fodder requirements. Cropping intensity increased by 5% in the treated watershed but decreased by 3.25% in the untreated watershed during the study period ([Table 4.1](#)).

In case of Hathni sub-basin, data pertaining to prewatershed intervention were not available for any of the watersheds. Postwatershed intervention, the percentage of irrigated area and winter cropped area to the geographical area in the treated watershed was higher than that of untreated watershed by 3.9% and 9.45%. The percentage of Kharif cropped area to geographical area remained the same for both the microwatersheds. This indicates higher cropping intensity and area under irrigation after watershed intervention in the sample watershed. In the absence of baseline data, one cannot say with a high level of confidence that the higher cropping intensity in the treated watershed of Hathni sub-basin is because of watershed intervention.

Source wise area under irrigation increased in Kundi basin. Maximum expansion in irrigated area occurred under sources other than tanks. The small water harvesting structures (WHSs) may be functioning as the alternative irrigation sources in the treated watersheds. Drastic reduction in tank-irrigated area was observed in the basin, which declined from 11,200 to 1200 ha. Area under well and tube well irrigation increased by 36%. Canal-irrigated area had reasonably increased. It clearly shows that ground-water development took place at a greater speed in the basin during the last decade. While surface irrigation shows mix trend because canal irrigation is progressing, tank irrigation is declining.

4.3.3 Hydrological changes

Data on annual rainfall available for 44 years in case of Kundi sub-basin area and 28 years in case of Hathni sub-basin area were analyzed. Five-year moving average of these rainfalls were analyzed and presented in [Fig. 4.2](#).

Table 4.1 Change in cropped area at microwatershed level (area in acres).

Period	Cropped area Geographical area	Kundi basin		Hathni basin	
		Treated-Khedi 1092.00	Nontreated-Jaljyoti 1331.00	Treated-Bada Bhawata 1411.00	Nontreated-Bahedwa 971.00
Prewatershed	Reported area	872.25	528.82	—	—
	Cultivated area	855.25	492.75	—	—
	Irrigated area	355.00	196.75	—	—
	Kharif cropped area	751.25	344.50	—	—
	Rabi cropped area	110.00	65.25	—	—
	Cropping intensity	114.64	118.94	—	—
Postwatershed	Reported area	938.75	662.82	—	—
	Cultivated area	927.75	598.75	585.50	417.50
	Irrigated area	517.50	287.25	140.50	59.00
	Kharif cropped area	858.25	543.00	896.50	626.50
	Rabi cropped area	168.50	81.90	169.00	24.50
	Cropping intensity	119.63	115.08	118.85	103.91

Source: Primary survey, 2004.

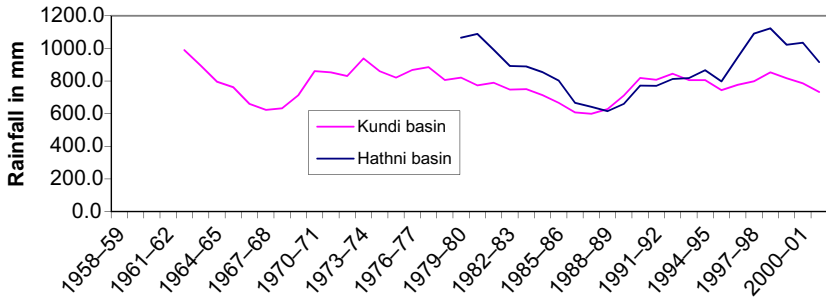


Fig. 4.2 Moving average of annual rainfall in two sub-basins.

In the case of Kundi sub-basin, the moving averages indicate cycles of approximately 20 years with steep rise reflecting consecutive wet years, followed by steady decline reflecting consecutive dry years. The year corresponding to lowest moving average value is same for both the basins. In the case of Hathni, steep decline and rise in moving average was found indicating a sharper difference between rainfall magnitudes of wet years and dry years. With a mean annual rainfall of 880 mm, Hathni sub-basin receives higher rainfall as compared to Kundi, which has a mean annual rainfall of 784 mm (source: authors' own analysis based on data from Office of Land Records, Khargone and Jhabua, MP).

Both the sub-basins experienced remarkable strides in groundwater development. Number of WHS created under WDP directly affects the local-level water availability. Data on pre- and postmonsoon well water levels of 39 observation wells in Kundi sub-basin and 51 observation wells in Hathni sub-basin available from Geo hydrological Survey units of the respective sub-basins were analyzed to estimate the average annual rise/fall in water levels at the sub-basin level. But apart from watershed treatment, annual rainfall also will have an effect on monsoon-water-level fluctuations. To factor out the effect of yearly variations in rainfall on groundwater recharge, we worked out recharge fraction, as a ratio of *Rise in water level* and *Average annual rainfall*. However, this method of estimating the "recharge fraction" has its own limitations, as it ignores the likely nonresponsiveness of water levels in shallow aquifers to excessively high rainfall due to the phenomenon of "rejected recharge" appearing as base flow. When the rainfall becomes excessively high, presence of recharge structures may not result in differential recharge as the shallow aquifer may not have adequate storage space to store the infiltrating water from the small reservoirs created by the recharge structures.

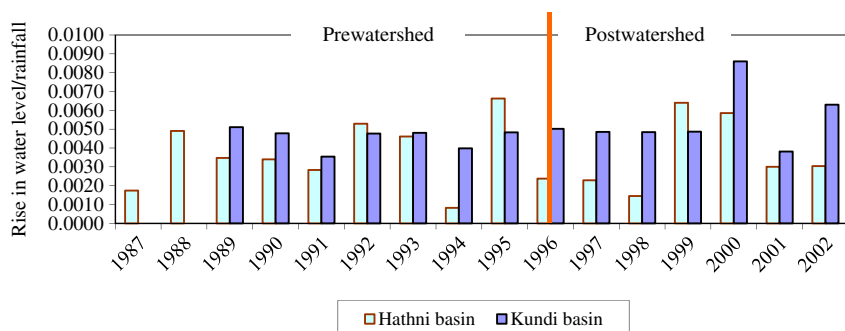


Fig. 4.3 Effect of watershed interventions on recharge fraction. (Source: *Geohydrological survey unit, Khargone and Jhabua, MP.*)

The estimated values of recharge fraction for the two sub-basins indicate positive change after introduction of WDP at the sub-basin level (Fig. 4.3), meaning higher rate of percolation of water for the same quantum of rainfall, which is indicative of the positive effect of watershed interventions in terms of increasing opportunity time for runoff water to infiltrate. The average recharge fraction for Kundi sub-basin was 0.0055 post-WSD (for the period from 1997 to 2002), against 0.0046 for the pre-WSD (1988 to 1996). The difference in “recharge fraction” was very marginal (0.0037 post-WSD against 0.0036 pre-WSD) in the case of Hathni sub-basin. Based on these results, one can argue that land treatment and WHS created under WDP might have contributed to augmenting ground recharge at the local level. But, alternatively, one could also argue that the higher percentage of rainfall getting underground is due to the effect of varying magnitudes of rainfall on the recharge process (that higher rainfall may not result in higher recharge rates but higher runoff) and not due to any effect of land treatment on the recharge rates. Therefore, it is important to compare the recharge behavior for treated and untreated watersheds for the same magnitude of rainfall.

Detailed analysis was done for the treated watersheds and the control watersheds in Hathni sub-basin, which enabled comparison of groundwater recharge for the same quantum of rainfall in different years. Like in the case of the sub-basins, the recharge fraction had substantially increased, what is striking is that the difference in recharge fraction between treated watershed and untreated watershed is larger at higher magnitudes of rainfall (Fig. 4.4). At lower magnitudes of rainfall, the portion of the rainwater that percolates down the soil to the shallow aquifer is more or less same for the treated and untreated watersheds.

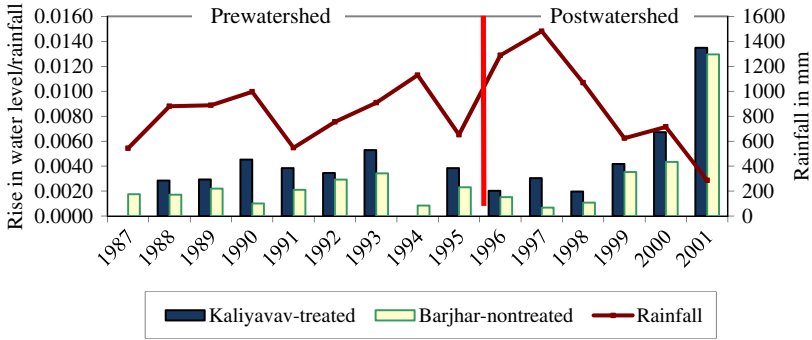


Fig. 4.4 Effect of watershed interventions on recharge fraction in microwatersheds, Hathni sub-basin. (Source: Geo-hydrological survey unit, Jhabua.)

4.3.3.1 Water balance at microwatershed level

Microwatershed level water balance was estimated on the basis of ground-water recharge and groundwater extraction for the year 2004 in Kundi basin. The groundwater recharge and groundwater extraction were estimated using the estimated values of average water-level fluctuations in wells during monsoon (FL_{WL}), the specific yield of the aquifer (S_y), and the geographical area of the watershed (A) to arrive at the net recharge ($RECH_{NET}$). To the net recharge figures, the estimated groundwater draft during kharif ($PUMP_{WELL}$) was added to arrive at the actual monsoon recharge.

$$\text{Net recharge during monsoon} = RECH_{NET} = FL_{WL} \times S_y \times A$$

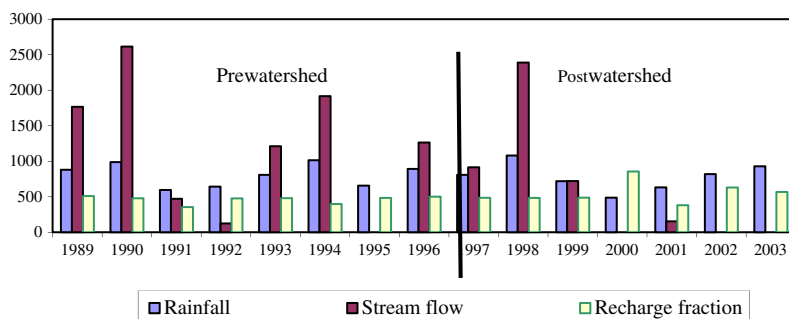
$$\text{Actual monsoon recharge} = RECH_{ACTUAL} = F_{WL} \times S_y \times A + PUMP_{WELL}$$

Estimates of water balance shown in Table 4.2 clearly indicate that not only the aggregate recharge is higher in the treated watershed as compared to the untreated one (102,300 against 59,500 m^3), but the recharge rate is also higher (0.027 MCM/km^2 against 0.022 MCM/km^2). On the other hand, the groundwater development reached a plateau in the treated watershed in spite of high recharge, owing to high rates of pumping. Though number of wells and bore wells and the well yields are nearly same for both the watersheds, annual pumping hours are remarkably higher in treated watersheds, giving warning signals against future problems of groundwater overdevelopment. The balance recharge in the treated watershed was only 2000 m^3 . Over and above, the abstraction figures include only that for irrigation. If we consider groundwater use in other sectors, especially, livestock,

Table 4.2 Water balance at microwatershed level in Kundi basin.

Details	Unit	Treated watershed	Nontreated watershed
No. of wells and borewells	No.	74	71
Average annual pumping hours per well	h	423	229
Average well discharge	m ³	32	33
Reported area	ha	376	265
Rise in well water level during monsoon	m	3.65	3.63
Specific yield of the basalt aquifer		0.02	0.02
Total groundwater recharge	ha m	102.30	59.50
Groundwater abstraction	ha m	100.17	53.65
Recharge rate (MCM/km ²)		0.027	0.022
Groundwater balance	ha m	2.11	5.89

Source: Author's calculation based on Primary survey, 2004.

**Fig. 4.5** Effect of watershed interventions on streamflows in Kundi sub-basin.

domestic purpose, there would be hardly any water left as buffer. It means that the extra water made available at the local level through WDP interventions was being utilized to its fullest potential by watershed community. Therefore, unless measures are taken to increase groundwater recharge rates on a sustainable basis, the communities should exercise precautions in further appropriation of the resources in areas where the abstraction levels are touching or even exceeding the recharge rates.

4.3.3.2 Impact of WDP on stream flow at sub-basin level

Fig. 4.5 presents the annual rainfall, annual stream flows (MCM), and recharge fraction (multiplied by 10^5) for Kundi sub-basin. Though “recharge fraction” is showing slightly increasing trend, stream flow of Kundi sub-basin was found to be showing declining trend over a period

of time. There are two possibilities: first: the land treatment reduces runoff rates; and second: the WHS capture a portion of the runoff. Alternatively, one could argue that ideally the stream flows would be lower at lower magnitudes of rainfall. Such an argument gets strengthened when one looks at the annual rainfall values during the post WDP period.

Therefore, to measure the real impact of watershed treatment on stream flow generation and the effect of water harvesting on downstream flows, we ran a regression between rainfall and stream flow for two time periods: pre-water harvesting period (15 years) and time period including post-WDP period (20 years). The results of the regression analysis are presented in Table 4.3. The beta coefficient of the regression equation is slightly smaller (3.97) for the period encompassing the post-WDP period, meaning the runoff corresponding to a unit rainfall (runoff coefficient) reduced after the watershed treatments. Also, the value of the Y intercept was smaller (−1914) than the pre-WSD situation (−1884). Hence, it confirms the preliminary findings discussed in the beginning of the paragraph that runoff rate is reduced in post-WDP period.

Regression was also run between annual rainfall and average rise in water levels (pre-post monsoon) in wells for the same time periods (i.e., 1989–95 and 1989–2003). The regression equation for the first time period (i.e., 1989–95) suggested drop in groundwater levels during the monsoon period for zero annual rainfall, whereas for the latter, the groundwater-level change was positive during monsoon (0.76 m), even for zero annual precipitation. However, the beta coefficient for the latter was lower (0.004) than that of the former (0.0047). A 1000-mm rainfall raised the water level by 4.75 m in the case of the latter, whereas the estimated average water level rise for the former was 4.55 m. The nature of regression equations suggests that the recharge would be more for higher magnitudes of annual rainfall if watersheds are treated.

Table 4.3 Regression between average annual rainfall vs rise in well water level and annual stream flow.

Variables	Period	"a"	b-Coefficients	t Value	R ²
Rise in well water level	Pre (1989–1995)	−0.145	0.0047	4.730	0.789
	Post (1989–2003)	0.759	0.0040	3.611	0.501
Stream flow	Pre (1980–1995)	−1883.727	3.988	8.427	0.845
	Post (1980–2001)	−1913.545	3.974	10.358	0.863

Source: Authors' analysis.

4.4 Conclusion and policy implications

The study provided sufficient evidence of positive socioeconomic impact of watershed development at the local level. The study also threw pointers to the fact that WDP led to increased land use with expanded winter cropping, enabled by greater access to irrigation sources. Also, the watershed communities increased the intensity of livestock keeping with greater access to water and biomass. Intensive treatment of land and extensive WHSs led to increased rate of rainfall recharge into the shallow aquifers at the sub-basin level, indicated by high recharge fraction for the same runoff during the postintervention period. The treated watershed showed higher recharge fraction than the untreated watershed, with higher effect in high rainfall years. However, water balance estimates done for the treated microwatershed indicates that groundwater recharge and extraction reached equilibrium, meaning almost all the recharged water gets used up within the watershed.

Analyses using limited hydrological data show that the availability of downstream runoff had reduced after the watershed/water harvesting interventions, manifested by lower estimated runoff coefficients. This can be attributed to the increased local pumping for irrigated agriculture, which followed recharge augmentation. Hence, there is no evidence of improved sustainability of groundwater use or ecological sustainability due to watershed development. Therefore, we need to consider such socioeconomic and hydrological changes that are likely to occur as a result of improved water availability locally, before planning and implementing any new water resource development program to ensure sustainable use of the resource. Also, it is desirable to plan and design WDP and water harvesting projects keeping in view the committed flows for downstream development to reduce the unintended effects. Such planning should start from the basins or sub-basins and not from the microwatersheds unlike as being done currently, so that there can be greater clarity on the constraints induced by the downstream development needs.

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